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# Hydrogeomorphological Assessment of Springs on the Northern Slope of Mount Merbabu

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## ABSTRACT

The northern slope of Mount Merbabu exhibits a volcanic landform with the possibility of spring formation, which can be analyzed using a hydrogeomorphological methodology. The objective of this study was to examine the hydrogeomorphological features of springs, including their physical attributes such as appearance, distribution, discharge, flow parameters, temperature, pH, total dissolved solids (TDS), and electrical conductivity. This research methodology involved the collection of primary data through the observation of specific geographical sites and the deliberate selection of sampling areas. The research findings indicated the presence of 30 spring locations on the northern slope of Mount Merbabu. These springs were found in various landform units, such as craters, cones, slopes, feet, plains, and volcanoes. The main numerical results indicated that the springs exhibited a wide range of discharge rates from 0.02 to 33.29 liters per second, temperature variations from 21.9 to 23.24 degrees Celsius, pH levels from 3.57 to 7.01, TDS values from 38 to 521 mg/L, and electrical conductivity from 40 to 814 µS/cm. The main conclusions were that these springs significantly contributed to the local water resources, with potential applications for agricultural and domestic use. However, the study was limited by the seasonal variations. The scientific novelty of this study lays in its comprehensive analysis of the hydrogeomorphological characteristics of these springs, which were previously undocumented. This research bridged a crucial gap in understanding the interactions between geological formations and spring water quality and quantity, offering valuable data for sustainable water resource management and conservation strategies.

**Keywords:** hydrogeomorphology, spring water quality, mount merbabu, volcanic landforms.

## INTRODUCTION

Water resources are essential natural resources for all living organisms, particularly humans, in fulfilling their daily requirements throughout several aspects of existence (Rasidi and Boediningsih., 2023) Ninety-seven percent of the Earth's water is comprised of salt water, whereas the remaining three percent is freshwater, which is essential for human survival (Wicaksono et al., 2019). Spring water refers to the groundwater that spontaneously rises to the surface of the ground (Aurilia et al., 2021). The formation of springs is influenced by geomorphological circumstances, which play a crucial role in determining the distribution and characteristics of springs (Ashari and Widodo., 2019).

Volcanic landforms are regions with significant potential for water resources (Santosa, 2006). The presence of abundant water resources in volcanic landforms is determined by variations in slope morphology, geomorphological processes, rock types, and geological structures (Santosa, 2021). A hydrogeomorphological approach can be employed to study the origin and features of landform springs. Hydrogeomorphology is the scientific investigation of the connection between water resources and landforms, as well as the processes that shape the Earth's surface (Jayanti., 2023). Mount Merbabu is a stratovolcano that was created by a series of eruptions and melting processes (Prasongko, 2019). Mount Merbabu is believed to have experienced volcanic eruptions in the years 1560, 1570, and 1797 (Kusumadinata, 1979). The northern incline of Mount Merbabu is situated within the administrative boundaries of Getasan District, Semarang Regency. The North Slope of Mount Merbabu is predominantly inhabited and relies primarily on springs to fulfill its water requirements (Figure 1). Due to the popularity of several settlements on the northern slopes of Mount Merbabu as tourist sites, and the construction of the main Magelang-Semarang route, there will be an increased need for water resources.

The variability of springs as groundwater potential is determined by the geomorphological factors, which are influenced by the origin and characteristics of the landform (Santosa, 2006). The ongoing growth of the population has a direct impact on the potential of springs (Amalia and Sugiri, 2014). In order to fulfill human needs, it is essential that the available water resources have sufficient quality, quantity, continuity, and cost (Djaja et al., 2022). Conversely, springs can undergo changes in various areas, resulting from both natural factors and human activity, leading to water resource issues (Almadani and Hermawan, 2023).

Efficient resource management is necessary to ensure the sustainable utilization of these springs by the community. Spring management encompasses more than just utilizing water from the spring; it also involves the measures to prevent harm and ensure upkeep, so enabling the community to utilize the spring in a sustainable manner (Said and Sudarmadji, 2013). The management of springs also takes into account the consumption of springs and the technology utilized in their utilization and maintenance (Lomi dkk., 2021). Given the growing complexity of water usage from springs, it is imperative to preserve the existing environmental knowledge, particularly for the younger

