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Clean Water Source Availability in Springs Within Karst Areas of Grobogan Regency

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Abstract: Grobogan Regency, Central Java, is characterized by karst landscapes, particularly in the Sukolilo Karst Landscape Area (Kawasan Bentang Alam Karst—KBAK Sukolilo), which plays a crucial role in regional water availability. Although the northern and western parts of the regency have the potential to store groundwater due to karstification, the southern regions often face water scarcity and prolonged droughts. This study aims to (1) identify the spatial distribution of springs in KBAK Sukolilo, and (2) analyze water availability across the karst area. A quantitative research approach was employed, focusing on 43 springs distributed across six subdistricts: Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan. Data collection involved field observations, interviews, and documentation, while spatial and environmental analyses were conducted using Geographic Information Systems (GIS). The findings reveal an uneven and dynamic distribution of springs, with some springs recorded in 2018 no longer active or traceable in 2024 due to land cover changes and diminished discharge. Based on study, it was seen that the water demand in three sub-districts exceeded the water availability. Water balance analysis indicates that Brati, Grobogan, and Ngaringan are categorized as water-deficit areas, whereas Klambu, Tawangharjo, and Wirosari experience a water surplus. These results highlight the urgent need for integrated water resource management in karst environments, particularly in addressing regional disparities in water availability.

Keywords: Springs, Water availability, Karstification, Water demand, Sukolilo Karst

1 Introduction

Water is essential for all living organisms, especially humans to meet daily needs. However, the population growth has not kept pace with the availability of water resources. Water availability is decreasing, necessitating sustainable water resource management. Karst landscapes are geomorphological landforms that play an important role in hydrology by serving as significant groundwater sources for nearby populations. These locations frequently have significant water resources, despite their location deep beneath the surface [1, 2]. Karst area has the potential for underground rivers and several springs as a result of the limestone dissolution process. Springs naturally form when water flows beneath the surface, frequently as a result of topographic features intersecting hydrological paths. These springs are usually found in lowland regions, on slopes, in valleys, or at the foot of hills.

The distribution of limestone creates a hydrological system in the karst area due to the dissolution of rainwater in the carbonate and evaporite layers in the limestone hills [3]. Karst is an area with distinctive relief and drainage characteristics, caused by the high dissolution of rocks [4]. Karstification is the process of forming karst landforms dominated by the process of limestone dissolution which is greatly influenced by rainfall, the purity of carbonate rocks, and carbon dioxide concentration [5]. The karst region is dominated by carbonate rocks, mainly limestone, resulting from marine deposition. The karst region is composed of limestone, which functions as an underground aquifer that stores and releases water [6]. Karstification can be analyzed through geological formation studies, as rock types provide critical insight into the geological conditions of an area. Identifying rock characteristics is essential for assessing karstification potential, which also indicates groundwater availability [7].

The Indonesian karst area spans approximately 15.4 million hectares and spreads from Aceh to Papua. The age range is estimated to be between 470 million years ago and 700,000 years at the latest [8, 9]. Geological evidence suggests that many Indonesian islands were once seabeds that later emerged and solidified to form karst topography. The "Sukolilo Karst Mountains" are a karst landscape in Central Java that stretches from west to east through Grobogan, Pati, and Blora Regencies. The Sukolilo Karst, also known as the North Kendeng Mountains Karst Area, is classified as a Karst Landscape Area (Kawasan Bentang Alam Karst—KBAK) under Indonesian Ministry of Energy and Mineral Resources Regulation No. 17 of 2012 [4, 10]. The Sukolilo KBAK is the largest water catchment area, as a Groundwater Basin (CAT) in the northern and western parts of Grobogan Regency. However, the southern part of Grobogan Regency experiences hydrometeorological drought almost every year [11].

KBAK Sukolilo in Grobogan Regency has potential natural resources in the form of limestone that is undergoing karstification [12]. The ongoing process of water dissolution on limestone produces interesting karst phenomena such as lapies, caves, stalactites, stalagmites, sinkholes, uvalas, dolines, and underground rivers. The karstification process can be recognised as a sign of groundwater sources based on the features of a rock formation [4, 13]. The rocks in the Sukolilo Karst are a variety of sedimentary rocks, ranging in age from young to old, calcareous and non-calcareous. The rock formations in the Sukolilo KBAK consists of the Ngranyong, Bulu, and Alluvium Deposit formations [12], with types of limestone, sandstone, and claystone orbiting [14, 15].

