Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.14.3.471

RESEARCH ARTICLE

OPEN ACCESS

Check for updates

Analysis of the Carrying Capacity of Groundwater Availability and Its Relationship with the Largest Population Growth in Karanganyar Regency

Lia Kusumaningrum, Ressa Karina, Nida U. Fil'ardiani, Muhammad B. Mardiyanto, Sa'ad A. Jabbar, Sofiyana Khoirunnisa, Yaqut Amjad A. Raharjo, Youhana E. Santika, Yunia P. Annisa Arta, Agnar P. Daniswara

Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Sebelas Maret University, Surakarta, 57126, Indonesia

Article History
Received 15 June 2023
Revised 31 October 2023
Accepted
16 Feberuary 2024

Keywords
carrying capacity, water availability, water demand

ABSTRACT

Colomadu District is an area on the outskirts of or around a city that is experiencing rapid development due to the local population's interest in moving, causing an increase in population. The aim is to determine the projected use of groundwater in Colomadu District, Karanganyar Regency, to determine the use of groundwater needs in each village in Colomadu District, Karanganyar Regency in 2021, and to determine when the balance between supply (availability) and demand of groundwater in Colomadu District will be exceeded or in deficit. The research method used was data collection in the form of sampling, measuring water quality, and interviews. Sampling was carried out by collecting water from the residents' wells and taking as many as two samples per village, which represented the water quality in each village. The samples were collected by first drawing water from the well, then the prepared sample bottles were rinsed three times using sample water (well water), and the rinsed bottles were then filled with sample water. The projection of groundwater use in Colomadu District in 2025 is 3,345,311.68 m^3 $year^{-1}$; in 2030 is 3,716,727.52 m^3 $year^{-1}$; in 2035 is 4,129,380.08 m^3 $year^{-1}$; and in 2040 is 4,587,847.71 m^3 $year^{-1}$. Projections are made until demand exceeds supply, namely, in 2085, when demand can reach 11,833,854.16 m^3 $year^{-1}$ with a population of 272,244 people.

Introduction

Water is an essential component of human health. Important needs have consequences for the sustainability of water resources, which can only be continuously ensured. The quantity of water resources was then measured. The need for water for human activity is typically met by the groundwater. Utilization of groundwater as a source of clean water was the best solution. Groundwater is one of the most important natural resources on Earth [1]. Groundwater systems offer a variety of services to humankind, either by providing water that can be abstracted and used or by various in situ functions, such as climate buffering and sustaining wet environments. Groundwater can be considered better than other water sources because it is stored in layers of rock below the soil surface; thus, its quality is maintained. Changes in environmental conditions include surface water quality and rainfall. Groundwater resources can supply the human needs system and ecosystems and support the soil structure. This results in depletion or damage to groundwater and hinders the provision of groundwater services. Therefore, they have an impact on geohazards, risks, and human health [2].

The utilization of groundwater resources includes domestic needs, such as drinking water, food, and MCK activities (bathing, washing, and toilets). The number of domestic needs is influenced by the pattern of life as well as the facilities and infrastructure in an area. In addition, the number of residents is the main determinant of the domestic water demand in an area. Indonesia is rich in groundwater resources; therefore, many people, especially domestic ones, use groundwater to meet their daily needs. The Colomadu District of

Corresponding Author: Lia Kusumaningrum Liakusumaningrum@staff.uns.ac.id Department of Environmental Science, Sebelas Maret University, Surakarta, Indonesia.

the Karanganyar Regency uses groundwater. Colomadu District has an area of 15.64 km^2, and consists of 11 villages, including Batur, Blulukan, Bolon, Gajahan, Gawanan, Gedongan, Klodran, Malangjiwan, Ngasem, Paulan, and Tohudan. Colomadu District is a suburban area that is considered to have a strategic location; therefore, population growth in Colomadu District is increasing annually, which causes an increase in groundwater demand as well.

Colomadu District is an area on the outskirts or around a city that is experiencing rapid development owing to the local population's interest in moving, causing an increase in the population [3]. Population growth will increase the demand for natural resources such as clean water, food, and residential land, which will have an impact on the reduction of natural resources and environmental degradation [4]. Population growth will also have a direct impact on the domestic needs of the community, one of which is the need for groundwater [5]. The higher the population, the greater the need for groundwater resources. Rapid population and economic growth have led to a sharp increase in water use, thereby worsening the balance between water supply and demand [6]. An area will not be able to meet water needs if it only relies on existing water supply [7].

It should be noted that social factors also influence the net availability and distribution of water [8]. Climate change significantly influences the availability of water resources [9]. Water shortages result in the displacement of water from areas with abundant availability and increased groundwater exploitation. This increases the cost and impacts the groundwater environment [10]. Decreasing the quality and quantity of water resources will cause problems in an area; therefore, efforts to manage natural resources by considering the carrying capacity and capacity of the environment are required [11]. The evaluation index system of water resource carrying capacity is the core of a study on regional water resource carrying capacity [12].

Carrying capacity is the ability to support human life and other living things as well as the balance between the two. The concept of carrying capacity is seen from two aspects: in terms of availability, knowing the characteristics and potential of natural resources in an area, and in terms of needs, knowing the needs of humans and living things to determine policies in an area. Calculation of the availability of natural resources shows that the carrying capacity of water is in a state of surplus (not exceeded) or deficit (exceeded) [13]. The carrying capacity status of environmental waters needs to be evaluated by focusing on socio-ecological principles such as welfare development and the sustainable use of water resources [14]. Many regulations and service culture can be improved through the development of water resources, so it needs a contribution from the government to increase it [15].

There is a need for water governance as a water supply technology to balance the social, ecological, and economic impacts of new sources [16]. This is because urbanization does not always worsen groundwater resources, which depend on urban waste management in the area [17]. In addition, the ability to provide benefits to the environment by absorbing substances, energy, or other components (capacity) also needs to be understood and used as a basis for planning the utilization of resources, especially groundwater resources. The limited availability and declining quality of groundwater must be considered when making predictions and planning, so that groundwater can be used as efficiently as possible. Based on the background of the problem, this study has the following objectives: to determine the projection of groundwater use in Colomadu District, Karanganyar Regency; to determine the use of groundwater needs in each village in Colomadu District, Karanganyar Regency in 2021; and to determine when the balance between supply (availability) and demand (need) of groundwater in Colomadu District, Karanganyar Regency will be exceeded or in deficit.

Methods

Study Area

This research was conducted in Colomadu District, Karanganyar Regency, Central Java, as shown in Figure 1. The study covered 11 villages: Batur, Blulukan, Bolon, Gajahan, Gawanan, Gedongan, Klodran, Malangjiwan, Ngasem, Paulan, and Tohudan. The research was conducted from November 3 to 5, 2022, in residential areas to collect samples of well water and measure its quality, pH, and total dissolved solids (TDS). Colomadu District is an administrative area of the Karanganyar Regency. Colomadu District is directly adjacent to the Surakarta City area, more precisely in the north. The development of Surakarta City has affected the surrounding areas. The growth of these housing blocks has resulted in many changes from unsettled land to settled land. Similarly, Colomadu District experienced changes in land use.

