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Cimandiri Watershed, Sukabumi District: A dynamic model for optimizing water resources

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ABSTRACT

Water is a very important element for human life. Humans cannot survive without water, therefore water is one of the basic needs for human survival. Water resources in Indonesia are abundant, but only a few can be utilized as drinking water. Of the total water available, only 5% is used for drinking water, while the rest is water that cannot be consumed before further treatment. In addition, the current trend is to reduce the supply of drinking water. In researching and evaluating the water resources of an area, the quantity and quality aspects must be considered because both factors are measures that need to be taken into account in the utilization of water resources. A water balance analysis is necessary to compare the water availability and demand in the Cimandiri Watershed in Sukabumi District. An overview of the state of the water balance in the Cimandiri Watershed in Sukabumi District is anticipated to be provided by this research. This study employs secondary data and is descriptive in nature, utilizing quantitative methods for data collection, processing, and analysis. This study approach comprises the following analyses: 2022–2052 surface water and groundwater sources; 2022–2052 population; industrial; tourism; agriculture and livestock water demand; as well as 2022–2052 water balance. The analysis of water availability and demand in 2052 showed that 263,639,967.40 m^3 of water was available and 76,738,969.50 m^3 of water was demanded. Thus, we must develop a strategy and take action to ensure that extra water is used effectively and responsibly, thereby establishing a buffer for future shortages while also benefiting the environment and the community.

ABSTRAK

Air merupakan elemen yang sangat penting bagi kehidupan manusia. Manusia tidak dapat bertahan hidup tanpa air, oleh karena itu air merupakan salah satu kebutuhan pokok bagi kelangsungan hidup manusia. Sumber daya air di Indonesia melimpah, namun hanya sedikit yang dapat dimanfaatkan sebagai air minum. Dari total air yang tersedia, hanya 5% yang digunakan untuk air minum, sedangkan sisanya merupakan air yang tidak dapat dikonsumsi sebelum diolah lebih lanjut. Selain itu, tren yang terjadi saat ini adalah berkurangnya pasokan air minum. Dalam meneliti dan mengevaluasi sumber daya air suatu daerah, aspek kuantitas dan kualitas harus diperhatikan karena kedua faktor tersebut merupakan ukuran yang perlu diperhitungkan dalam pemanfaatan sumber daya air. Analisis neraca air diperlukan untuk membandingkan ketersediaan dan kebutuhan air pada Daerah Aliran Sungai (DAS) Cimandiri di Kabupaten Sukabumi. Gambaran mengenai keadaan neraca air di DAS Cimandiri Kabupaten Sukabumi diharapkan dapat diperoleh melalui penelitian ini. Penelitian ini menggunakan data sekunder dan bersifat deskriptif dengan menggunakan metode kuantitatif dalam pengumpulan, pengolahan, dan analisis data. Pendekatan studi ini terdiri dari analisis berikut: sumber air permukaan dan air tanah tahun 2022–2052; jumlah penduduk tahun 2022–2052; industri; wisata; kebutuhan air pertanian dan peternakan; serta neraca air tahun 2022–2052. Analisis ketersediaan dan kebutuhan air pada tahun 2052 menunjukkan ketersediaan air sebanyak 263.639.967,40 m^3 dan kebutuhan air sebanyak 76.738.969,50 m^3. Oleh karena itu, kita harus mengembangkan strategi dan mengambil tindakan untuk memastikan bahwa kelebihan air digunakan secara efektif dan bertanggung jawab, sehingga dapat menjadi penyangga kekurangan air di masa depan sekaligus memberikan manfaat bagi lingkungan dan masyarakat.

Keywords: *Cimandiri, dynamic model, watershed, Sukabumi District, water balance*

INTRODUCTION

Water is an essential component for human survival. Humans cannot survive without water, hence it is one of the most basic need for survival. Furthermore, the UN's Sustainable Development Goals (SDGs) prioritize the availability and sustainability of clean water, which is a major priority for Indonesia's central and regional governments (Andriyanto et al., 2023; Rachmawati et al., 2024). Indonesia has an abundance of water resources, however only a small portion of them can be used for drinking. Only 5% of the total accessible water is used for drinking, with the rest being water that cannot be drunk without additional treatment (Triatmodjo, 2008). Furthermore, the current trend is to reduce the availability of drinking water. Water is critical to the survival of humanity and the environment since it is a source of life that cannot be replaced, and humans, animals, and plants cannot exist without it. Water has various uses beyond fundamental human needs, such as bathing, washing, and other domestic chores (Fulazzaky, 2014). Water resource management, as defined in Law of the Republic of Indonesia Number 17 of 2019 Concerning Water Resources, is required to maintain a balance between decreasing water availability and increasing water demand.

