The influence of vegetation types on the infiltration capacity of Ie Suum geothermal area in Mount Seulawah Agam

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Abstract. The availability of groundwater, largely influenced by the infiltration process and the vegetation cover types, is an important component for the sustainability of geothermal energy. The lack of reference in the relationship between infiltration and vegetation types in geothermal areas causes the lack of information to understand the overall availability of groundwater. Therefore, research on this subject is particularly significant. In this study, the focus was on the difference of the infiltration capacity among vegetation types in Ie Suum geothermal area of Mount Seulawah Agam in Aceh, Indonesia. The study employed the line transect method. The infiltration rate was measured by a double ring infiltrometer and was determined by Horton’s equation. Transect lines were determined according to the four directions of the winds (south, west, north and east) with the transect length at 500 m each. Then, in each transect line, three infiltration measurement points were set at 100 m, 300 m, and 500 m. The results showed that the infiltration capacity was extremely high in tree (9.08 cm/min) and shrub (5.12 cm/min and 3.41 cm/min) areas, but markedly low in herbaceous vegetation (0.57 cm/min). The differences in the infiltration rates for the tree, shrub, and herbaceous vegetation types indicated that the vegetation types affected the infiltration rates and also the groundwater availability in Ie Suum geothermal area.

1. Introduction

Theoretically, the future development and sustainability of geothermal energy requires three (3) main components that are interconnected. One of the three most important components, aside of cap rocks and heat sources, is the availability of groundwater [1]. Many studies have noted the importance of groundwater availability in the development of geothermal energy. In Iceland, the development of the geothermal energy sustainability project used the assessment and environmental management of water resources [2]. In China, the prospects for the development and application of geothermal energy resources in the future are towards technology, geothermal energy heat utilization, sustainable exploitation, and utilization of geothermal reservoirs [3]. The applications and case studies on the sustainable use of geothermal resources in northern Italy indicated that hydro-geology (groundwater) played a major role in both low- and high-enthalpy geothermal regions [4]. Further, in Poland, the results of the simulation of Podhale geothermal reservoirs were used for the sustainable use of geothermal production [5].

In addition, the results of research in the geothermal areas of Borinquen-Costa Rica also described the main elements in the utilization of high-enthalpy geothermal energy such as water catchment zone, reservoir, main stream, and direction of water flow, which will be useful as a guide.
for the exploration and development of future exploitation of geothermal sources [6]. Numerical modeling of geothermal groundwater flow has also been conducted [7, 8], becoming an important data source for the exploitation and utilization of geothermal resources. In the United States, data on water use in geothermal energy facilities were measured [9] and water cycles were analyzed [10] and then they became environmental policy documents in each region. The availability of groundwater and the surface of the Taupo Volcanic Zone in New Zealand has been researched using hydrological observations and 3D geological models to calculate groundwater infiltration in geothermal areas, and undeniably, groundwater infiltration greatly affected geothermal systems of volcanoes [11].

Other studies also documented the importance of groundwater availability in the sustainability of geothermal energy utilization in the future, but little has been known on the availability of groundwater in geothermal areas in relation with infiltration and vegetation. Infiltration and vegetation cover are the main components necessary to investigate the mechanism of groundwater content and infiltration. Several studies have shown the importance of infiltration data for the interaction modeling of soil water and water surface [12, 13]. Meanwhile, some studies found a strong correlation between infiltration and the presence of vegetation cover. A review showed that the interaction between groundwater and vegetation appeared to have a greater and more important role than what was believed in the past [14]. Moreover, other research results found that vegetation cover types have had different effects on groundwater infiltration [15, 16]. In addition, land use changes and vegetation changes have also caused an impact on infiltration [17, 18]. Recent research in Iceland has depicted the vegetation mapping in high-temperature geothermal areas as one of the framework plans for sustainable use of water energy and geothermal energy in the future [19].

The increase of infiltration capacity, which greatly affects the water balance in various soil types, is highly influenced by the presence of surrounding vegetation. In Australia, water modeling has been carried out on vegetation and groundwater infiltration influenced by climate variability in the less fertile zone of savannas [20]. The relationship between vegetation and groundwater was also used as an indicator of spontaneous restoration of wetlands in Polish National Park [21]. In the highland ecosystem "Paramo" of the northern Andes of Ecuador, the infiltration capacity of water into the soil was affected by vegetation types and cover plants. In shrubland and polylepis forests, water infiltration was very high and it was gradually lower in grassland, pine plantations, and cattle trails. The layers of vegetation cover have contributed significantly to total infiltration capacity [22].

Ecologically, not only is infiltration affected by vegetation but also vegetation is affected by infiltration and groundwater availability. Groundwater capacity greatly influences plant density and plant growth in an area [23]. In temperate forests, rainfall and topography play an essential role in groundwater sources and surface water, and affect vegetation changes above [24].