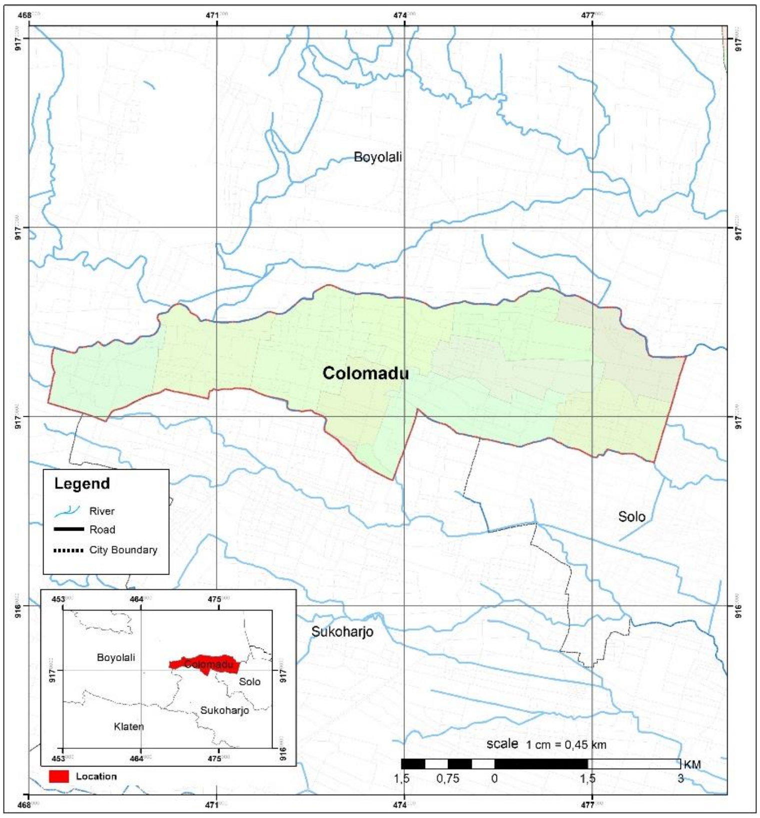

Figure 1. Map of research location.

Data Collection

This study uses qualitative data analysis methods with descriptive and quantitative data analysis to calculate the amount of water supply and demand in Colomadu District. Data management uses both the primary and secondary data. Primary data were obtained from direct interviews with residents in each urban village and water sampling per urban village as well as secondary data obtained from various literature studies, such as journals, articles, theses, and other references. The study used data collection methods such as sampling, water quality measurements, and interviews. Sampling was conducted by collecting water from the residents' wells and taking as many as two samples per village, which represented the water quality. The collection was performed by first drawing water from the well; then, the prepared sample bottles were rinsed three times using sample water (well water), and the rinsed bottles were then filled with sample water.

The quality of the samples was measured using the Lutron YK-20005WA multi-parameter tool. Quality measurements were performed by calibrating the instrument using distilled water. After calibration, the pH measurement is first carried out by inserting the tool into the sample water and waiting until the tool is stable so that the measurement results are obtained. For TDS measurements, the tool was first calibrated in the same way and then inserted into the sample water until it was stable, and the results of the TDS measurement were obtained. The interviews were conducted by asking several questions to residents living in Colomadu District, including the identity of the informant (name, family status, and number of family members at home). The questions are listed in Table 1.

Table 1. Potential of fish resources in Ogan Komering Ilir Regency and the rules for their utilization.

No.	Question
1	Where does the water you use come from?
2	Why use well water and why?
3	How long have you been using the water source?
4	If you are willing to change from well water to Local Water Company (PDAM)? Include the reason!
5	What do you use well water for?
6	Have you ever had problems using well water?
7	Is well water always available?
8	What is the quality of the water used to meet daily needs?

Data Analysis

Research has used calculation methods in the form of sample measurements and data calculations. The sample calculation method was based on Sugiyono [18]. provides a general reference for determining sample size; namely, that a sample size of more than 30 and less than 500 is appropriate for most studies. The data calculation method used the following two formulas: The population projection formula is as follows:

$$P_t = P_0(1 + r)^t \quad (1)$$

where P_t is Population projection, r is ratio (population growth rate), and t is the distance between the year you want to project and the last year.

The population growth rate (up and down) was calculated as follows:

$$\underline{x}(average) = \frac{r_{2016}+r_{2017}+r_{2018}+r_{2019}+r_{2020}}{5} \quad (2)$$

Formula Water use per capita per year (L year^{-1}) was calculated as follows:

$$Qf\ total = Qf\ day \times \sum resident \times 365\ (day) \quad (3)$$

where Qf total is amount of water used per capita per day.

Results and Discussion

Population Projection of Colomadu District

Colomadu District in Karanganyar Regency, with 11 villages within it: Malangjiwan, Ngasem, Baturan, Klodran, Gedongan, Blulukan, Gawanan, Bolon, Tohudan, Gajahan, and Paulan. Each village in Colomadu District has a different population level. This is caused by several factors, one of which is the factor of land area, where the largest village land area is obtained by Malangjiwan of 206.40 ha and the smallest village is obtained by Gajahan of 72.60 ha.

In this study, there are limitations in calculating the proportion of water use for each population based on the community of activity units in the area, such as household, industrial, and other activities. This study used a population-based approach. Population projections can be calculated using geometric formulas with several objects. The population projection calculations are influenced by the population growth rate, as shown in figure 2. This study used the population growth rate over the last five years, which was averaged to obtain a ratio of 0.021280, as one of the objects of calculation. After calculating using the geometric formula, the results obtained include the following: in 2025, Colomadu District has a population of 76,961; in 2030 is 85,505; in 2035 is 94,998; in 2040 is 105,546; and a few years later, in 2085 is 272,244. From the calculation of this population projection, it can be seen that the possibility of population growth in Colomadu District increased annually.

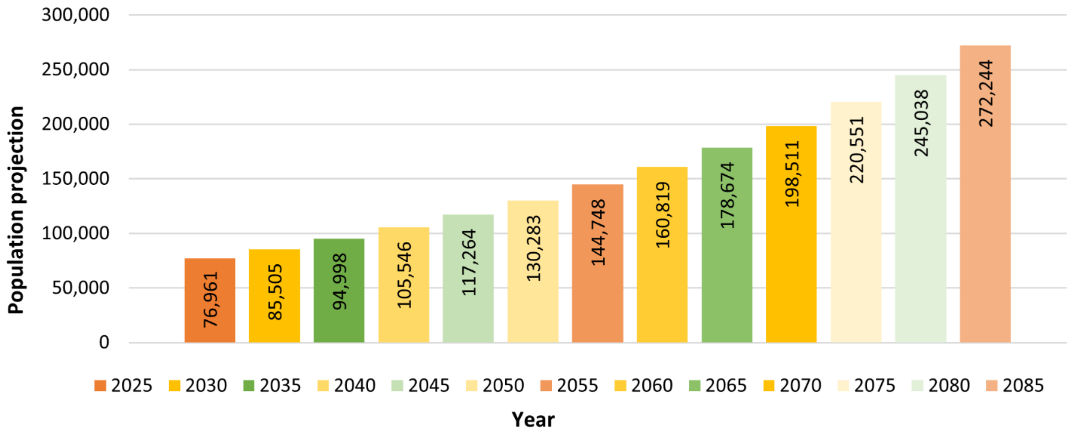

Figure 2. Population projection of Colomadu District.