Water availability is strongly tied to water sources, whereas water demand is driven by fundamental community needs as well as other business or farming activities. Water cultivation requires supervision in order to monitor the use of water for economic activities. If water use is not managed and exceeds the carrying capacity, it will result in an imbalance between utilization and recharge of water resources in the recharge area (Cahyo et al., 2016).

The watershed (or called DAS in Indonesian) encompasses the entire jurisdiction of the river and its primary drainage (Kendarto et al., 2021). Therefore, the watershed border is a shadow line that runs along the top of a mountain, cliff, or hill, separating one flow system from another. According to this concept, the watershed is divided into two parts: the watershed which forms the upstream area, and the water distribution area which is downstream. (Fuady & Azizah, 2008). Sukabumi District has two water resources: surface water and groundwater. Both water resources are found in the Cimandiri Watershed, which includes 15 sub-districts: Bojong Genteng, Caringin, Cicantayan, Cibadak, Cicurug, Cidahu, Cikembar, Cikidang, Cisaat, Kadudampit, Kalapanunggal, Nagrak, Parakansalak, Parungkuda, and Warungkiara. In this location, there are numerous businesses and agricultural activities that use water. It is feared that this will have an impact on the water balance in these 15 subdistricts.

The purpose of this study is to develop a water balance model by calculating the comparison between existing water carrying capacity and the need for water for the community, other businesses, and cultivation activities, with the intention of optimizing the use of potential water resources in 15 sub-districts in Sukabumi District, which is located in the Cimandiri Watershed.

METHODS

Research Location

The study was undertaken in Cimandiri Watershed, Sukabumi District, which covers 15 sub-districts: Bojonggenteng, Caringin, Cicantayan, Cibadak, Cicurug, Cidahu, Cikembar, Cikidang, Cisaat, Kadudampit, Kalapanunggal, Nagrak, Parakansalak, Parungkuda, and Warungkiara (Figure 1). The research was conducted between January and September 2022.

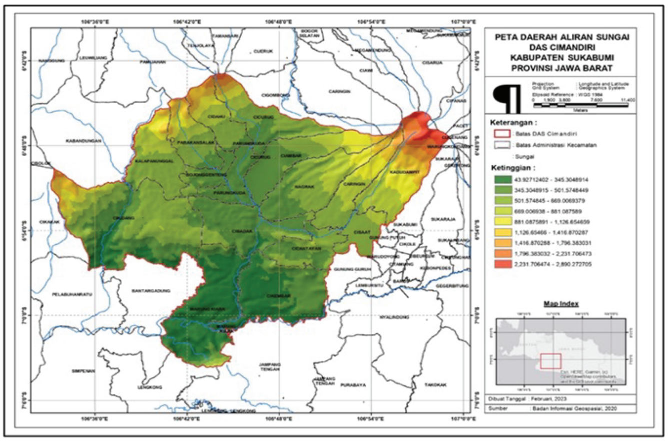

Figure 1. Map of the study area in Cimandiri Watershed, Sukabumi District.

Data Analyses

This descriptive quantitative research employs a dynamic system (Asmorowati & Sarasanty, 2021), to determine whether the water balance will be surplus or deficit over the next 30 years projected from 2022. The data used in analyzing the water balance in the Cimandiri Watershed were collected from various sources at the related agencies in Sukabumi District (Table 1). To establish if there is a surplus or deficit in the water balance, we compare water availability to water demand. Water availability in the Cimandiri Watershed in Sukabumi District is determined by the region's groundwater and surface water resources. Both water potentials are exploited in order to satisfy population's water needs as well as other economic activities. Water demand is determined using the basic water consumption for people, industry, tourism, agriculture, and livestock. This is due to the fact that in the research area, which spans 15 sub-districts of Sukabumi District, the only viable water resources are groundwater and surface water, whereas five activities account for the majority of water demand (Figure 2). The water balance analysis will evaluate the availability of water from surface and groundwater to the demand for water from industrial operations, tourism, agricultural, livestock, and population use, all provided in the form of a water balance.

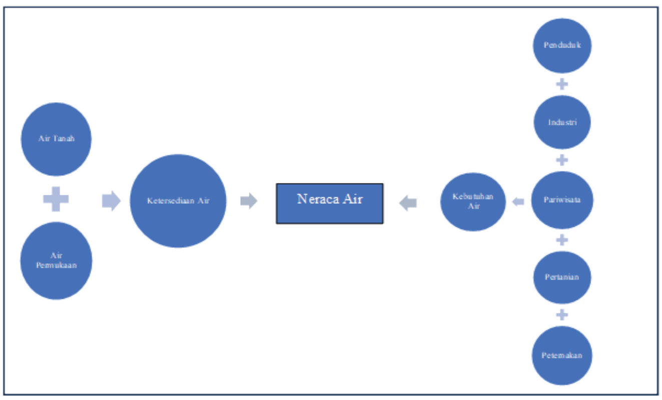

Figure 2. Water balance.