Springs in KBAK Sukolilo tend to have uneven distribution characteristics, both for surface water and groundwater, in terms of quality and quantity [16, 17]. In addition to their uneven distribution, springs in the karst area also show different variations in discharge. This phenomenon causes people to face water shortages during the long dry season and rely on government assistance to meet their clean water needs. When Grobogan Regency experienced drought in 2019, the Regional Disaster Management Agency (BPBD) helped by donating 104 clean water tanks, totalling 422,000 litres [11, 18]. This phenomenon is also associated with the effects of climate change, which are typified by rising temperatures and altered rainfall patterns distributed relatively evenly throughout Indonesia [19]. As air temperature rises, evaporation accelerates. However, patterns of rainfall also change. Climate change can alter the pattern, timing, and number of rainy days, affecting water discharge and shifting the schedule of crops [20]. Climate change impacts the varying drought periods, which are classified as meteorological, hydrological, and agricultural droughts. Meteorological drought refers to decreased rainfall, hydrological drought refers to a surface water deficit, and agricultural drought refers to reduced soil moisture [21, 22].

Karst areas that are sensitive to human activity must be protected to ensure water availability and other karst functions remain optimal. Apart from providing water, karst areas serve visually pleasing and educational functions [23]. This study aimed to determine the spring distribution in karst regions. Understanding the distribution of springs can assist the government and community achieve water equity. Furthermore, this study can help the community better use springs, as water availability in karst areas is limited, particularly during the dry season. On the other hand, these limited water resources must meet the demands of a population that will undoubtedly continue to grow.

This study addresses two issues: information on spring characteristics and water availability in karst area. The potential, distribution, and existence of springs in Indonesia and other parts of the world have not been thoroughly documented [24, 25]. Water availability in karst areas is difficult to determine, particularly the presence of surface water, because karst areas cannot store water but instead pass it on and dissolve it underground [22, 26]. This issue highlights the necessity of this research to create a spring management plan, and the following problems serve as the foundation for the research objectives: (1) Determining the spring distribution in KBAK Sukolilo and (2) Assessing water availability in karst regions.

2 Materials and Method

The study was conducted in Grobogan Regency, Central Java, Indonesia, with a total area of 2,023.84 km^2. Grobogan Regency is administratively divided into 19 subdistricts and 280 villages. This research was limited to six subdistricts that are specifically related to the concern of water availability in karst areas, which include Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan. These six subdistricts are located within the Sukolilo Karst Landscape Area (KBAK Sukolilo) of Grobogan Regency (Figure 1).

This study used a quantitative research approach to gather numerical data and examine relationships, differences, effects, explanations, or predictions between two or more variables. The primary object of investigation was springs found within the karst region of Grobogan Regency. A stratified sampling technique was used based on regional characteristics and the number of springs in each area. There are fourteen sub-districts in Grobogan Regency, and only six sub-districts (Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan Sub-districts) cover the KBAK Sukolilo area. The next strata are based on the number of samples: the number of springs in 14 sub-districts is 153, while the springs in the Sukolilo karst area (8 sub-districts) have 73 springs. In this study, the research area is only in KBAK Sukolilo alone, covering six sub-districts, and there are as many as 43 springs (which can still be traced and found when the research is conducted in 2024).

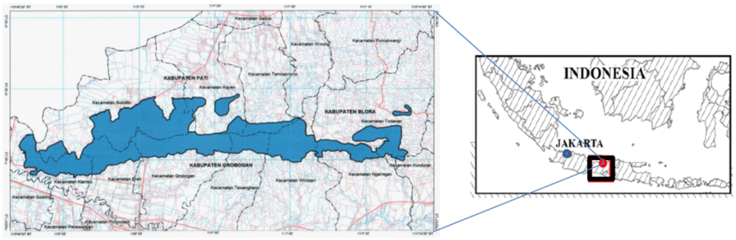

Figure 1. Location map of study area

Data collection techniques included direct observation, interviews, and document analysis. Observations were conducted to assess spring conditions, particularly discharge volumes and water availability. Interviews were used to gather information on spring usage by local communities. Supporting data were collected through document analysis, including reports and archival records from relevant institutions. This study used spatial and environmental data analysis, which was supported by Geographic Information System (GIS) technology for spring mapping. Mapping was carried out using ArcGIS 10.8 software. The location of each spring in each subdistrict, the water discharge rate, and the area's use are all necessary for the mapping process. The data set is mapped, examined, and described in paragraphs.