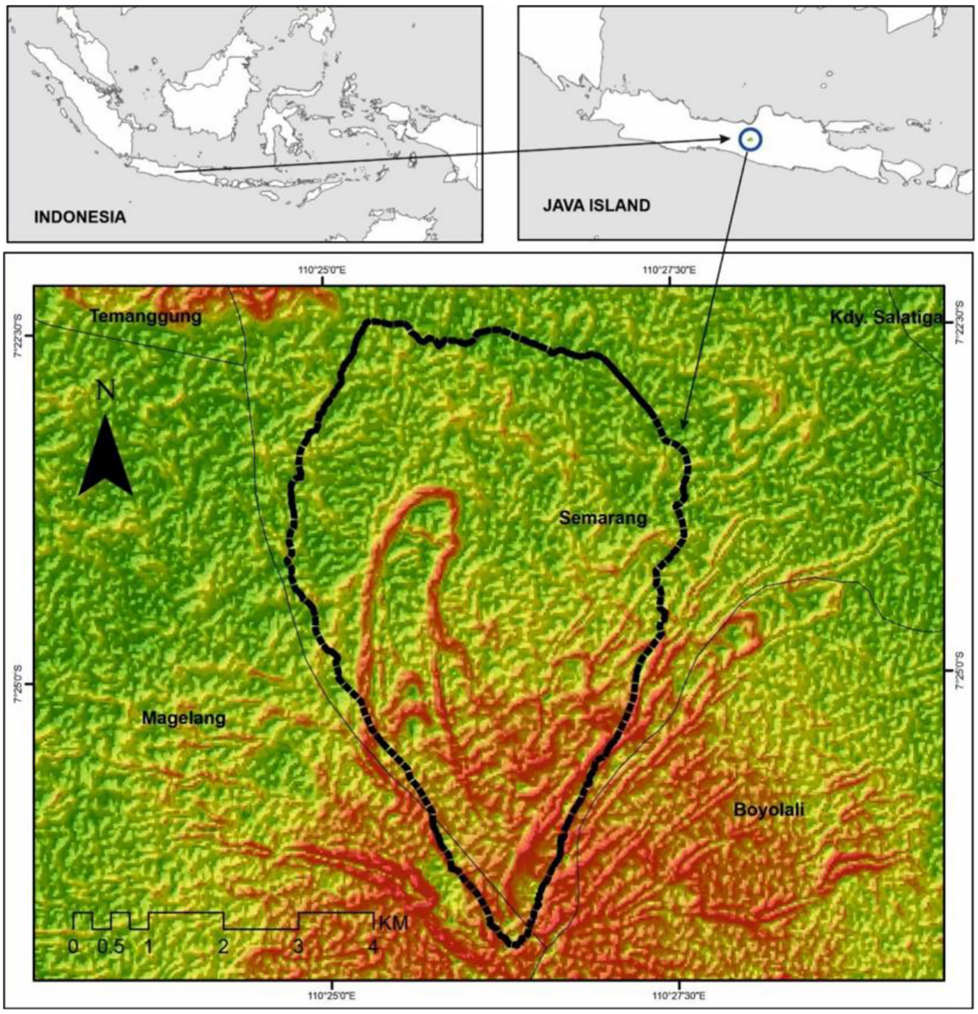


**Figure 1.** North slope of Mount Merbabu

generation, in order to prevent further erosion of environmental values (Sudarmadji et al., 2016).

The objective of this study was to examine the hydrogeomorphological features of springs located on the northern slopes of Mount Merbabu (Figure 2), focusing on such factors as emergence, distribution, discharge, flow characteristics, temperature, pH, total dissolved solids (TDS), and electrical conductivity. Despite the crucial significance of springs and their potential uses, there is a notable deficiency in the thorough documentation and research of the hydrogeomorphological features of springs in the Mount Merbabu area. Prior research has lacked comprehensive quantitative data regarding the physical and chemical characteristics of these springs, as well as the relationship between water quality and geomorphological features. This study aimed to bridge these knowledge gaps by investigating the hydrogeomorphological characteristics of springs on the northern slopes of Mount Merbabu. By examining such parameters as emergence, distribution, discharge, flow characteristics, temperature, pH, TDS, and electrical conductivity, this research sought to create a foundational dataset that will enhance the understanding of the hydrogeomorphology of these springs. Additionally, it will provide valuable information for sustainable water resource management and conservation strategies, as well as create opportunities for better utilization and protection of these natural water sources.

## METHOD

### Study location

This research was conducted on the northern slope of Mount Merbabu at coordinates ± 7°25’20.6” S, 110°26’16.4” E and in UTM coordinates 49 S. The northern slope of Mount Merbabu is bounded by the eastern and western slopes. Administratively, it is located in Getasan District, Semarang Regency, including Batur Village, Getasan Village, Kopeng Village, Samirono Village, and Tajuk Village, Getasan Village.

### Data collection method

The data included in this research consisted of both primary and secondary sources. Primary data was obtained by field observations, which involved

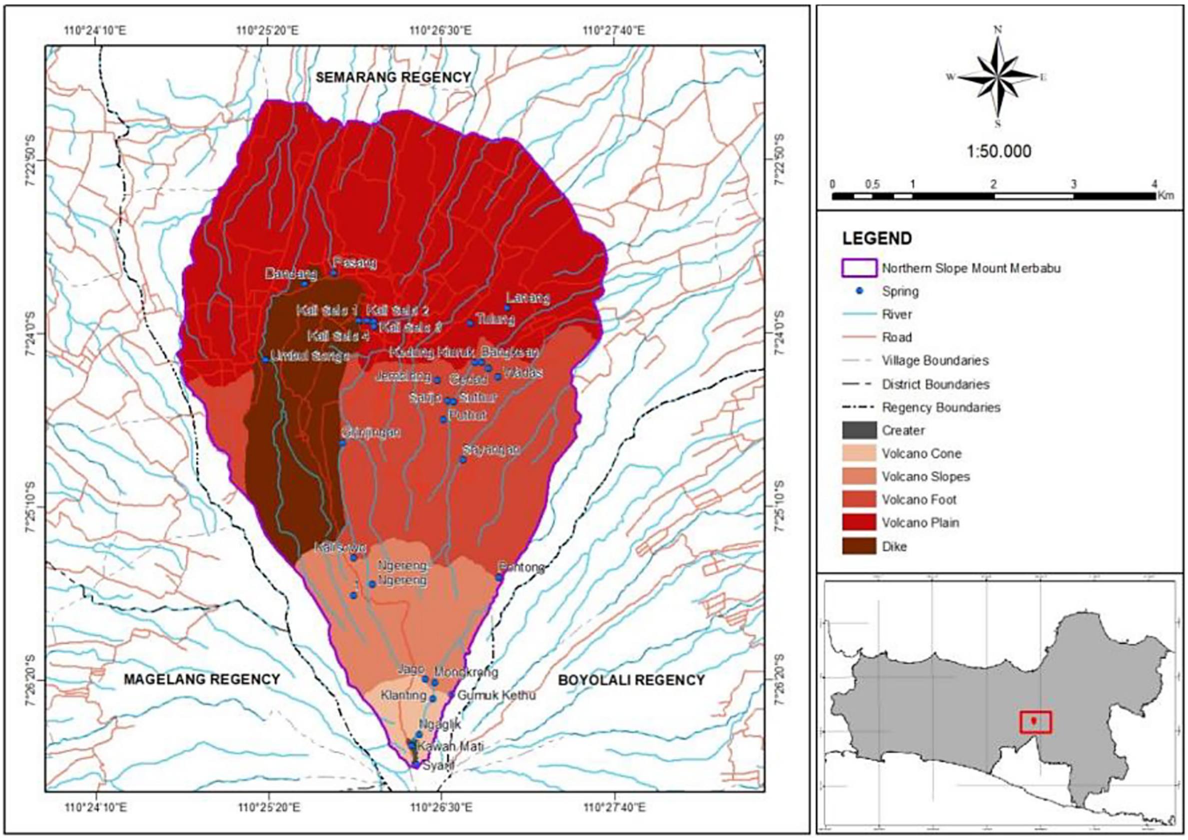


**Figure 2.** Hydrogeomorphological of the north slope of Mount Merbabu

directly observing and measuring spring sources. The quality of spring water was assessed by conducting field observations and measurements at each spring site. This involved utilizing a pH meter and a Horiba Water Quality Checker to collect the data on such parameters as pH value, temperature, total dissolved solids (TDS), and electrical conductivity. The volumetric approach was used to measure the water flow discharge and provide the data on the quantity of spring water. Secondary data, such as numerical data, visuals, maps, results from earlier studies, and data available at institutions, also provided support for primary data.