Table 1. Secondary data used in the research were collected from various sources in Sukabumi District.

Data Type	Data Form	Year	Sources
Cimandiri watershed in Sukabumi district	shp	2022	West Java Provincial Water Resources Office
Surface Water Potential	Numerical	2019	West Java Provincial Water Resources Office
Groundwater potential in 15 sub-districts in Cimandiri watershed	Numerical and shp	2019	Geological Agency, Ministry of Energy and Mineral Resources of the Republic of Indonesia and Central Bureau of Statistics of Sukabumi District
Total Population	Numerical	2021	Badan Pusat Statistik
Total Industry	Numerical	2021	Sukabumi District Trade and Industry Office
Total Livestock Population	Numerical	2021	Livestock Service Office of Sukabumi District
Number of Tourism Facilities and Infrastructure	Numerical	2021	Sukabumi District Tourism Office

After comprehending the ideas and operational definitions, as well as the research technique and design, the following phase in this study is to identify the three objectives of the study such as water carrying capacity, water demand, and water availability (Rejekiningrum et al., 2010). Each of the objects employed in this research analysis is described as follows: a). Water demand for population, industry, agriculture, livestock, and tourism (Figure 3); b). Water availability, including groundwater and surface water (Figure 4).

This study also developed a water balance model, which compares the total water demand of different sectors (i.e. raw water for people, industry, agriculture, livestock, and tourism) towards the availability of water resources which are groundwater and surface water (Purnama, 2013). Some computer programme and softwares such as Microsoft Excel, Powersim 10 Studio (Asmorowati & Sarasanty, 2021), as well ArcGIS version 10.8. were used to support the data analyses.

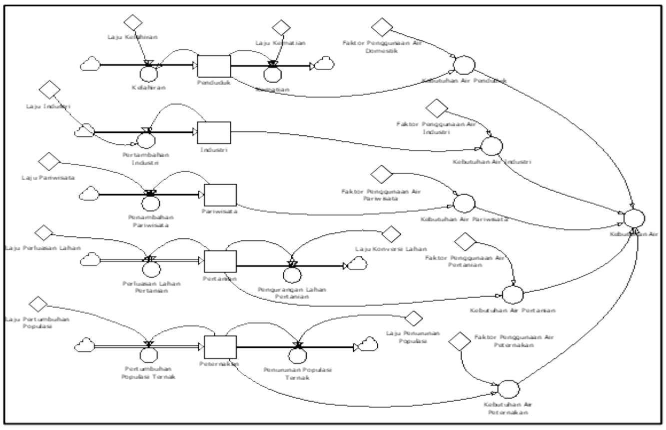

Figure 3. Water demand sub-system.

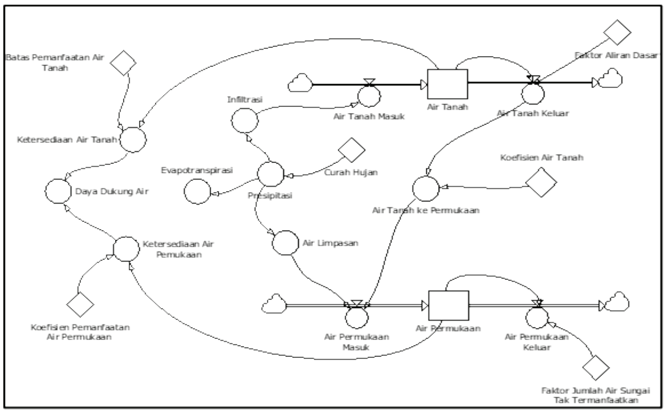

Figure 4. Water availability sub-system.

RESULTS AND DISCUSSION

Availability of Groundwater

Groundwater potential in 15 sub-districts of the Cimandiri Watershed in Sukabumi District was 56,409,120 m^3. The estimation of groundwater availability is impacted by rainwater infiltration, which accounts for 36% of groundwater availability. Groundwater availability also takes into account groundwater that emerges as springs and later serves as a recharge source for surface water. Groundwater springs have a base flow factor of 25.7%. The calculation findings show that groundwater availability will be 105,480,612.99 m^3 in 2052 (Figure 5).

Groundwater quality could be deteriorated due to overexploitation, resulting in land subsidence and other environmental issues (Tirtomihardjo, 2016). Studies show that the groundwater in the region of West Java, Indonesia, is primarily fresh, but the increasing extraction rates pose risks to its sustainability (Azy et al., 2016). Despite the critical role of groundwater in supporting urban and agricultural needs, the ongoing overexploitation raises concerns about long-term availability and environmental health. Sustainable management practices are essential to mitigate these challenges.