Analysis of water availability in the research area was calculated using the SA formula. Spring availability (SA) was obtained by calculating the value of the spring potential (S_p) minus the value of the population's water demand (W_d). The results of this subtraction would show the ability of the spring to meet clean water needs. Based on this statement, the availability of springs was calculated using the following equation [27]:

$$SA = S_p - W_d$$

where, SA is spring availability, S_p is spring potential, and W_d is water demand.

This equation was derived from a simplified water balance model used to estimate water availability in a given area [27, 28]. The original formula typically applied to rainwater harvesting systems, was modified to accommodate spring-based water sources. Therefore, the population in the study area was assumed to rely only on springs to meet their clean water needs. W_d includes domestic and agricultural needs. While domestic water needs include daily use such as drinking, cooking, cleaning, and washing.

3 Result and Discussion

This study was conducted in the karst region of Grobogan Regency, specifically on the Sukolilo Karst Landscape Area (KBAK Sukolilo) (Figure 1). According to data provided by the Environmental Office of Grobogan Regency, the administrative area of KBAK Sukolilo encompasses six subdistricts: Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan. A total of 43 springs located within this region were selected as the primary objects of the study. These springs serve as critical sources of freshwater and play a pivotal role in maintaining the ecological and hydrological sustainability of the karst system.

The presence of karst in Grobogan District's KBAK Sukolilo offers a crucial illustration of how the karstification process affects water availability. Karstification which ultimately forms a hydrological system plays an important role in capturing and distributing rainwater. Rainwater passes through underground caverns and other cavities created during the karstification process. The water may emerge on the surface through cavities created by different tectonic and karstification processes. According to Atalay et al. [29], the karstification process began in Mesozoic limestone, which formed calcareous mud, followed by flowing water or rivers in Late Mesozoic limestone, and vertical tectonic movements during the Miocene, which resulted in the formation of tectonic basins in the Taurus Mountains [29].

3.1 Geological Characteristics of Grobogan Regency

The geological setting of Grobogan Regency is characterized by a diverse range of ecoregional units and bordered by folded hills to the north and south. This topography suggests significant potential for groundwater resources, particularly those associated with spring systems. The region's complex geological conditions considerably influence its natural hydrological systems. The presence of karst terrain formed by carbonate rock dissolution shapes Grobogan's hydrology and ecology. These geological processes can be understood by analyzing lithological formations, key indicators of a region's geophysical characteristics [28]. Specifically, with its complex geological conditions, karst land poses challenges to its management [4]. The utilization of the area and the management of water resources need to be considered carefully. There are potential risks, including land subsidence due to continuous rock dissolution. Understanding geological conditions can provide an essential foundation for understanding various aspects of the environment, development, and management of natural resources, including the availability of springs.

Based on the spatial data of the Geological Map of Grobogan Regency (Figure 2), the geological formations in Grobogan Regency consist of Alluvium rock formations, Undecomposed Volcanic Rock Formations, Miocene Limestone Facies rock formations, Miocene Sedimentary Facies rock formations, Pliocene Limestone Facies, Pliocene Sedimentary Facies and Pliocene Sedimentary Facies rock formations. The characteristics of each formation influence the potential for springs.