## Data analysis method

The research was structured into three distinct phases: the pre-field, field, and post-field stages. The preliminary stages involved conducting a thorough review of existing literature, defining the boundaries of the study area, creating a map that depicted the landforms and features of the area, and conducting a survey prior to going into the field. Field phases encompassed such activities as determining the precise coordinates of springs using GPS, assessing water quality using a Horiba water quality checker, quantifying spring discharge through the use of the volumetric method, and verifying the accuracy of geomorphological maps. Post-field stages encompassed the activities of processing data obtained from field measurements, creating maps and refining them, as well as performing data analysis.

The results included discharge measurement, as well as the physical and chemical quality of springs in the field. The spring distribution pattern was analyzed by GIS average nearest neighbour analysis using the ArcGIS 10.8 device by paying attention to the Z score and P value (Figure 3). The distribution pattern was clustered, indicated by the value z-score being negative (-); the distribution pattern was dispersed, indicated by the value z-score being increasingly large and positive (+); and the distribution pattern was random, indicated by the value z-score being 0 or close to 0.

The quality aspect of spring water was analyzed comparatively using a matching method based on the drinking water quality standards criteria, in accordance with Permenkes No. 2 of 2023 on the Implementation Regulation of Government Regulation No. 66 of 2014 on Environmental Health to determine the potential of the springs. The quantity aspect of spring water was analyzed by calculating the ratio of availability to the overall water demand. The availability

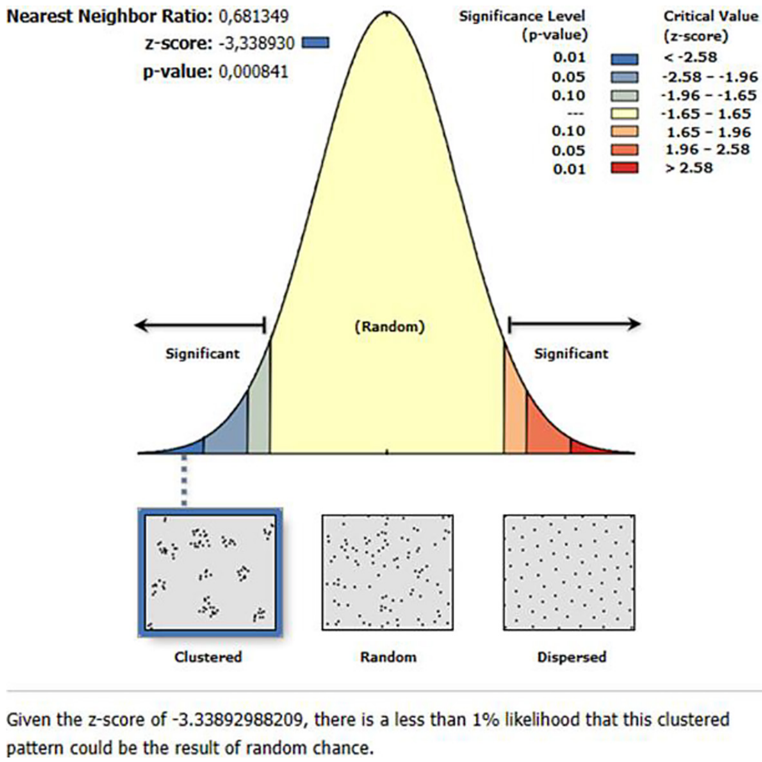


**Figure 3.** Analysis results graph average nearest neighbour

amount from the discharge data was calculated using the equation:

$$Availability = \\ = Q \times the\ number\ of\ seconds\ per\ year \quad (1)$$

where: $Q$ – discharge flow (liters/second).

The calculation and estimation of water demand were done using a formula based on SNI 19-6728.1-2002. The research area was structured as a rural area; thus the domestic water demand standard was 60 liters per person per day. Knowing the per capita daily water demand, it was formulated as follows:

$$Water\ demand = \\ = \sum population \times 365 \times 60L \quad (2)$$

## RESULTS AND DISCUSSION

### The emergence and distribution of springs

Strato volcanoes comprised several landform units characterized by slope bending (Simoen., 2001). In general, volcanic area springs were found in landform unit changes (Santosa., 2006). Differences in geomorphological conditions and characteristics of each volcanic landform unit influenced the potential and pattern distribution, as well as the characteristics of springs (Ratih et al., 2019). On the basis of the information above, spring observations on the northern slopes of Mount Merbabu focused on areas of change in landform units. This research found 30 springs on the northern slopes of Mount Merbabu.

On the basis of observations made on 30 spring samples, it was known that the emergence of springs was mostly found in the landform units at the foot of volcanoes, followed by volcanic cones and plains, volcanic slopes, and some in volcanic craters and dikes. Many springs in volcanic areas occurred due to energy from within the earth and were not influenced by gravitational forces or non-gravitational springs (Santosa, 2006). In this research, emergence of one spring occurred due to energy from within the earth and was not influenced by gravitational forces, namely the Dead Crater spring. Most of the springs on the northern slopes of Mount Merbabu occurred due to pressure from within the earth, which cut off the flow of water. Since Mount Merbabu has not been active for a long time, exogenous factors had a significant influence on the emergence of springs. The distribution of springs on the northern slopes of Mount Merbabu, based on the results of GIS analysis using the average nearest neighbour method carried out using ArcGIS 10.8, obtained a z-value of -3.338930 and a p-value of 0.000841. With the negative z-value results, it was concluded that the distribution of springs on the northern slopes of Mount Merbabu had a clustered pattern. The p-value showed that the hypothesis test was correct, because it did not result in 0.

In this study, the emergence of springs was found around a break of slope, which indicated that the spring belt pattern whereabouts were no longer clear. Jago Spring, Kalisowo, Ngaglik, and Syarif Spring were found around the bend of the slopes of Mount Merbabu as fracture springs. The erosion and mass movement process caused the slope to buckle, indicating that changes in landform units were no longer visible (Santosa, 2006). This process also caused the closure of places that allowed springs to appear (Ashari and Widodo, 2019). The process of erosion and mass movement on the northern slopes of Mount Merbabu was also shown by the valley development, which experienced more intensive widening and deepening. According to the research results, springs were appearing in river valleys with a radial pattern on the northern slopes of Mount Merbabu as depression springs, namely Spring 1, Bangkean, Gumuk Kethu, Grinjingan, Kali Selo 3, Kali Selo 4, Kedung Kluruk, Klanting, Lanang, Mongkrong, Ngereng-ngereng, Pontong, Puthut, Sarijo, Sayangan, and Suthur Springs.