Availability of Groundwater in Settlements in Colomadu District

The Karanganyar Regency has good groundwater availability. This can be seen in various factors, such as rainfall, slope, soil type, hydrology, morphology, and land use. The colors on the Karanganyar Regency rainfall map show the amount of rainfall in millimeters. One millimeter of rain is rainwater that falls in an area of one square meter, which has a height of one millimeter if the rainwater does not seep, flow, or evaporate. On the rainfall map in Figure 3 of Karanganyar Regency, Karanganyar Regency is included in an area with a high rainfall rate, whereas Colomadu District has a rainfall rate of 2,000–2,500 mm $year^{-1}$ [19]. From the threshold value for determining rain intensity, Colomadu District has a rain intensity of approximately 5–6 mm day^{-1}; therefore, Colomadu District can be said to experience light-intensity rain more often. This proves that Colomadu District has a fairly good water supply from rainwater.

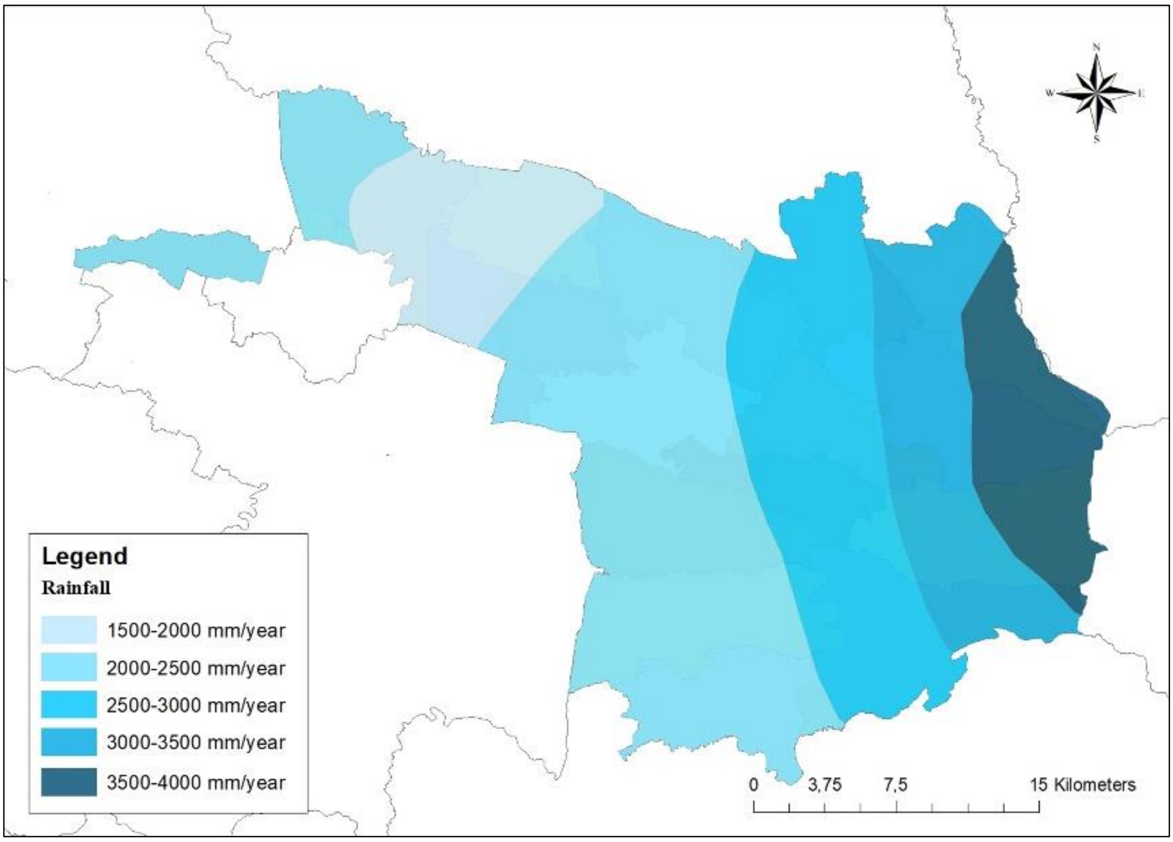

Figure 3. Rainfall map of the Karanganyar Regency.

Rainfall is a determinant of the amount of water available that will later infiltrate the groundwater. The infiltration of rainwater is directly affected by slope [20]. Steep areas have high levels of surface runoff; therefore, the level of surface water infiltration is low. Conversely, a relatively flat area has the potential to have abundant groundwater availability owing to small surface runoff, such that the infiltration rate is quite high [21]. The steeper the slope of the area, the lower the ability of the surface to retain water; therefore, the time required for water to infiltrate was not achieved. In relatively flat areas, the potential availability of groundwater is high because the water has the time to infiltrate.

The Karanganyar Regency slope classification shown in Figure 4 was divided into five classes: flat (0–8% slope), gentle (8–15% slope), rather steep (15–25% slope), steep (25–40% slope), and very steep (>40% slope). The classification was guided by the Indonesian Ministry of Environment and Forestry [22], who compiled an engineering plan for the rehabilitation of forests and land in river basin areas. The Karanganyar Regency is dominated by gentle slopes, based on the resulting slope map [23]. Areas with a slope of 0–8% are partly scattered in the districts of Colomadu, Banjarsari, Gondangrejo, Jaten, Kebakkramat, Tasikmadu, Mojogedang, and Karanganyar. The distribution of slopes of 8–15% is mostly in the districts of Jumapolo, Jatipuro, Jumantono, Matesih, Karangpandan, Mojogedang, Karanganyar, and Kerjo; some are in the districts of Gondangrejo, Jatiyoso, Jenawi, Kebakkramat, Tasikmadu, Ngargoyoso, and Tawangmangu. Slopes with a slope of 15–25% are scattered in the districts of Tawangmangu, Kerjo, Karangpandan, Jatiyoso, Jumapolo, Jatipuro, Jumantono, Matesih, Jenawi, and Ngargoyoso. The distribution of 25–40% slopes is in the districts of Kerjo, Karangpandan, Matesih, Jatipuro, Jenawi, Jatiyoso, Tawangmangu, and Ngargoyoso. Slopes of more than 40% are spread across parts of the Jenawi, Ngargoyoso, Tawangmangu, and Jatiyoso Districts. Thus, the Colomadu District is included in a flat area, so it has the potential for high water availability.