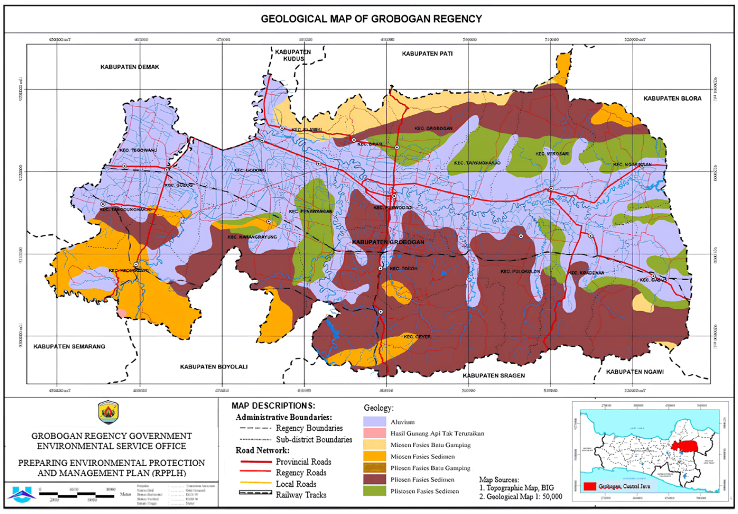

Figure 2. Geological map of Grobogan Regency

The types of rocks in the Wirosari Subdistrict have different effects on the availability of spring. Grobogan Regency is mainly covered by alluvium formations, which affect not only the area but also the livelihoods of its people, particularly in agriculture, such as rice farming. Primary alluvium formations in this region are crucial for soil fertility and agriculture. This formation's dominance impacts the community's socioeconomic and geological aspects. Alluvium formations consist of cobblestones, gravel, silt and mud, which were formed by river sedimentation in the form of unconsolidated material, containing organic material, minerals and nutrients that make the soil fertile.

The Ledok Formation is located south of Tawangharjo, Grobogan, Klambu, and Brati Subdistricts. It is also part of the alluvium formation used for rice fields. However, the fertility of alluvial-deposited land tends to decrease over time. The Ledok Formation results from deep-sea sedimentation over a long geological period. This formation consists of gray mudstone, marl, and thin-layered limestone (calcarenite), sometimes containing glauconite sandstone. The sandstone in this formation serves a vital role as a high-quality reservoir [7]. This shows that rainwater can be trapped in the reservoir, thus allowing the community to have clean water. If a crack occurs in this layer, it can form a spring. In addition to sandstone functioning as a natural reservoir, the Ledok Formation also contains limestone, which is a key material in forming the karst area. Limestone in the karst area serves as an aquifer, which is a subsurface layer that stores and flows water [22]. The Ledok Formation is located in two sub-districts, Wirosari and Tawangharjo.

The Kalibeng Formation consists of interbedded tuffaceous sandstone, limestone siltstone, sandstone, and pebbly sandstone. The materials of this formation are the result of shallow marine sedimentation [6]. The presence of limestone siltstone indicates that the area in Wirosari District may experience a karstification process. This is also accompanied by the presence of sandstone, which acts as a good natural reservoir. A reservoir is a container for fluids such as crude oil and water. This formation is present in Wirosari and Tawangharjo Subdistricts.

The Wonocolo Formation consists of marl interbedded with calcareous sandstone at the top and clastic limestone at the bottom. Calcareous sandstone has high porosity, which allows water to be stored within the rock's pores. Furthermore, the calcification of calcareous sandstone determines its permeability. The permeability and porosity of the rock can also result in the formation of aquifers. This type of rock can also dissolve in acidic water when it comes into contact with carbon dioxide. Geological evidence indicates a lot of organic material in the Wonocolo Formation [12, 30]. This formation is found in Wirosari, Tawangharjo, Grobogan, and Brati Subdistricts.

Anggota Ngrayong of the Tuban Formation is made up of alternating layers of claystone, calcareous sandstone, and limestone in the lower section, and sandy claystone in the upper section, which is also made up of alternating limestone, sandstone, and claystone [8]. Claystone can act as an impermeable layer due to its water-resistant properties. Calcareous sandstone can function as a rock that absorbs rainwater into the ground because of its good porosity.

However, the upper part of this formation is prone to erosion as it consists of sandy claystone. This rock is not very effective in storing and transmitting water, but it can act as an impermeable layer. This formation is found in Wirosari, Tawangharjo, Grobogan, and Brati Subdistricts.

One of the regions with a broad expanse of limestone is the Bulu Formation [12, 30]. The extensive coverage of limestone in this formation suggests karstification. An acidic rainwater mixture can dissolve limestone, creating a hydrological network of water channels. The presence of limestone also indicates that this formation is derived from shallow marine deposits. Apart from limestone, calcarenite is another mineral that can be found in environments that range from shallow to deep sea. It is 248 meters thick and is composed of sandy limestone that contains echinoids, bryozoa, large foraminifera, algae, and quartz minerals (30%) [30]. This formation can be found in Wirosari, Tawangharjo, and Grobogan Subdistricts.

3.2 Distribution of Spring Water Discharge in KBAK Sukolilo, Grobogan Regency

The availability of clean water remains a challenge for some people in Grobogan Regency, particularly during the dry season. Optimising local water resources, such as springs, is one way to address this issue. Springs in the karst have distinct characteristics from springs in general. This unique characteristic is due to the drainage system in the karst area, which is formed by rock dissolution. This phenomenon leads to the development of underground rivers with variable flow rates, which frequently get heavier during the rainy season. Grobogan Regency is surrounded by limestone mountains and valleys with a diverse topography. The research area is located within the Watuputih Groundwater Basin area, a karst landscape. The exposed springs at Watuputih Groundwater Basin are primarily perennial or flow year-round, with a small portion being seasonal. The karstification process created a cave system, water sources, and underground rivers [10, 28].