Differences in the main materials that made up landform units (lithology) also influenced the emergence of springs on the northern slopes of Mount Merbabu. The northern slope of Mount Merbabu consisted of two rock formations, namely Merbabu Volcanic rocks and Sumbing lava rocks. Sumbing lava rock formations had high permeability and allowed underground water to flow through pores or fissures easily. Meanwhile, the rock formations of Merbabu Volcano had lower permeability and tended to obstruct water flow so that the water flow could not continue its journey and was forced to come to the surface as contact springs. These springs were Dandang Spring, Kali Selo 1, Pasang, and Umbul Songo.

Apart from that, on the northern slopes of Mount Merbabu, springs were found that emerged due to the interaction between large rocks that caused obstructions and the surrounding lithology, so that the water found a way out through cracks under large rocks as artesian springs, namely Gedad Springs, Tulung, and Wadas Springs. The emergence of springs was also influenced by vegetation, where Jemblong Springs and Kali Selo 2 Springs were found, which were not cut by topography or influenced by the main material that made up the landform unit, but vegetation was found in the form of banyan trees that had deep roots and could penetrate the aquifer layer, thereby causing water to come out towards the ground surface (Purnama., 2010).

## Spring characteristics

Spring characteristics are specific attributes of a spring (Table 1). In this research, spring characteristics were reviewed based on their discharge and flow properties, and indicators of temperature (°C), pH, total dissolved solids (TDS), and electrical conductivity. Factors in the emergence of springs in landform units had distinctive properties, and certain responses to spring characteristics were expressed in spring hydrogeomorphological units.

The characteristics of springs were specific indicators that could be assessed based on their quantity and quality. The quantity of springs was demonstrated by their discharge and flow properties, while the quality was indicated by such parameters as temperature (°C), pH, total dissolved solids (TDS), and electrical conductivity (EC).

**Table 1.** Hydrogeomorphological characteristics of springs on the north slope of Mount Merbabu

| Landform | Springs | Classification | | | | | Flow properties |
|---|---|---|---|---|---|---|---|
| | | Flow rate (L/s) | pH | TDS (mg/L) | Electrical conductivity (µs/cm) | Temperature (°C) | |
| Creator | Kawah Mati | 0.41 | 3.57 | 521 | 814 | 21.98 | Perennial |
| Volcano Cone | Gumuk Kethu | 2.74 | 6.48 | 89 | 137 | 22.27 | Perennial |
| | Jago | 0.80 | 6.59 | 73 | 119 | 22.25 | Perennial |
| | Planting | 0.85 | 6.47 | 95 | 145 | 22.18 | Perennial |
| | Mongkrong | 0.85 | 6.54 | 66 | 107 | 22.35 | Perennial |
| | Ngaglik | 0.20 | 6.58 | 86 | 123 | 22.47 | Perennial |
| | Syarif | 1.70 | 6.57 | 65 | 98 | 21.98 | Perennial |
| Volcano Slopes | 1 | 0.34 | 6.93 | 40 | 52 | 22.61 | Perennial |
| | Kalisowo | 0.98 | 6.76 | 61 | 88 | 22.93 | Intermittent |
| | Ngereng-ngereng | 0.07 | 6.56 | 81 | 95 | 22.64 | Perennial |
| | Pontong | 0.65 | 6.68 | 63 | 71 | 22.90 | Perennial |
| Volcano Foot | Bangkean | 0.31 | 6.59 | 46 | 52 | 22.75 | Perennial |
| | Gedad | 0.25 | 6.64 | 51 | 55 | 22.47 | Perennial |
| | Grinjingan | 0.17 | 6.49 | 84 | 86 | 23.14 | Perennial |
| | Jemblong | 0.05 | 6.52 | 76 | 81 | 22.49 | Perennial |
| | Kedhung Kluruk | 0.34 | 7.01 | 64 | 69 | 22.69 | Perennial |
| | Puthut | 0.02 | 6.80 | 46 | 52 | 22.31 | Intermittent |
| | Sarijo | 0.15 | 6.60 | 43 | 45 | 22.58 | Perennial |
| | Sayangan | 0.08 | 6.84 | 47 | 48 | 22.35 | Intermittent |
| | Author | 0.10 | 6.73 | 39 | 40 | 22.73 | Perennial |
| | Wadas | 0.05 | 6.52 | 43 | 43 | 22.40 | Intermittent |
| Volcano Plain | Kali Selo 2 | 0.05 | 6.93 | 38 | 43 | 22.84 | Intermittent |
| | Kali Selo 3 | 0.08 | 6.81 | 42 | 56 | 22.86 | Intermittent |
| | Kali Selo 4 | 0.35 | 6.74 | 51 | 68 | 22.93 | Perennial |
| | Lanang | 0.48 | 6.84 | 38 | 51 | 23.24 | Perennial |
| | Tulung | 2.74 | 6.84 | 39 | 55 | 23.15 | Perennial |
| Dikes | Danang | 2.65 | 6.97 | 76 | 118 | 23.06 | Perennial |
| | Kali Selo 1 | 5.27 | 6.68 | 39 | 67 | 22.85 | Perennial |
| | Pasang | 3.32 | 6.89 | 52 | 93 | 23.01 | Perennial |
| | Umbul Songo | 33.29 | 6.51 | 62 | 94 | 22.39 | Perennial |

Springs possessed numerous characteristics and could thus be classified into various categories. The emergence of springs in different landform units had unique properties and specific responses to spring characteristics, expressed in hydrogeomorphological units of springs.

The spring flow discharge in this study was classified according to Meinzer's (1923) classification into eight classes: class I with a discharge >10,000 liters/second, class II with a discharge of 1,000–10,000 liters/second, class III with a discharge of 100–1,000 liters/second, class IV with a discharge of 10–100 liters/second, class V with a discharge of 1–10 liters/second, class VI with a discharge of 0.1–1 liter/second, class VII with a discharge of 0.01–0.1 liter/second, and class VIII with a discharge <0.01 liters/second (Said and Sudarmadji., 2013). Field measurements in this study were conducted in January-February 2024, during the rainy season. The spring discharge measurements in the field showed varying discharge classes, with the highest in class IV and the lowest in class VII. On the basis of these measurements, springs with high discharge emerged in the younger rock formations of Mount Merbabu, particularly in landform units, such as dikes, which appeared due to differences in geological formations, resulting in high spring discharge. These springs included Umbul Songo, Dandang, Kali Selo 1, and Pasang springs. Springs in other geological formations exhibited varying discharge rates influenced by rainfall and aquifer characteristics. According to Santosa (2006), the older the volcanic rock, the less it influenced spring discharge. This occurred because the compaction and cementation processes were more intensive, reducing the pore spaces between rock grains, leading to lower permeability and smaller spring discharge.