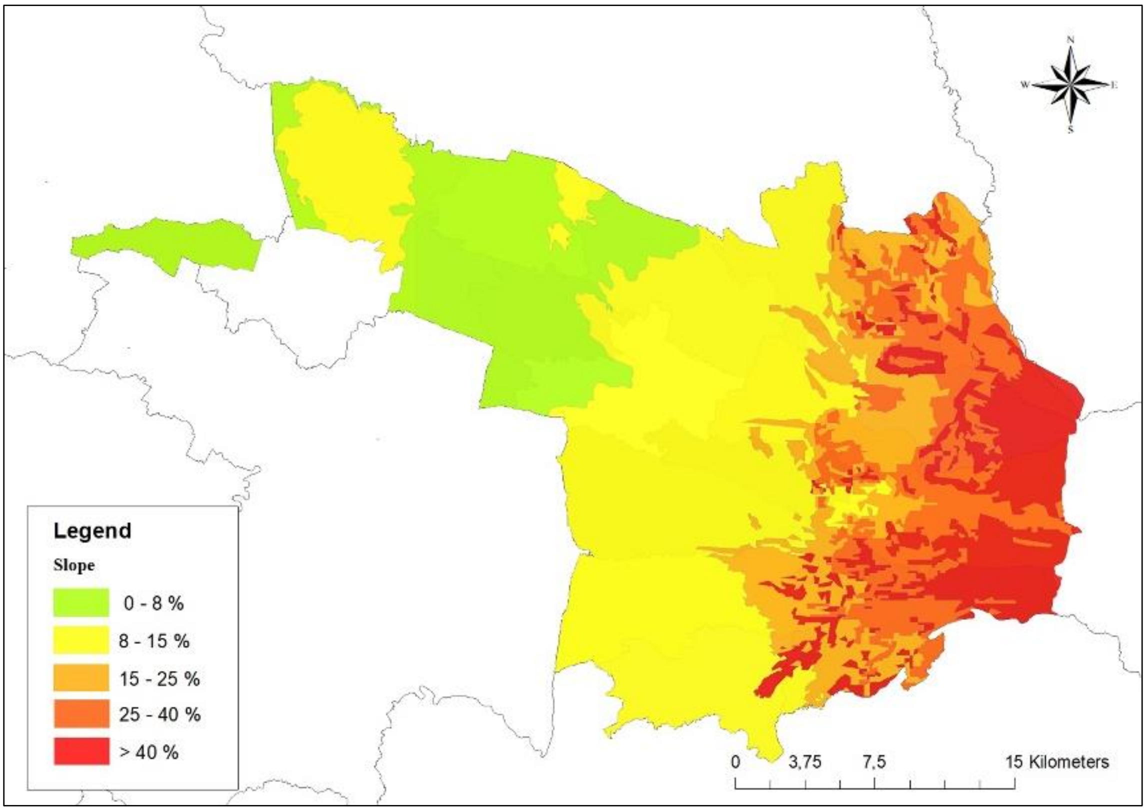

Figure 4. Slope map of Karanganyar Regency.

The availability of groundwater continuously rotates throughout Earth, forming a cycle. The groundwater cycle is the process by which water passes through the soil, starting from water on the surface of the soil, which partially evaporates and flows from high to low areas, then seeps into the soil through cracks in the soil or rocks, and finally becomes reserve water. Groundwater occupies rock pores below the soil surface in a water-saturated zone [24]. The water that enters and is absorbed by the soil passes through rock cracks in the ground, and rock crevices then form an underground river flow to form groundwater. In this study, the distribution of soil types in Karanganyar Regency was found, such as gray alluvial, alluvial and grayish alluvial associations, gray grumusol, reddish brown Mediterranean gray grumusol, brown and yellowish andosol complex, brown litosol, reddish brown litosol, brown Mediterranean, brown Mediterranean reddish, and gray regosol [25]. The Colomadu District itself has a grey regosol soil type, as shown in Figure 5.

According to the Indonesia Ministerial Decree of Agriculture Number 837/1980 [26], the regosol soil type is included in the soil type that is very sensitive to erosion, with a score of 75, so it is very easily affected by erosion. This is because gray regolith soil easily absorbs water. Thus, these properties prove that Colomadu District has very good groundwater reserves based on the soil type factor. Land use is a parameter that affects water catchment areas. This can affect land use, which is directly related to groundwater recharge, surface water runoff, and infiltration. Areas can be grouped based on land use, such as built-up land, vacant land, water bodies, and vegetation cover. The better the land cover vegetation, the greater the detention time and water infiltration because vegetation can inhibit surface runoff. Built-up land can inhibit surface runoff but does not allow infiltration; therefore, it does not have the potential to become a water catchment area [27].

Based on the land use map in Figure 6, the Karanganyar Regency is classified into several land cover types: irrigated rice fields, rainfed rice fields, gardens and plantations, dry land and fields, shrubs, forests, rivers, reservoirs, settlements, and buildings. Most of the Karanganyar Regency area is rice dominated. Land cover in Colomadu District is mostly in the form of buildings, settlements, rice fields, fields, and plantations. Although part of its territory is in the form of settlements and buildings, the Colomadu District has high water availability because some of its areas are irrigated and rainfed rice fields, which have a low infiltration rate, as well as fields and plantations, which have a moderate infiltration rate [28]. The results of this study were also reported by Kusumaningrum et al. [29] in the Jebres area close to the research location, that is, demand settlements (demand) did not exceed the capacity to support settlements as a living environment (supply).

In addition to residential areas, respondents rated the support facilities for clean water as quite good, even though they were available in several villages with clean water quality problems and sometimes uneven flow.

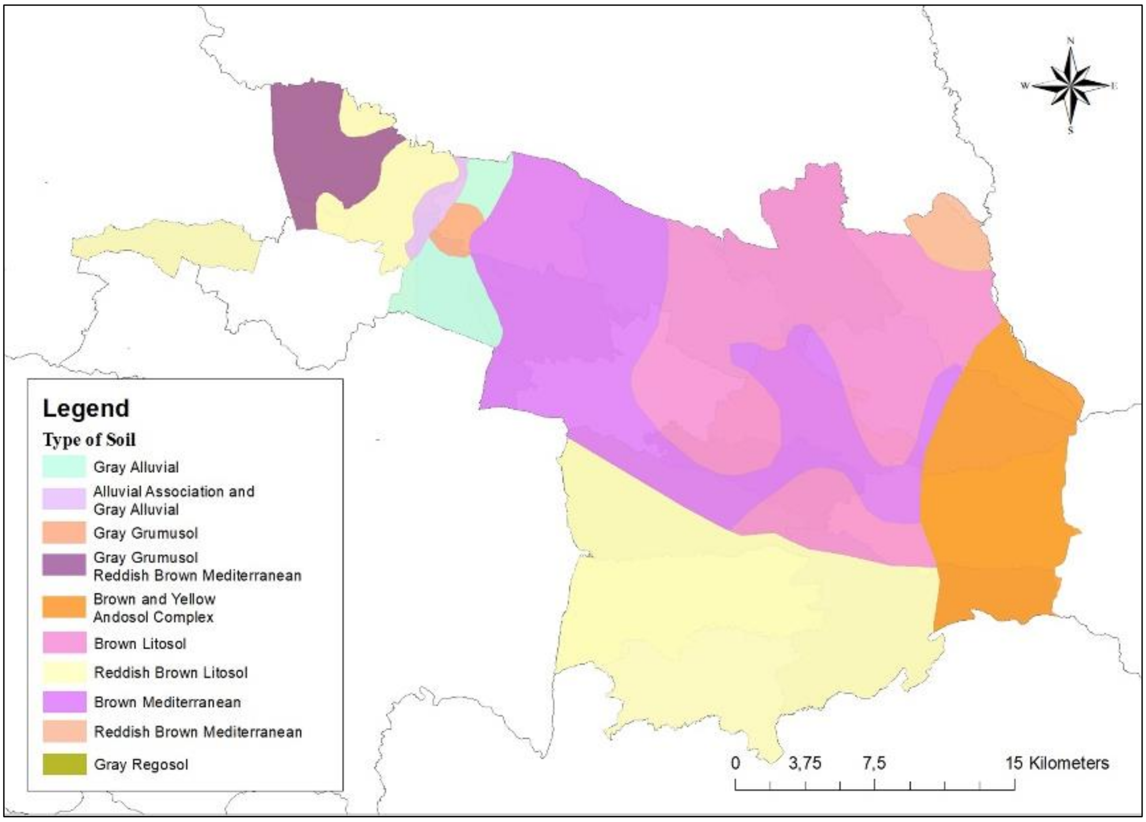

Figure 5. Map of soil types in the Karanganyar Regency.