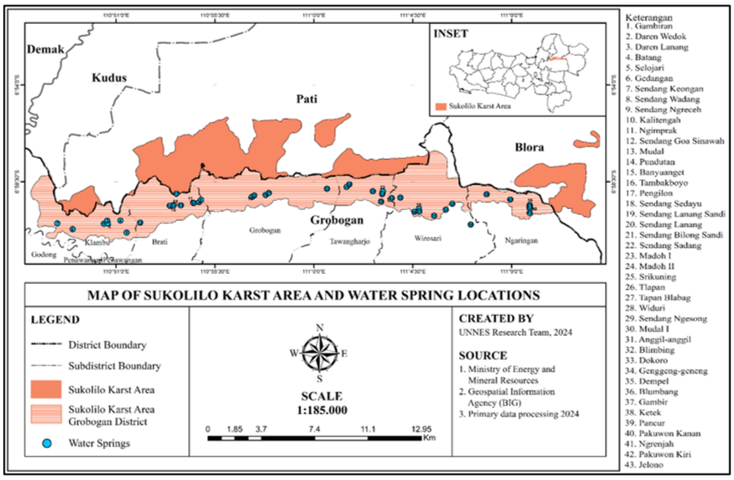

Figure 3. Distribution of springs in the karst area of Grobogan Regency

Figure 3 shows the distribution of springs in the Sukolilo Karst research area, Grobogan Regency. Spring distribution in the karst area tends to extend in an arc shape in the Grobogan Regency's northern region. Several of the sub-districts in the north of the Kendeng Mountains, including Brati, Grobogan, Tawangharjo, and Wirosari, exhibit this distribution pattern. There is a tendency for the distribution of springs in the karst region to be uneven, both in terms of quantity and quality of surface and groundwater [31]. This unique phenomenon can occur due to rainwater infiltrating cavities in karst soil and flowing through underground channels. Underground rivers are created as a result of this percolation process. Springs are likely to form in the karst soil if fissures exist in the underground river channels [10, 24].

Grobogan Regency has karst soil, especially in the Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan Subdistricts. This indicates that the karst hydrological system is the source of clean water in these sub-districts. Springs in karst areas can produce water if the flow is in the same direction as the underground river. The water will not flow if the direction is incorrect. The dissolution process of specific rocks in each area significantly impacts groundwater properties in karst areas [13, 25].

Local residents mainly use the land in the northern Kendeng Mountains for rice fields. In contrast, the residents of the southern Kendeng Mountains cultivate plantations on the land. The water requirements for plantations and rice fields are very different. This demonstrates that Klambu, Brati, Grobogan, Tawangharjo, and Wirosari Subdistricts have greater water demand for agricultural land than other districts, particularly in the southern Grobogan Regency. Springs are concentrated in certain areas, but their flow is threatened by urbanization and massive development.

Spring protection, prioritizing protection zones, and analyzing appropriate support systems are necessary to ensure the sustainability of these water sources [23, 32].

The distribution of water discharge for each spring in each sub-district varies, as does the change in discharge from 2018 to 2024. Changes in spring discharge are related to changes in land cover. Data on discharge and changes in spring discharge in six sub-districts can be seen in Tables 1, 2, 3, 4, 5, and 6. These tables provide information on the name of the spring, spring water discharge, and changes in discharge.

The Klambu Subdistrict had seven springs spread throughout the area. The highest discharge reached 91.56 liters/second at the Batang spring. The lowest discharge was 2.36 liters/second at the Gedangan spring. Discharges between 2 liters/second and 10 liters/second can be a potential water source for the community (Table 1). Despite their small discharges, these springs can still be used by locals. This practice was also common in other karst areas of Indonesia, such as Pracimantoro, where spring discharges only range from 2 to 20 litres per second [33]. In Klambu Subdistrict, springs were mainly used for raw water. The quality of raw water must be tested to ensure that it meets standards. Clean water requirements must adhere to the parameters established by the Minister of Health of the Republic of Indonesia's Regulation No. 32 of 2017 [34].