One of the volcanoes in Indonesia that has a potential geothermal source is Mount Seulawah Agam in Aceh Province. The mount has a zone of up-flow reservoir which is water heated dominated with a temperature between 206-228°C coming directly from deep water. This reservoir is a type of intermediate enthalpy reservoirs. The energy of Mount Seulawah Agam has been projected to generate electricity of about 165 MW and therefore the mount has a potential to be developed into a power plant [25]. The potential of Seulawah Agam was then followed up by the Aceh government by planning the construction of geothermal power plant in Seulawah Agam, marked by the signing of Shareholder Agreement (SHA) or Geothermal Seulawah Project Shareholdership between the Aceh Government through the Perusahaan Daerah Pembangunan Aceh (Regional Development Company of Aceh/PDPA) and Pertamina’s Geothermal Energy at the Hall of Governor of Aceh on May 10, 2016 [26]. The development planning of Seulawah Agam’s geothermal power plant has certainly taken into account its sustainable development in the future. Information on the infiltration capacity in each type of vegetation in Seulawah’s geothermal area is very important and necessary as a basis to develop the geothermal power plant in Aceh. In this study, the aim was to investigate the difference of infiltration rate in each vegetation type in Ie Suum geothermal area of Mount Seulawah Agam.
2. Research Methodology
This study was conducted in the geothermal area of Ie Suum at the foot of Mount Seulawah Agam with an altitude of 153 m asl and located at 5°31'14.45" N and 95°34'27.52" E. The research location was situated in Mesjid Raya Sub-district, Aceh Besar District, Aceh Province, Indonesia. The method used in this study was line transect method. The infiltration rate was measured by using a double ring infiltrometer (middle ring diameter of 16.5 cm with height of 25 cm and outer ring diameter of 27.5 cm with height of 15 cm) in an interval of 5 minutes until constant. Transect lines were determined based on the four directions of the wind, i.e. east (shrubs), south (trees), west (herbaceous), and north (shrubs) with the respective transect length at 500 m. In each transect line, three infiltration measurement points were set at 100 m, 300 m, and 500 m [27].

The infiltration data were then analyzed by using Horton’s equation [28] as follows:

\[ f = f_c + (f_0 - f_c) e^{-kt} \]

in which \( f \) is the infiltration capacity (cm/hr), \( f_c \) is the ultimate infiltration rate (cm/min), \( f_0 \) is the initial infiltration capacity (cm/min), \( k \) is the empirical time constant, \( t \) is time (min), and \( e \) is 2.78.

All data were analyzed descriptively and displayed in tables, graphs, and figures.

3. Results and Discussion
The results of the study found that there was a difference in the infiltration rate of each type of vegetation. Typical curves of cumulative infiltration for different vegetation types are depicted in Figure 1. As seen in figure 1, the infiltration rate starts at a high value and then decreases slowly to a relatively constant value as time progresses. However, the stable infiltration rates vary depending on the vegetation types.

The infiltration process here is listed for simplification. The trees (south) and shrubs (north and east) areas have a constant interval range between 25-40 min. On the other hand, the herbaceous area (west) has a stable infiltration rate (at 15 min) faster than other types of vegetation. The time largely influences the infiltration rate, in which each additional time causes the infiltration rate to decrease. This suggests that in general the longer the soil absorbs the water, the lower the infiltration rate is until reaching a constant rate, except on moist soil (west herbaceous vegetation). The rise of water content in the soil causes the soil becomes saturated, leading to low infiltration. The Horton’s equation found the differences in infiltration capacity from various vegetation types (Table 1).

![Figure 1. Water infiltration rate](image-url)
Table 1. Total infiltration capacity in vegetation types

| Vegetation types | Infiltration capacity (mm/min) | Average infiltration capacity | Infiltration capacity scale |
|------------------|-------------------------------|-----------------------------|---------------------------|
|                  | 100 m | 300 m | 500 m |                       |
| Shrubs (North)   | 3.28  | 3.81  | 3.15  | 3.41 Middle           |
| Herbaceous (West)| 0.48  | 0.82  | 0.42  | 0.57 Slow             |
| Trees (South)    | 9.1   | 8.54  | 9.6   | 9.08 Fast             |
| Shrubs (East)    | 6.42  | 4.63  | 4.33  | 5.12 Middle           |

Table 1 shows that the infiltration capacity is extremely high in trees (9.08 cm/min) and shrubs (5.12 cm/min and 3.41 cm/min) and decreases markedly in grass (herbaceous) (0.57 cm/min). The magnitude of the infiltration rate in the southern of this tree type has been affected by the surrounding trees such as laban (*Vitex pinnata*), red-stem fig (*Ficus variegata*) and Malacca (*Phylanthus emblica*). The roots of these trees enable pores to emerge in the soil, making the soil to have spaces to fill with water for accelerating the absorption [29]. The floor forest in the tree-based area also has enormous litterfall, and high litterfall production increases the rate of infiltration [30]. A thick layer of litterfall gives protection to the soil from the rain, while the soil structure remains intact allowing rain water to submerge in. Furthermore, the thick litterfall layer maintains soil microclimate (moisture and soil temperature) to be favorable for the development of soil macrofauna, especially earthworms, and root plants. Organisms in soil will increase the number of macro pores in the soil and also soil infiltration [31].

On the other hand, the infiltration capacity in the grassland/herbaceous vegetation has been found to be slow due to the presence of several plants such as torpedoggrass (*Panicum repens*), nutgrass (*Cyperus rotundus*), and Indian goosegrass (*Eleusin indica*). These herbaceous cover plants grow tightly close and in groups, and they also have shallow fiber roots causing the soil to have a high humidity. This highly humid soil condition covers the soil pores and leads to water become difficult to enter the soil and get absorbed [32]. The findings here indicate that the infiltration rate will be greatly supported by the abundance of soil pores, and the plant roots are one major factor that help create the formation of porosity in the soil.

4. Conclusion
This study was conducted to investigate the influence of vegetation types on infiltration capacity in Ie Suum geothermal area of Mount Seulawah Agam. Findings indicated that different vegetation types have had an impact on the infiltration rate and infiltration capacity. Tree-based vegetation area has a stable, long range infiltration rate and capacity which is higher than the other vegetation types. This is mainly because the trees have their roots directly into the soil and heaps of litterfall on the ground, a good condition for soil macrofauna activities. These two factors enable the enlargement of pores of the soil and thus, enhance the water infiltration capacity.

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