According to Todd (1959), the conditions in the area directly affected the amount of rainwater entering the ground as groundwater, and permeable geological or rock conditions allowed water to penetrate rock pores, resulting in a higher volume of water compared to impermeable intrusive rocks. Landforms and slope gradients also influenced spring discharge, as steeper slopes generally led to higher water flow. However, based on the analysis of 30 spring samples, there was an observed increase in water discharge at spring locations with higher slope gradients, although the effect was weak at 0.02 (Figure 4).

Darcy's Law asserts that the flow rate of water emanating from a spring is contingent upon the disparity in elevation between the water source and the surface of the ground. As the elevation of the spring location on the mountain decreases (resulting in a larger height differential), the water discharge produced by the spring increases. However, after analyzing 30 spring samples, it was shown that spring locations at lower elevations saw an increase in water discharge. This rise had a weak influence, measured at 0.01 (Figure 5).

Naudeau and Rains (2007) divided the flow characteristics of springs into three categories: perennial, intermittent, and ephemeral springs.

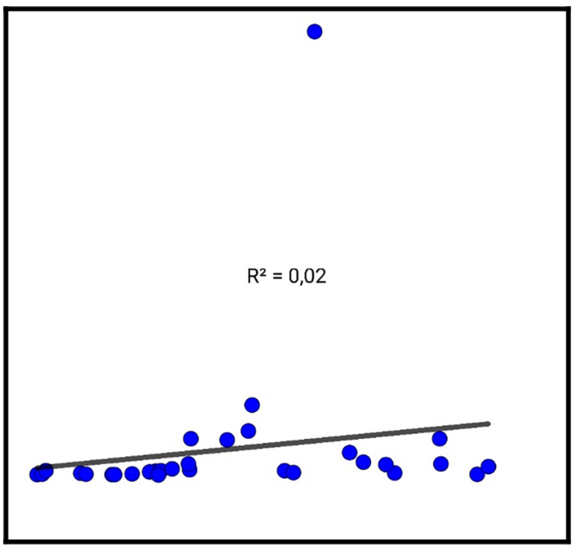


**Figure 4.** Relationship between flow discharge and slope gradient

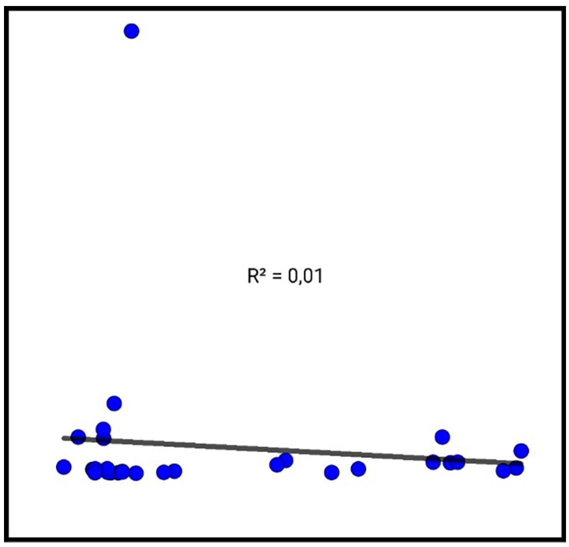


**Figure 5.** Relationship between flow discharge and elevation

Perennial springs are characterized by a continuous flow throughout the year, unaffected by rainfall. Intermittent springs, on the other hand, only flow for a few months each year and are influenced by rainfall. Ephemeral springs also flow for a few months each year and are influenced by rainfall, but their discharge changes are not directly dependent on rainfall. Research findings indicate that the majority of springs located on the northern slope of Mount Merbabu are perennial springs. Perennial springs provide a constant flow of water throughout the year and are not directly affected by precipitation, thereby ensuring a consistent and reliable water source (Purnama., 2010). According to the interviews performed, these springs have a consistent history of never running dry or being influenced by seasonal variations, and can therefore be categorized as permanent springs. Furthermore, there are multiple sporadic springs, like Kali Selo 2, Kali Selo 3, Kalisowo, Puthut, Sayangan, and Wadas. Intermittent springs release groundwater periodically as a result of seasonal factors (Purnama, 2010). Interviews suggest that these springs are influenced by continuous precipitation. In the dry season, the flow of these springs can diminish and cease, but in the rainy season, the formerly arid springs will resume flowing. Arsyad and Rustiadi (2012) identified several factors that affect the flow characteristics of springs. These factors include rainfall, surface hydrology characteristics, topography, aquifer formation, and geological structure. These factors can cause fluctuations in spring discharge rates, which can vary from minutes to years.

According to Santosa (2021) and Jayanti (2023), the springs on the northern slope of Mount Merbabu are categorized based on the temperature during springtime. Springs with temperatures below 16 °C are classified as extremely cold, while temperatures ranging from 16–22 °C are considered cold. Springs with temperatures between 22–28 °C are categorized as normal, while those with temperatures ranging from 28–34 °C are classified as hot. Springs with temperatures exceeding 34 °C are considered extremely hot. The research findings indicate that there are no discernible variations among the springs. The springs located on the northern slope of Mount Merbabu have water temperatures ranging from 21.98 to 23.24 °C, which categorizes them as springs with normal temperature. Bowen (1986) states that the temperature of springs is mostly determined by the air temperature and altitude. Higher air temperature or altitude results in lower water temperature. After analyzing 30 spring samples, it was revealed that water temperature tends to increase in spring locations situated at lower altitudes. This increase is influenced to a small extent, with a correlation coefficient of 0.42 (Figure 6). The occurrence of these results can be attributed to the random timing of temperature readings in this study, which were also affected by rainfall variables.