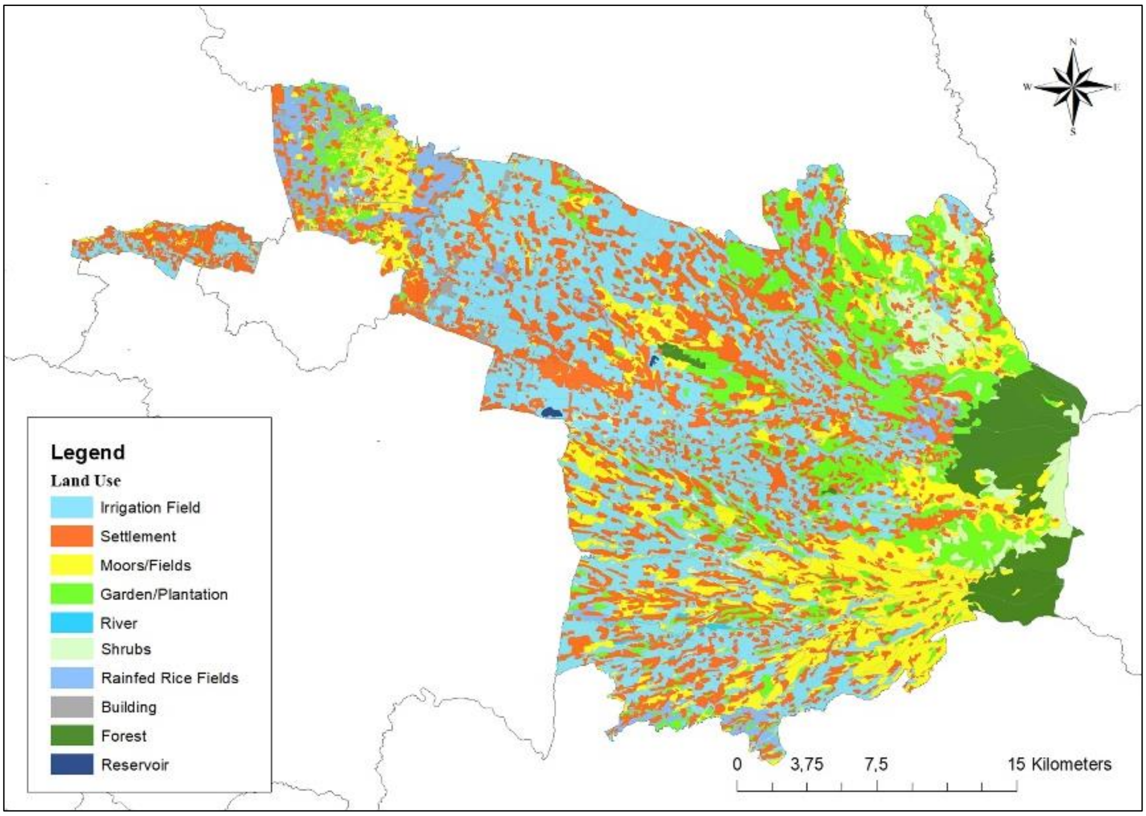

Figure 6. Land use map of the Karanganyar Regency.

Groundwater Use Projection in settlements in Colomadu District

The amount of demand for or use of groundwater is an important factor in determining the carrying capacity of water resources because the carrying capacity of water resources can be determined by comparing availability with the demand for water. The use of groundwater in large areas affects the availability of water. This can occur because there is no balance between availability, which is always constant, and the need for or use of water, which increases annually because of population growth. If the carrying capacity of water resources is exceeded, human activities and living organisms are hampered. The concept of "carrying capacity" is proposed to support human environmental sustainability. Research on carrying capacity includes ecological, resource, and environmental carrying capacities [30].

The descriptive analysis in this study was based on interviews conducted with several residents of scattered villages in Batur, Blulukan, Bolon, Gajahan, Gawanan, Gedongan, Klodran, Malangjiwan, Ngasem, Paulan, and Tohudan in Colomadu District. This interview contained questions about the type of water used, the situation and condition of the water used, the use of water in daily activities, and the reasons why residents of each village used it. In Baturan, residents use groundwater in wells because there is no PDAM close to their homes, access to well water is easier and faster due to easy access to wells, and the quality of the water is clean, clear, and odorless. Previous studies reported relatively high pH values. However, the water in Batur contained lime. Groundwater was first used for this purpose in 1987. In other villages, the water quality was good, clear, and never dry, prompting residents to choose groundwater with the help of a water pump to move water from wells to water reservoirs so that it can be easily used for bathing, washing clothes, and drinking every day. Thus, from the results of the interviews, it can be concluded from the descriptive analysis that the water quality in Colomadu District is good and suitable for daily activities.

Many factors affect water carrying capacity, including water quantity, water quality, degree of water exploitation, water demand for the ecosystem, technical conditions, level of productivity and social consumption, and regional exchange. In this study, the projected use or demand for groundwater was calculated using data calculated from the projected population. This calculation is performed in a way that is the result of the projected population multiplied by the amount of water use per capita per day and 365 days, so that the amount of groundwater use will be known in the years to come. The calculations indicate that the amount of groundwater used in Colomadu District (Figure 7) by 2025 would be 3,345,311.68 m^3 $year^{-1}$. By 2030, Colomadu District will have a total groundwater use of 3,716,727.52 m^3 $year^{-1}$. In 2035, Colomadu District will have a total groundwater use of 4,129,380.08 m^3 $year^{-1}$. By 2040, the Colomadu District will have a total groundwater use of 4,597,847.71 m^3 $year^{-1}$. After projecting the use of groundwater for several years and knowing that the total availability of groundwater in Colomadu District is 11,147,764.3 m^3 $year^{-1}$, the result is that the use of groundwater in Colomadu District will exceed the availability of groundwater in the region in 2085 with a total use of groundwater use of 11,833,854.16 m^3 $year^{-1}$ and a population of 272,244.