Table 1. Spring discharge in Klambu Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Gambiran	5	45.77	increase	raw water, irrigation
2	Daren Wedok	5	5.23	increase	raw water
3	Daren Lanang	6	11.93	increase	raw water, irrigation
4	Batang	39	91.56	increase	raw water
5	Selojari	100	8.76	decrease	raw water, irrigation
6	Gedangan	75	2.36	decrease	raw water, irrigation
7	Sendang Keongan	200	91.11	decrease	raw water, irrigation

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

This study monitored ten springs in the Brati Subdistrict. The most significant water discharge reached 38.58 liters/second at the Pundutan spring. The spring with the smallest water discharge was Banyuanget with a value of 0.37 liters/second. The total amount of spring discharge in Brati District reached 109.59 liters/second with an average of 10.96 liters per second (Table 2). Brati District uses springs for fish ponds, raw water, irrigation, PAMSIMAS (Community-Based Water and Sanitation Provision Program), tourism, and PDAM (Regional Water Company). The large amount of water used in springs demonstrates the population's reliance on these sources.

Table 2. Spring discharge in Brati Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Sendang Wadang	4	6.25	increase	raw water
2	Sendang Ngreceh	4	3.21	decrease	raw water
3	Kalitengah	3	4.01	increase	raw water
4	Ngimprak	2	0.49	decrease	raw water
5	Sendang Goa Sinawah	100	35.56	decrease	raw water, irrigation
6	Mudal	8	5.35	decrease	raw water
7	Pundutan	10	38.58	increase	raw water, irrigation
8	Banyuanget	5	0.37	decrease	raw water
9	Tambakboyo	3	5.77	increase	raw water
10	Pengilon	10	6.5	decrease	raw water

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

Grobogan Subdistrict had six active springs that are being studied. The highest discharge was 47.78 litres per second at Sendang Sedayu (Wedok spring). The spring with the lowest discharge was in Watusong, with a flow rate of 0 litres per second due to water infiltration, which cannot be measured. According to Table 3, the average spring discharge in Grobogan District was 9.48 litres per second, with a total discharge of 66.38 litres per second. The geological map shows that Grobogan District was dominated by the Ngrayong Tuban Member Formation, which has a top layer of sandy clay. Sandy loam is a mixture of clay and sand, with clay as the dominant component. This results in less effective water infiltration, resulting in lower spring discharge. Spring water in the Grobogan Subdistrict was used for raw water and irrigation.

Table 3. Spring discharge in Grobogan Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Sendang Sedayu	27	47.78	increase	raw water, irrigation
2	Sendang Lanang Sandi	2	0.35	decrease	raw water
3	Sendang Lanang	2	4.25	increase	raw water
4	Sendang Bilong Sandi	10	12.5	increase	raw water
5	Sendang Sadang	24	9.52	decrease	raw water, irrigation
6	Watusong	0	0	unidentified	raw water

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

The highest water discharge from springs in Tawangharjo Subdistrict reached 83.4 liters/second at the Widuri spring. The spring with the lowest water discharge was the Tlapan spring at 10.32 liters/second. The total water discharge from springs in Tawangharjo Subdistrict reached 273.91 liters/second, with an average of 45.65 liters/second. Tawangharjo Subdistrict springs were used for raw water, irrigation, fish ponds, and bathing (Table 4).

Table 4. Spring discharge in Tawangharjo Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Madoh I	90.4	83.4	decrease	raw water, irrigation
2	Madoh II	-	8.75	-	raw water
3	Srikuning	10	48.42	increase	raw water
4	Tlapan	-	10.32	-	raw water
5	Tapan Blabag	71.5	55.5	decrease	raw water, irrigation
6	Widuri	109.2	67.52	decrease	raw water, irrigation

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

The Sendang Ngesong spring in Wirosari District had the highest water discharge, with 2,588.1 liters/second. The spring with the lowest water discharge measured 0.63 litres per second. The total water discharge from springs in Wirosari Subdistrict was 2,744.16 liters/second, with an average of 304.9 liters/second. Spring water was used for irrigation as well as raw water. Springs in Wirosari Subdistrict had the most significant water discharge compared to other subdistricts (Table 5). Although all of the springs' potential has been realised, sustainable management is still required. Other nearby areas that need water regularly can benefit from the abundant spring flow in Wirosari Subdistrict. Several parties must be involved in the distribution process.