The pH is a measure of the acidity or alkalinity of water, determined by the concentration of hydrogen ions. It is intimately linked to carbon dioxide and alkalinity (Ala et al., 2018). The pH levels of springs on the northern slope of Mount Merbabu are categorized based on the classification systems developed by Santosa (2021) and Jayanti (2023). According to these systems, a pH value below 3 is considered very acidic, a pH value between 3 and 6 is classed as acidic, a pH value between 6 and 8 is considered neutral, a pH value between 8 and 12 is classified as alkaline, and a pH value between 12 and 14 is considered very alkaline. The pH values of the springs on the northern slope of Mount Merbabu exhibit a range of 6–8, indicating a neutral nature. The Kawah Mati spring is the only spring with a pH value of 3.57, indicating its acidity. The analysis indicates that the formation of the Kawah Mati spring is influenced by its location on a gas flow line that has been obstructed by the ground surface. According to Nugraha's (2008) research, the area is a site where hydrogen sulfide gas (solfatara)

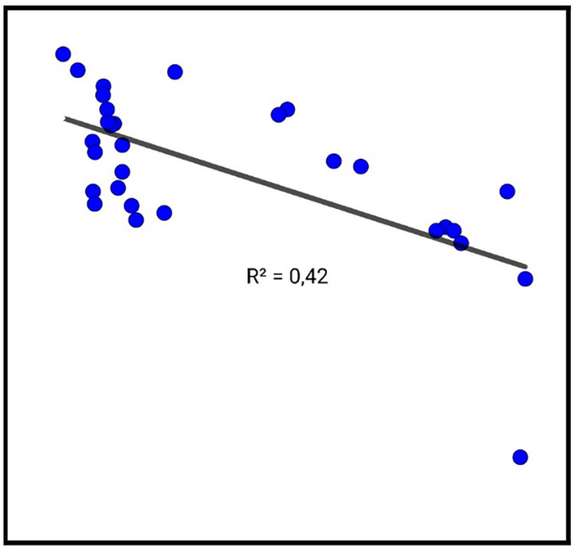


**Figure 6.** Relationship between water temperature and elevation

is emitted and there is also a significant amount of $CO_2$ present. This suggests that there is a release of hot fluids in the form of steam from a hydrothermal system, which in turn releases carbon dioxide ($CO_2$) through the soil layers near the surface. This phenomenon may be connected to volcanic gas originating from beneath the surface. Carbon dioxide ($CO_2$) can react with water to produce carbonic acid, which reduces the pH of the water (Hadi, 2005).

The elevation of the spring site can also impact the pH level of the spring water. Pingki (2021) stated that there is a direct correlation between the altitude of the spring location and the pH value, meaning that the pH value increases with altitude. The higher pH of the water is a result of the lower content of $CO_2$. After analyzing 30 spring samples, it was revealed that the pH value increased in spring locations with lower altitudes. This increase was influenced to a weak extent, with a value of 0.20 (Figure 7).

Total dissolved solids (TDS) encompass all substances that are dissolved in water, such as ions, compounds, or colloids. TDS levels mostly arise from the presence of inorganic substances resulting from the process of rock erosion, the runoff of soil, or human actions (Lestari et al., 2021). The TDS of springs located on the northern side of Mount Merbabu is categorized based on the classification systems proposed by Santosa (2021) and Jayanti (2023) as outlined below: The TDS levels can be used to determine the clarity of springs. TDS levels ranging from 0–1,000 indicate that the springs are very clear. TDS levels between 1,000–3,000 indicate clear springs. Slightly turbid springs are indicated by TDS levels ranging from 3,000–10,000. Turbid springs are indicated by TDS levels between 10,000–100,000. Lastly, TDS levels over 100,000 indicate very turbid springs. The measurements of 30 springs on the northern slope of Mount Merbabu indicate that the TDS values are below 1,000 mg/L, categorizing them as springs with excellent clarity. The TDS readings of the Kawah Mati spring are significantly greater compared to other springs on the northern slope of Mount Merbabu. High TDS in the spring water is a result of the spring emergence along a gas flow pathway and the presence of a significant amount of minerals derived from geological processes under the Earth's surface. The infiltration of water into the soil surrounding the crater might result in the dissolution of minerals from the adjacent rocks, leading to an elevation in the levels of TDS. As per Jayanti (2023), elevated TDS levels are a result of the breakdown of rocks, presence of fine particles, solid matter, or the introduction of minerals and other chemical compounds into the water owing to volcanic activity, leading to the dissolution of metal ions in the water.

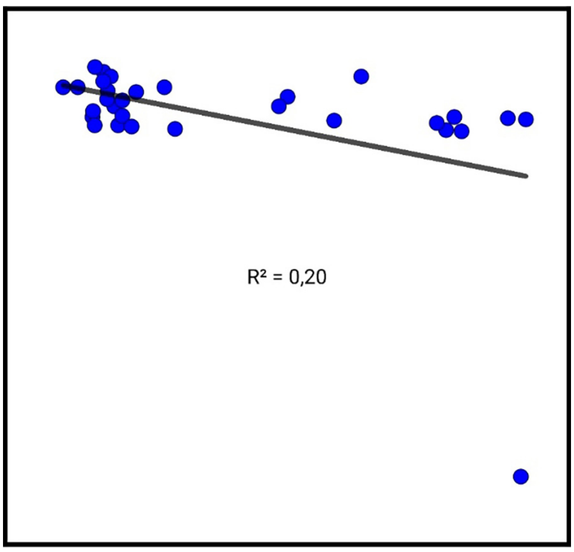


**Figure 7.** Relationship between water pH and elevation

Electrical conductivity (EC) is a measure of the capacity of water to conduct electricity, which is determined by the presence of dissolved chemicals in the water (Taryana, 2016). The categorization of springs based on EC is established by evaluating the TDS measurements, as outlined by Santosa (2010) and Jayanti (2023). TDS levels below 1,200 indicate the presence of fresh water springs. TDS levels between 1,200 and 2,500 indicate the presence of brackish-fresh water springs. TDS levels between 2,500 and 4,500 indicate the presence of brackish water springs. TDS levels between 4,500 and 10,000 indicate the presence of salty springs. TDS levels above 10,000 indicate the presence of highly saline springs. Analysis of 30 springs located on the northern slope of Mount Merbabu revealed that the total dissolved solids (TDS) levels do not surpass 1,200 mg/L, indicating that these springs can be categorized as freshwater springs.

The electrical conductivity of water was determined by its TDS concentration, ion concentration, and temperature. TDS is a measurement that reflects the level of salinity in water. This was because when solids dissolved in water, they separated into positively charged ions (cations) and negatively charged ions (anions), which could conduct electricity and hence impact the EC of water. After analyzing 30 spring samples, it was noticed that an increase in EC occurred when TDS levels increased. This relationship was found to have a strong correlation coefficient of 0.98, as shown in Figure 8.