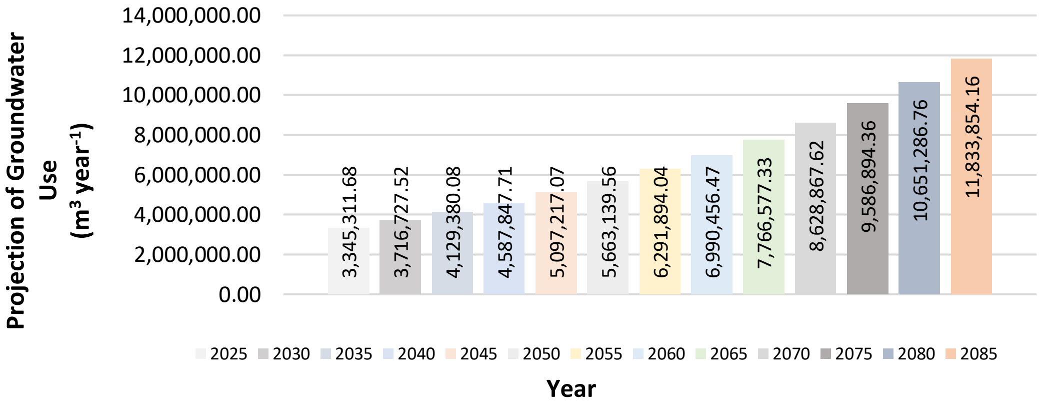

Figure 7. Projection of groundwater use in settlements in Colomadu District.

Total Use of Groundwater per Village in Settlements in Colomadu District in 2021

Colomadu District has 11 villages, each with a different level of groundwater use. Several factors influence the use of different groundwater types. The main factor affecting the level of groundwater use in each urban village was the population. In this case, the area of the village in Colomadu District does not significantly influence the population factor because there are several small villages in Colomadu District that have large populations. According to Colomadu District data, each village in Colomadu District has a different percentage of population. For each village in 2021, Malangjiwan has a population of 8%, Paulan 12%, Gajahan 8%, Blulukan 3%, Gawanan 9%, Gedongan 5%, Tohudan 11%, Klodran 16%, Baturan 8%, Ngasem 9%, and Bolon 9%. From these data, the population per village was obtained by multiplying the total population of the Colomadu District by the percentage of each village. Population data will be used to calculate the use of groundwater in each village of Colomadu District in 2021.

The results of groundwater use in each village were obtained after performing the above calculations, as shown in Figure 8. Malangjiwan has a total groundwater usage of 262,048.5 m^3 $year^{-1}$, Ngasem 262,048.5 m^3 $year^{-1}$, Batur 360,316.7 m^3 $year^{-1}$, Klodran 524,097.1 m^3 $year^{-1}$, Gedongan 163,780.3 m^3 $year^{-1}$, Gawanan 294,804.6 m^3 $year^{-1}$, Blulukan 98,268.2 m^3 $year^{-1}$, Bolon 294,804.6 m^3 $year^{-1}$, Tohudan 360,316.7 m^3 $year^{-1}$, Gajahan 262,048.5 m^3 $year^{-1}$, and Paulan 393,072.8 m^3 $year^{-1}$. In this way, the urban village that has the highest use of groundwater is Klodran, with a total use of groundwater of 524,097.1 m^3 $year^{-1}$ and a population of 12,057. The urban village with the least use of groundwater was Blulukan, with a total use of water and land area of 98,268.2 m^3 $year^{-1}$ and a population of 2,260.

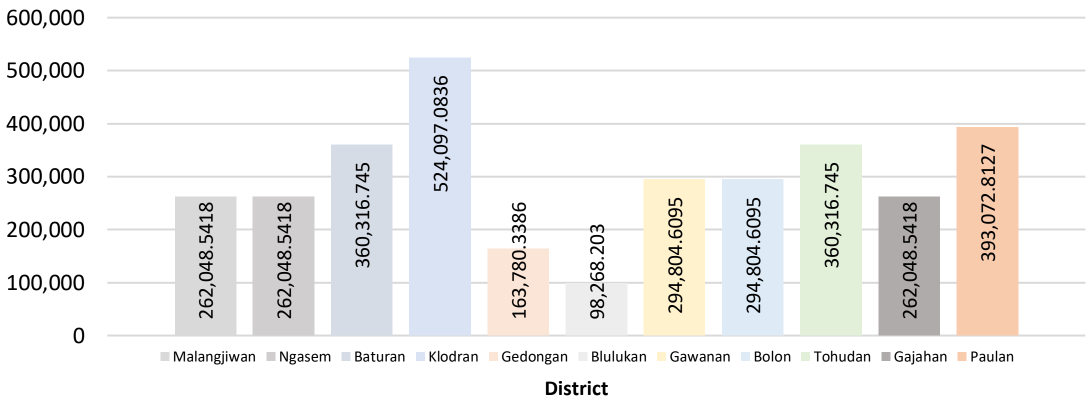

Figure 8. The use of groundwater per village in settlements in Colomadu District in 2021.

After obtaining the results for groundwater use per village described above, groundwater use per village was mapped in settlements in Colomadu District in 2021 using three classes or ranges, as shown in Figure 9. The first class has a vulnerable groundwater use of 1–200,000 m^3 $year^{-1}$ and is colored green; therefore, it was included in the classification of low groundwater use. The second class has a vulnerable use of groundwater ranging from 200,001–400,000 m^3 $year^{-1}$ and is colored yellow; therefore, it is included in the classification of moderate groundwater use. The third class is vulnerable to the use of groundwater at 400,001–600,000 m^3 $year^{-1}$ and is colored red. Therefore, it is included in the classification of high groundwater use. In this study, it was found that the urban villages included in the classification of low groundwater use with a green color included Gedongan and Blulukan. The villages included in the classification of moderate groundwater use with yellow color include Ngasem, Bolon, Malangjiwan, Paulan, Gajahan, Gawanan, Tohudan, and Batur. Then, one village is included in the classification of high groundwater use with a red color, namely Klodran.

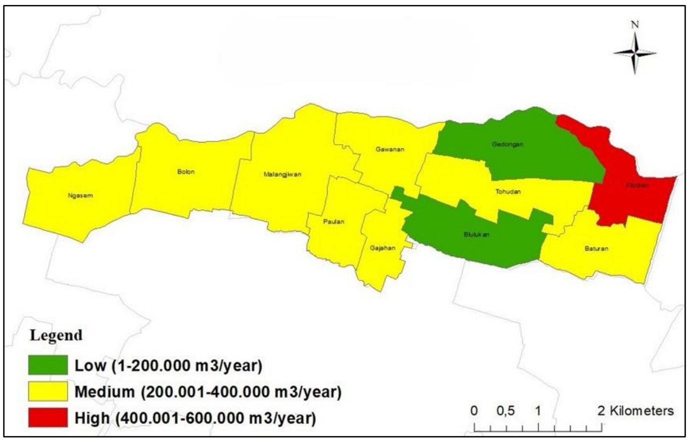

Figure 9. Map of groundwater use per village in settlements in Colomadu District in 2021.