Table 5. Spring discharge in Wirosari Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Sendang Ngesong	1.000	2,588.1	increase	raw water, irrigation
2	Mudal I	200	2.78	decrease	raw water, irrigation
3	Anggil-Anggil	13	65.04	increase	raw water, irrigation
4	Blimbing	65	9.28	decrease	raw water
5	Dokoro	27	12.62	decrease	raw water
6	Genggeng Geneng	32.5	42.53	increase	raw water, irrigation
7	Dempel	4	21.15	increase	raw water, irrigation
8	Blumbang	2	0.63	decrease	raw water
9	Gambir	2	2.03	increase	raw water
10	Sendang Ngesong	10	6.5	decrease	raw water

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

This study examined six springs in the Ngaringan Subdistrict. The Jelono spring had the highest water discharge, at 38.39 liters/second. The spring with the lowest water discharge was 2.30 liters/second. The total water discharge in the springs in Ngaringan District reached 74.44 liters/second, with an average of 59.12 liters/second. The water utilization in the springs included raw water and irrigation (Table 6). The potential of springs had been maximised, but they must still be managed sustainably. In the Ngaringan Subdistrict, the Jelono spring in Jono Village was uniquely formed, creating a saltwater spring that the locals used for salt farming. This aquifer was known as a perched aquifer because its groundwater mass was separated from the main groundwater mass by a relatively impermeable layer that was not very extensive and located in the water-saturated zone [20, 36]. However, the freshwater springs in this subdistrict were unaffected by the salinity or salty taste factor.

Table 6. Spring discharge in Ngaringan Subdistrict

No.	Spring	Spring Discharge (liters/second)		Discharge Change	Utilization
		2018	2024		
1	Ketek	22	32.5	increase	raw water, irrigation
2	Pancur	13	5.98	decrease	raw water
3	Pakuwon Kanan	2.5	6.75	increase	irrigation
4	Ngrenjah	7.7	2.30	decrease	raw water
5	Pakuwon Kiri	26	8.52	decrease	raw water, irrigation
6	Jlono	171.6	38.39	decrease	raw water, irrigation

Source: Department of Public Works and Spatial Planning Grobogan Regency [35]

The sub-districts of Klambu, Brati, Grobogan, Tawangharjo, Wirosari, and Ngaringan are six districts located in the karst area. Some of these districts were included in the Sukolilo Karst Landscape Area (KBAK Sukolilo), which is protected by Decree of the Minister of Energy and Mineral Resources No. 2641/K/40/MEM/2014. Through management and conservation initiatives, this designation can guarantee the region's water availability for a longer period, which should benefit the community.

3.3 Springs Availability

A water crisis occurs when water demand exceeds supply, making it difficult for communities to meet their clean water needs. Water is a natural resource that is considered renewable, but climate change has caused unpredictable rainfall. Indonesia is also experiencing climate change, which is typified by increasing temperatures and changing precipitation patterns [21]. Drought is one of the impacts that must be monitored. Understanding the availability of springs as a source of clean water is one way to deal with this issue. Spring availability can be assessed by comparing spring potential with water demand.

One of the most important factors in regional development is population. Stable and controlled population growth can benefit many aspects of life, including the economy, society, and environment, and vice versa. The ongoing population growth in both urban and rural regions necessitates careful consideration when managing clean water resources. Based on population projections generated using the Arithmetic method, which demonstrate consistency with historical data (a Standard Deviation approaching 1), clean water needs for the next few years can also be calculated. The daily amount of clean water needed by each person was estimated to be between 120 and 150 litres in urban areas and between 60 and 80 litres per person in rural areas. This difference was caused by differences in lifestyle, infrastructure, and access to clean water sources between the two areas.

Total clean water requirements for the analysed area can be estimated using population projections and clean water demand standards. These computations were contrasted with the available water flow from nearby springs to ascertain whether there is a water surplus or deficit. The comparison indicated that in the coming years, there will be significant difficulties in meeting clean water needs due to population growth.

The largest potential springs were found in Wirosari Subdistrict, where water demand did not exceed the springs' potential, resulting in a water surplus. Tawangharjo and Klambu Subdistricts experienced similar conditions. However, low water demand in Tawangharjo Subdistrict was caused by the lack of irrigated rice fields, so water was primarily needed for household needs. The subdistrict with the highest water demand was Brati, reaching 113,553,974 liters per day. This significant water demand was not matched by the availability of springs, causing this district to be categorized as a water deficit.