Suyono et al. (2009) stated that the mobility of ions in water was affected by temperature, with higher temperatures leading to greater electrical conductivity. Each increase of 1 °C in temperature resulted in a 2% increase in EC. After analyzing 30 spring samples, it was noticed that there was a rise in EC as the temperature increased. This increase showed a modest correlation of 0.52, as depicted in Figure 9. A study conducted by Ashari and Widodo (2019) on the southwest slope of Mount Merbabu discovered that as temperature increased, there was a corresponding increase in electrical conductivity. However, the correlation between the two variables was weak, measuring only 0.19.

The EC values were influenced by the elevation of spring emergence, with springs at lower elevations exhibiting greater EC levels. Mount Merbabu, a stratovolcano, underwent substantial precipitation on its higher slopes due to orographic rainfall, resulting in the upper section of the mountain serving as a water recharge zone. Lower elevation springs had extended contact with rock, resulting in a greater buildup of dissolved minerals. As a consequence, springs at lower elevations experienced higher EC values. After analyzing 30 spring samples, it was revealed that there was an increase in EC (electrical conductivity) at lower elevations.

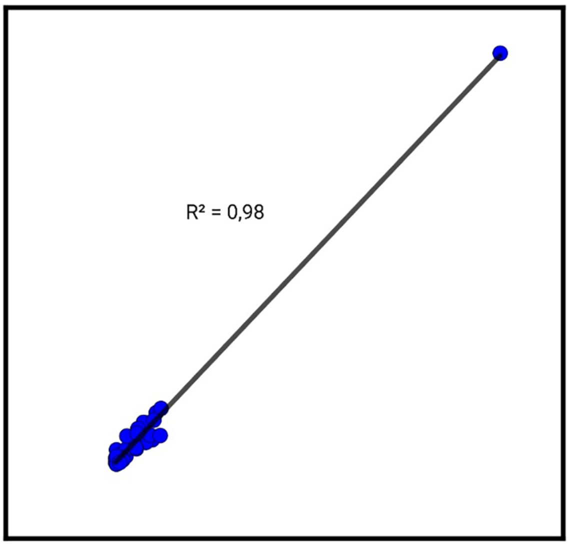


**Figure 8.** Relationship between water electrical conductivity and TDS

This rise had a weak correlation of 0.23, as shown in Figure 4.21. Ashari and Widodo (2019) conducted a study on the southwest slope of Mount Merbabu and discovered that there was a rise in electrical conductivity in springs at lower elevations. They observed a weak correlation of 0.27.

## Spring water qualities

Water quality is closely related to the environmental conditions of the surrounding area (Rizky et al., 2024). The water quality element pertained to the attributes of water in terms of its physical

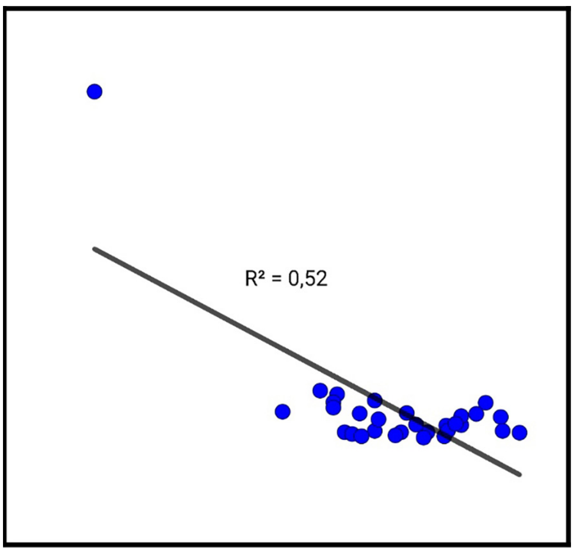


**Figure 9.** Relationship between water electrical conductivity and water temperature

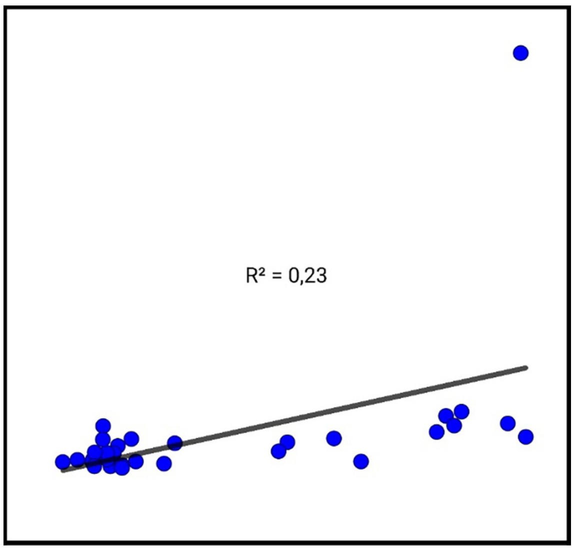


**Figure 10.** Relationship between water electrical conductivity and elevation

qualities and properties resulting from organic and non-organic substances (indicators). These attributes had to adhere to the relevant requirements for clean water quality in order to be considered safe for use. The water quality indicators utilized in this study were temperature, pH, TDS, and electrical conductivity. These indicators served to offer a comprehensive understanding of the differences in water quality across multiple springs located on the northern slopes of Mount Merbabu. Water quality indicators were assessed according to the standards set for drinking water quality.

The measurement results indicated that the temperature of the springs on the northern slopes of Mount Merbabu fell within the range of 21.98–23.24 °C. This classification categorized the springs as having normal temperatures, making them suitable for drinking water and other purposes that adhered to the drinking water quality standards. The pH indicator measurements showed that the spring water on the northern slopes of Mount Merbabu had a pH value that complied with the regulations for drinking water quality, thus confirming its safety for consumption. However, one spring, specifically the Kawah Mati spring, failed to meet the guidelines for drinking water quality due to its pH value of 3.57. The acidic nature of Kawah Mati spring water rendered it unsuitable for any usage, including water recreation facilities, fish aquaculture, animal husbandry, and agriculture.

The TDS value of spring water measured on the northern slopes of Mount Merbabu consistently indicated that the TDS value of the water was below 300 mg/L, making it suitable for consumption as drinking water and for other purposes. Similar to the water pH indication, the TDS value of Kawah Mati spring water also failed to fulfill the established quality criteria for drinking water, as it had a TDS value of 521 mg/L. The measurement findings for the electrical conductivity indicator showed that the electrical conductivity value of spring water on the northern slopes of Mount Merbabu complied with the regulations for drinking water quality, thereby confirming its safety for consumption. The TDS concentration of Kawah Mati spring water was elevated, resulting in a correspondingly high electrical conductivity value of 814 µS/cm. On the basis of the indication of electrical conductivity, the value indicated that Kawah Mati spring failed to meet the quality criteria for drinking water.