Based on the results of interviews with the community in Colomadu District, most of the groundwater used to meet their daily needs was of good quality, as evidenced by the water being clear or cloudy, odorless, and lacking lime. Samples were also collected to test water quality using TDS and pH parameters in the three villages. The lower the TDS value, the better the water quality. While the normal pH value for groundwater is in the range of 6 to 8.5, water with a pH below 6.5 is included in the acidic category. Based on Table 2, the water quality tests showed that the lowest TDS value (278 mg L^{-1}) occurred in the 2^{nd} location of the village. The highest TDS value of 339 mg L^{-1} was observed in Batur, which was located at 1. The pH values at the four sampling locations were normal, with the lowest value being 6.67 at the 2^{nd} location in Tohudan.

Table 2. Groundwater quality in settlements in Colomadu District.

No	Urban village	TDS (mg L^{-1})	pH
1	Malangjiwan	342	6.78
2	Tohudan 1	338	6.70
3	Tohudan 2	278	6.67
4	Baturan 1	339	6.85
5	Baturan 2	386	6.95

Linkage of Environmental Issues with Environmental Principles

3rd Environmental Principle

Principle 3, which reads "Material, energy, space, time, and diversity, including the category of natural resources." This principle is related to the increasing population because competition for groundwater (demand) is increasing. An increase in the population of an area affects the source of groundwater in that area or region. This is because an increase in the number of residents in an area also affects space availability; therefore, competition is increasing. Therefore, it took time for the area to provide groundwater.

4th Environmental Principle

The 4th principle reads, "For all categories of natural resources, if the supply of the resource is sufficiently high, the effect of the unit increase often decreases by adding natural resources to a maximum level. Exceeding this maximum limit is no longer profitable. For all categories of nature (except biodiversity and time), an increase in procurement that exceeds the maximum limit will have a detrimental effect because of poisoning. This is the saturation principle. For many constraints, the possibility of destruction is often applied, because the procurement of natural resources is close to their maximum limits. This principle is related to the management of the groundwater resources. Water, especially groundwater, is used by people in the Colomadu District for domestic purposes and in various sectors. The availability of groundwater in Colomadu District decreases in line with population growth. This means that the carrying capacity of groundwater in Colomadu District cannot meet the needs of the community. Therefore, it is necessary to control and manage groundwater resources so that they can be maintained and increased to meet the community needs.

5th Environmental Principle

Principle 5, which reads: "There are two types of natural resources, namely, those whose procurement can stimulate continued use and those that do not have the incentive to further use." Principle 5 relates to the availability of groundwater in the Colomadu District, where water is a natural resource that can be used sustainably. However, if confectionaries are used continuously by many people, it will cause a scarcity of groundwater resources will run out.

10th environmental principle

The 10th principle reads, "In a stable environment, the ratio between biomass and productivity increases over time to reach an asymptote." The 10th principle relates to population growth, resulting in an increase in the water needs of the people of Colomadu District. The increasing demand for water has created the need for a water supply and management system to provide and manage more groundwater.

Conclusion

Projections of water availability and demand in Colomadu District and Karanganyar Regency are influenced by the rate of population growth in Colomadu District. The projection of groundwater use in Colomadu District in 2025 is 3,345,311.68 m^3 $year^{-1}$; in 2030, it is 3,716,727.52 m^3 $year^{-1}$; in 2035, it is 4,129,380.08 m^3 $year^{-1}$; and in 2040, it is 4,587,847.71 m^3 $year^{-1}$. Projections are made until demand exceeds supply, namely, in 2085, when demand can reach 11,833,854.16 m^3 $year^{-1}$ with a population of 272,244 people. Furthermore, the water demand in each village of Colomadu District is obtained as follows: Malangjiwan has a total groundwater usage of 262,048.5 m^3 $year^{-1}$, Ngasem is 262,048.5 m^3 $year^{-1}$, Batur is 360,316.7 m^3 $year^{-1}$, Klodran is 524,097.1 m^3 $year^{-1}$, Gedongan is 163,780.3 m^3 $year^{-1}$, Blulukan is 98,268.2 m^3 $year^{-1}$, Gawanan is 294,804.6 m^3 $year^{-1}$, Bolon is 294,804.6 m^3 $year^{-1}$, Tohudan is 360,316.7 m^3 $year^{-1}$, Gajahan is 262,048.5 m^3 $year^{-1}$, and Paulan is 393,072.8 m^3 $year^{-1}$.

The availability of groundwater in Colomadu District is 11,147,764.3 m^3 $year^{-1}$. The availability of groundwater in Colomadu District is influenced by several factors, including rainfall (2,000–2,500 mm $year^{-1}$), soil type (Regosol Gray), slope (0–8%), and land use (mostly settlements). In addition, most of the groundwater in Colomadu District has good water quality. It is evident from the water that it is clear or cloudy, does not smell, and does not contain lime. However, the need for groundwater in Colomadu District can only be met by 2085 when there is a deficit because demand will exceed supply.

Author Contributions

LK, RK: Conceptualization, Methodology; **MBM, SAJ, YAAR**: Software, Investigation; **SK, NUF, LK:** Writing; **YES, YPAA, APD:** Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

References

1. van der Gun, J. Groundwater resources sustainability. *Global Groundwater* **2021**, 331–345, doi:10.1016/B978-0-12-818172-0.00024-4.
2. Jia, X.; O'Connor, D.; Hou, D.; Jin, Y.; Li, G.; Zheng, C.; Ok, Y.S.; Tsang, D.C.W.; Luo, J. Groundwater depletion and contamination: Spatial distribution of groundwater resource sustainability in China. *Science of the Total Environment* **2019**, *672*, 551–562, doi:10.1016/j.scitotenv.2019.03.457.
3. Pradana, A.C.; Soedwiwahjono, S.; Nurhadi, K. Fenomena perubahan penggunaan lahan pertanian menjadi perumahan: Studi kasus kawasan peri-urban Kecamatan Colomadu. *Desa-Kota: Jurnal Perencanaan Wilayah, Kota, dan Permukiman* **2021**, *3*, 24–35, doi:10.20961/desa-kota.v3i1.37622.24-35.
4. Akhirul, A.; Witra, Y.; Umar, I.; Erianjoni, E. Dampak negatif pertumbuhan penduduk terhadap lingkungan dan upaya mengatasinya. *Jurnal Kependudukan dan Pembangunan Lingkungan* **2020**, *1*, 76–84.
5. Nabi, G.; Ali, M.; Khan, S.; Kumar, S. The crisis of water shortage and pollution in Pakistan poses a risk to public health, biodiversity, and ecosystems. *Environmental Science and Pollution Research* **2019**, *26*, 10443–10445, doi:10.1007/s11356-019-04483-w.
6. Wang, C.; Hou, Y.; Zhang, J.; Chen, W. Assessing the groundwater loss risk in Beijing based on ecosystem service supply and demand and the influencing factors. *Science of The Total Environment* **2023**, *872*, 162255, doi.org/10.1016/j.scitotenv.2023.162255.
7. Hasbiah, A. W.; Kurniasih D. Analysis of water supply and demand management in Bandung, Indonesia. *IOP Conference Series: Earth and Environmental Sciences* **2019**, *245*, 1–6, doi:10.1088/1755-1315/245/1/012030.
8. Ren, C.; Dong Y.; Xue, P.; Xu, W. Analysis of water supply and demand based on a logistic model. *IOP Conference Series: Earth and Environmental Science* **2019**, *300*, 1–5, doi:10.1088/1755-1315/300/2/022013.
9. Hssaisoune, M.; Bouchaou, L.; Sifeddine. A.; Bouimetarhan, I.; Chehbouni, A. Moroccan groundwater resources and their evolution with global climate change. *Geosciences* **2020**, *10*, 1–26, doi:10.3390/geosciences10020081.