Table 7 shows that springs were unable to meet the water needs of the local population near the karst area. Three subdistricts were in the deficit category. Three other subdistricts were in the surplus category: Klambu, Tawangharjo, and Wirosari. This means that the springs in these subdistricts were able to meet the water needs of the local community. This data indicates an imbalance in the distribution of water availability in Grobogan Regency. Subdistricts with water availability in the deficit category require alternative sources of clean water besides springs.

Table 7. Spring availability in the karst area of Grobogan Regency

Subdistrict	Springs Potential (liters/day)	Water Demand (liters/day)	Springs Availability (liters/day)	Category
Klambu	34,819,200	4,692,180	30,127,020	surplus
Brati	9,468,576	113,553,974	-104,085,398	deficit
Grobogan	5,735,232	22,096,800	-16,361,568	deficit
Tawangharjo	19,734,624	7,242,000	12,492,624	surplus
Wirosari	238,391,424	63,971,280	174,420,144	surplus
Ngaringan	1,555,200	8,754,000	-7,198,800	deficit

Karst areas in Indonesia have unique hydrological characteristics, characterized by aquifer systems strongly influenced by the seasons. Studying water discharge during the dry and rainy seasons is essential to determine water availability capacity, drought potential, and proper water management. This research was conducted during the dry season, in July 2024. During the dry season, water availability reflects the actual condition of the springs because there is no additional rainfall. During the rainy season, water availability in springs increases, and springs have the potential for increased water discharge. The increase in discharge was quite significant during the rainy season. The dry season discharge was recorded at 5.2 liters/second, while during the rainy season it reached 1,719.12 liters/second [37]. The dry season showed increased dissolved substance concentration, while the rainy season caused nutrient leaching and changes in water quality. Water availability during the rainy season can be stored in water storage that can be used to meet dry season water needs.

Residents have implemented several alternatives to store water during the rainy season by building a rainwater harvesting system from the roof of the house, collecting it by making tendon tanks, making biopores, and rainwater infiltration to put water into the ground. Collecting rainwater from the roof of the house when it rains can be used to store water [38]. Rainwater that falls on the roof of the house will be collected through gutters and channeled to the rainwater reservoir, while excess rainwater can be channeled to the infiltration tank [36]. This alternative can help reduce drought risk during the long dry season. In 2022, Grobogan Regency had an average rainfall of 2,405 mm [39]. The minimum rainfall required for an area to implement a rainwater harvesting system is 1,300 mm [39]. This shows that the districts in Grobogan Regency can implement a rainwater harvesting system as an alternative to meet the need for clean water sources.

4 Conclusion

This study identified six karst-influenced subdistricts in Grobogan Regency (Kedungjati, Tanggungharjo, Brati, Grobogan, Tawangharjo, and Wirosari) characterized by geological formations conducive to karstification, particularly those dominated by carbonate rocks such as limestone. Land use in these areas, especially for agriculture, is concentrated on alluvial formations due to their high soil fertility. The geological formations identified include Alluvium, Ledok, multiple Kalibeng members, Wonocolo, Anggota Ngrayong (Tuban), and Bulu Formations. Bulu Formation has the highest spring potential, supported by extensive, porous limestone that enables large and continuous discharge. In contrast, Anggota Ngrayong (Tuban Formation) shows the lowest potential, as its upper clay-rich layers limit infiltration and spring emergence.

The findings show that spring distribution is uneven and influenced by geological formations, land use change, and karstification processes. Three of the six subdistricts studied (Brati, Grobogan, and Ngaringan) were categorized as water-deficit areas, while the others (Klambu, Tawangharjo, and Wirosari) showed a surplus. These results highlight the critical role of karst springs in local water availability and the need for sustainable management to address spatial disparities and increasing water demand. This includes protecting existing springs, optimizing rainwater harvesting, and incorporating alternative water sources such as reservoirs and river systems. In conclusion, the study affirms that karst springs remain a vital yet fragile component of water supply systems in Grobogan Regency.

Author Contributions

Conceptualization, D.L.S. and P.H.; methodology, J.; software and GIS processing, E.T.A.-H.; validation, E. K.P., T.M.P.A.; formal analysis, D.L.S.; investigation, J.; resources, P.H.; data curation, E.T.A.-H.; writing original draft preparation, Y.D.A.; writing review and editing, Y.D.A. and E.K.P.; visualization, Y.D.A.; supervision, D.L.S.; project administration, T.M.P.A; funding acquisition, D.L.S. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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