**Table 2.** Quality standards for water quality indicators based on the regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023 on the Implementation of Government Regulation No. 66 of 2014 concerning Environmental Health

| Indicator | Unit | Quality standards |
|---|---|---|
| Temperature | °C | ± 3 |
| pH | - | 6.5–8.5 |
| Total dissolve solid (TDS) | mg/L | <300 |
| Electrical conductivity | μs/cm | 400 |

### Spring water quantities

The quantity aspect referred to the availability of water that needed to meet the amount used.

**Table 3.** Total spring water availability

| Spring | Discharge (liter/second) | Water availability ($m^3$/year) |
|---|---|---|
| 1 | 0.34 | 10,722.24 |
| Bangkean | 0.31 | 9,776.16 |
| Dandang | 2.65 | 83,570.40 |
| Gedad | 0.25 | 7,884.00 |
| Grinjingan | 0.17 | 5,361.12 |
| Gumuk Kethu | 2.74 | 86,408.64 |
| Jago | 0.80 | 25,228.80 |
| Jemblong | 0.05 | 1,576.80 |
| Kali Selo 1 | 5.27 | 166,194.72 |
| Kali Selo 2 | 0.05 | 1,049.76 |
| Kali Selo 3 | 0.08 | 1,679.61 |
| Kali Selo 4 | 0.35 | 11,037.60 |
| Kalisowo | 0.98 | 20,575.29 |
| Kedung Kluruk | 0.34 | 10,722.24 |
| Klanting | 0.85 | 26,805.60 |
| Lanang | 0.48 | 15,137.28 |
| Mongkrong | 0.85 | 26,805.60 |
| Ngaglik | 0.20 | 6,307.20 |
| Ngereng-ngereng | 0.07 | 2,207.52 |
| Pasang | 3.32 | 104,699.52 |
| Pontong | 0.65 | 20,498.40 |
| Puthut | 0.02 | 419.90 |
| Sarijo | 0.15 | 4,730.40 |
| Sayangan | 0.08 | 1,679.61 |
| Suthur | 0.10 | 3,153.60 |
| Syarif | 1.70 | 53,611.20 |
| Tulung | 2.74 | 86,408.64 |
| Umbul Songo | 33.29 | 1,049,833.44 |
| Wadas | 0.05 | 1,049.76 |
| Total | 1,845,135.05 | |

Water availability from springs could be seen from the amount of water discharge released by the springs (Said and Sudarmadji, 2013). Calculations from field measurement data showed that the amount of discharge released by springs on the northern slopes of Mount Merbabu was 58.93 L/s; when calculating its availability for a year (365 days) and considering the nature of the flow, it amounted to 1,845,135.05 m³/year.

Measuring the amount of water needed for domestic purposes was based on the population in an area (Noperissa and Waspodo, 2018). This research area included Batur Village, Getasan Village, Kopeng Village, Samirono Village, and Tajuk Village, which were categorized as rural areas, so the domestic water requirement standard was 60 liters/person/day. Domestic water needs for the research area were estimated at 535,236.00 m³/year, with details as follows: Batur Village, with a population of 7,463 people, had estimated domestic water needs of 163,439.70 m³/year; Getasan Village, with a population of 3,136 people, had domestic water needs of 68,678.40 m³/year; Kopeng Village, with a population of 7,159 people, had a domestic water need of 156,782.10 m³/year; Samirono Village, with a population of 2,531 people, had a domestic water need of 55,428.90 m³/year; and Tajuk Village, with a population of 4,151 people, had a domestic water requirement of 90,906.90 m³/year.

The analysis results showed a large difference in the availability and demand for water on the northern slopes of Mount Merbabu. The springs on the northern slopes of Mount Merbabu could still meet domestic water needs with a surplus of 1,309,899.05 m³/year. They could be used for purposes other than domestic, such as irrigation, animal husbandry, industry, etc.

**Table 4.** Domestic water needs based on the Semarang Regency Civil Registry Office (2024)

| Village | Population | Demand (m³/year) |
|---|---|---|
| Batur | 7.463 | 163.439,70 |
| Getasan | 3.136 | 68.678,40 |
| Kopeng | 7.159 | 156.782,10 |
| Samirono | 2.531 | 55.428,90 |
| Tajuk | 4.151 | 90.906,90 |
| Total | | 535.236,00 |

## CONCLUSIONS

This study effectively accomplished its objective of conducting a thorough analysis of the hydrogeomorphological features of springs on the northern slope of Mount Merbabu, uncovering numerous novel scientific findings that have not been previously recorded. The key findings consist of a comprehensive quantitative analysis of the springs, which reveals discharge rates ranging from 0.02 to 33.29 litres per second, temperature variations between 21.9 and 23.24 degrees Celsius, pH levels ranging from 3.57 to 7.01, TDS values ranging from 38 to 521 mg/L, and electrical conductivity ranging from 40 to 814 µS/cm. In addition, the study recorded the spatial arrangement and hydrogeomorphological patterns of the springs, thereby improving the comprehension of how geological formations impact the features of springs. The investigation also discovered potential applications for agricultural and home utilisation, showcasing the pragmatic significance of these springs for nearby people. This study enhances the understanding of spring hydrogeomorphology in this particular area by addressing the existing gaps. It establishes a fundamental dataset that can be used for sustainable water resource management and conservation strategies. Consequently, it creates opportunities for better utilization and protection of these natural water sources. The recent scientific findings, including comprehensive quantitative attributes, provide a more profound comprehension that previous researchers have not attained, establishing the foundation for future investigations and decision-making, notably in the fields of environmental and geological studies. The authors anticipate that these findings will stimulate additional research on the hydrogeomorphological attributes of springs in different areas, thereby enhancing the overall worldwide comprehension of these crucial natural resources. Nevertheless, this study is limited by the fact that data collection occurred only

**Tabel 5.** Comparison of water availability with water needs

| Availability (m³/year) | Demand (m³/year) | Total comparison (m³/year) |
|---|---|---|
| 1.845.135,05 | 535.236,00 | 1.309.899,05 |

once, hence neglecting any seasonal fluctuations. It is advisable for future studies to gather data repeatedly in order to consider the influence of seasonal variations.

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