10. Li, M.; Xu, Y.; Fu, Q.; Singh, V.P.; Liu, D.; Li, T. Efficient irrigation water allocation and its impact on agricultural sustainability and water scarcity under uncertainty. *Journal of Hydrology* **2020**, *586*, 1–12, doi:10.1016/j.jhydrol.2020.124888.
11. Febriarta, E.; Oktama, R. Pemetaan daya dukung lingkungan berbasis jasa ekosistem penyedia pangan dan air bersih di Kota Pekalongan. *Jurnal Ilmu Lingkungan* **2020**, *18*, 283–289, doi:10.14710/jil.18.2.283-289.
12. Zhang, J.; Zhang, C.; Shi, W.; Fu, Y. Quantitative evaluation and optimized utilization of water resources-water environment carrying capacity based on nature-based solutions. *Journal of Hydrology* **2019**, *568*, 96–107, doi:10.1016/j.jhydrol.2018.10.059.
13. Kusumawardhani, N.P. Analysis of water-carrying capacity for regional planning development in the Malang Regency. *JAUR (Journal of Architecture and Urbanism Research)* **2020**, *3*, 166–174, doi:10.31289/jaur.v3i2.3331.
14. Zhang, W. The Evaluation of Regional Water Resources Carrying Capacity Based on Grey Correlation Analysis and Set Pair Analysis. Master Thesis, Hefei University of Technology, Hefei, China, 2019.
15. Karmaoui, A.; Ifaadassan, I.; Babqiqi, A.; Messouli, M.; Khebiza M.Y. Analysis of the water supply-demand relationship in the Middle Draa Valley, Morocco, under climate change and socioeconomic scenarios. *J. Sci. Res. Rep*. **2016**, *9*, 1–10, doi:10.9734/JSRR/2016/21536.
16. Olivier, D.W.; Xu, Y. Making effective use of groundwater to avoid another water supply crisis in Cape Town, South Africa. *Hydrogeology Journal* **2019**, *27*, 823–826, doi.org/10.1007/s10040-018-1893-0.
17. Wilopo, W.; Putra, D.P.E.; Hendrayana, H. Impact of precipitation, land use change, and urban wastewater on groundwater level fluctuation in the Yogyakarta-Sleman Groundwater Basin, Indonesia. *Environmental Monitoring and Assessment* **2021**, *193*, 1–14, doi: doi.org/10.1007/s10661-021-08863-z.
18. Sugiyono. *Metode Penelitian Pendidikan Pendekatan Kuantitatif, Kualitatif, dan R&D*; Alfabeta: Bandung, Indonesia, 2014.
19. BPS (Badan Pusat Statistik). Banyaknya Hari Hujan (HR) dan Curah Hujan (MM) menurut Bulan dan Tempat Pengukuran di Kabupaten Karanganyar Tahun 2020. Available online: https://karanganyarkab.bps.go.id/statictable/2021/05/17/302/banyaknya-hari-hujan-hr-dan-curah-hujan-mm-menurut-bulan-dan-tempat-pengukuran-di-kabupaten-karanganyar-2020.html (accessed on 10 September 2023).
20. Selvam, S.; Dar, F.A.; Magesh, N.S.; Singaraja, C.; Venkatramanan, S.; Chung, S.Y. Application of remote sensing and GIS for delineating groundwater recharge potential zones of Kovilpatti Municipality, Tamil Nadu using IF technique. *Earth Science Informatics* **2016**, *9*, 137–150, doi:10.1007/s12145-015-0242-2.
21. Duan, H.; Deng, Z.; Deng, F.; Wang, D. Assessment of groundwater potential based on multicriteria decision making model and decision tree algorithms. *Mathematical Problems in Engineering* **2016**, 1–11, doi.org/10.1155/2016/2064575.
22. MoEF (Ministry of Environmental and Forestry). Peraturan Menteri Kehutanan Republik Indonesia Nomor: P. 32/Menhut-II/2009 tentang Tata Cara Penyusunan Rencana Teknik Rehabilitasi Hutan dan Lahan Daerah Aliran Sungai (RTKRHL-DAS). Available online: https://jdih.menlhk.go.id/new2/uploads/files/P.32%20(9).pdf (accessed on 10 September 2023).
23. Bappeda (Badan Perencanaan dan Pembangunan Daerah). Peta Kemiringan Lereng Kabupaten Karanganyar. 2016. Available online: https://jdih. karanganyarkab.go.id/admin/pdf/1657-1660.pdf (accessed on 10 September 2023).
24. Santosa, L.W.; Adji, T.N. *Karakteristik Akuifer dan Potensi Airtanah Graben Bantul*; Gadjah Mada University Press, Yogyakarta, Indonesia, 2014.
25. BPS (Badan Pusat Statistik). Jenis Tanah Menurut Kecamatan di Kabupaten Karanganyar Tahun 2018. Available online: https://karanganyarkab.bps.go.id/statictable/2019/12/19/139/jenis-tanah-menurut-kecamatan-di-kab-karanganyar-2018.html (accessed on 10 September 2023).
26. Ministry of Agriculture (MoA). Surat Keputusan Menteri Pertanian No 837/KPTS/UM/1980 Tentang Kriteria dan Tata Cara Penetapan Kawasan Hutan Lindung. Available online: https://mrbudisantoso.wordpress.com/wp-content/uploads/2009/02/kriteria-hlhp-keppresmentan.pdf (accessed on 10 September 2023).

27. Mandal, U.; Sahoo, S.; Munusamy, S.B.; Dhar, A.; Panda, S.N.; Kar, A.; Mishra, P. Delineation of groundwater potential zones of coastal groundwater basin using multi-criteria decision making technique. *Water Resources Management* **2016**, *30*, 4293–4310, doi:10.1007/s11269-016-1421-8.

28. Ministry of Public Works and Housing (MoPWH). Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 02/PRT/M/2013 Tahun 2013 tentang Pedoman Penyusunan Rencana Pengelolaan Sumber Daya Air. 2013. Available online: https://peraturan.go.id/files/bn536-2013.pdf (accessed on 10 September 2023).

29. Kusumaningrum, L.; Amalia, B.W.; Pramudita, D.A.; Fahrurozi, D.E.; Berlin, G.E.; Sulton, M.N.; Silaningtyas, N.W.; Hanum, U.; Himawan, W.; Armadhan, W.S.; et al. Study of settlements carrying capacity in Jebres Subdistrict, Surakarta with *das sein – das sollen* approach. *Journal of Natural Resources & Environment Management* **2023**, *13*, 140–146, doi:10.29244/jpsl.13.1.140–146.

30. Zhou, X.Y.; Zheng, B.; Khu, S.T. Validation of the hypothesis on carrying capacity limits using the water environment carrying capacity. *Science of the Total Environment* **2019**, *665*, 774–784, doi:10.1016/j.scitotenv.2019.02.146.