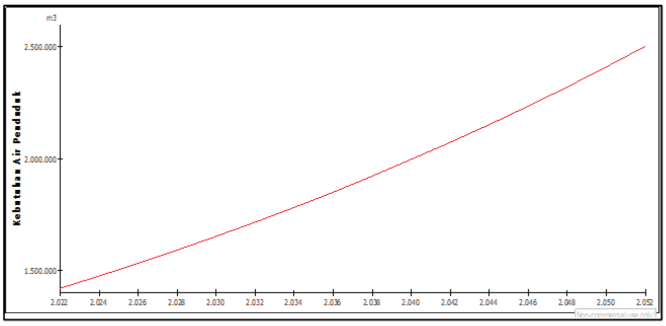

Figure 5. Graph of Groundwater availability rate 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Availability of Surface Water

Surface water availability in the Cimandiri Watershed in Sukabumi District is derived from the Cimandiri River's major tributaries, i.e. Cicatih (41.047 km long), Citarik (44.07 km long), and Cipelang (17.25 km long), as well as three other small tributaries, such as Cigadung, Cicareuh, and Citalahab. The average potential discharge from each site in the Citarik River is 23.65 m^3/second, enough to irrigate over 13,500 hectares of rice fields. The Cicatih river has an average discharge of 15.52 m^3/second, which can water almost 8,800 hectares of rice fields. The Cipelang River has an average discharge of 9.83 m^3/second, enough to irrigate almost 5,600 hectares of rice fields. The rate of surface water availability 2022-2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 6.

The availability of surface water in West Java, Indonesia, is influenced by several interrelated factors, primarily climate change, land use changes, and socio-economic dynamics. These elements interact to affect water yield and distribution across the region, particularly in the Citarum River Basin, which has been the focus of multiple studies. Changes in rainfall patterns significantly impact water yield, with studies indicating that rainfall variations can account for 14.06% to 27.53% of changes in water yield (Nahib et al., 2021). Besides that, rising temperatures contribute to altered hydrological cycles, affecting evaporation rates and overall water availability (Jayanti, 2020). Furthermore, the conversion of land for agriculture and urban development has led to a decrease in water yield, with LULC changes contributing between 10.29% and 12.96% to water yield variations (Nahib et al., 2021; Nahib et al., 2022). Viewed from a socioeconomic standpoint, increasing population density raises water demand, leading to significant supply-demand imbalances, particularly during dry seasons (Mirrah & Kusratmoko, 2017). Besides that, agricultural practices, especially those reliant on water-intensive crops, place additional stress on available water resources.

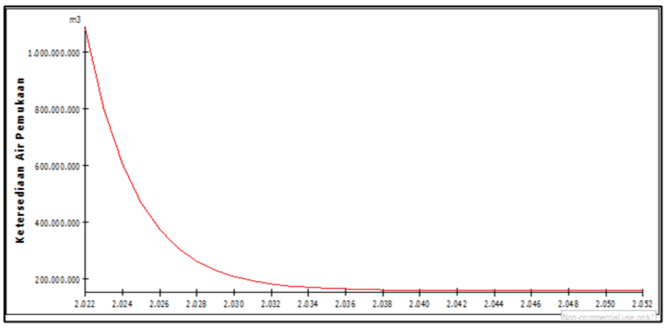

Figure 6. Graph of surface water availability rate 2022-2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Population

The water demand for the population in 15 sub-districts of the Cimandiri Watershed in the Sukabumi region is determined using the total population in 15 sub-districts and the percentage of the existing population's birth and death rates (Figure 7). The standard water requirement per person per day is also utilized as a criterion when calculating the population's water requirement. In 2021, the total population of 15 sub-districts will be 1,185,340, with a population birth rate of 2.3% and a population mortality rate of 0.4%. In urban areas, the average person needs 120 liters of water each day. In 2052, the population of 15 sub-districts demanded 2,501,783.3 m^3 of water. As the population grows year after year, so will the demand for water to meet basic necessities till 2052.

In West Java, Indonesia, the average groundwater requirement per person varies greatly between localities. According to research, socioeconomic characteristics and local infrastructure have an impact on home water usage. The average daily water consumption ranges from 117 liters in peri-urban areas to 214.3 liters in middle-class families. In suburban communities, individuals consume an average of 117 liters of domestic water per day, above the WHO's recommended range of 50-100 liters (Utami et al., 2023). Meanwhile, in a metropolitan city such as Bandung, the average daily consumption is reported to be 163.6 liters per person (Zevi et al., 2022).

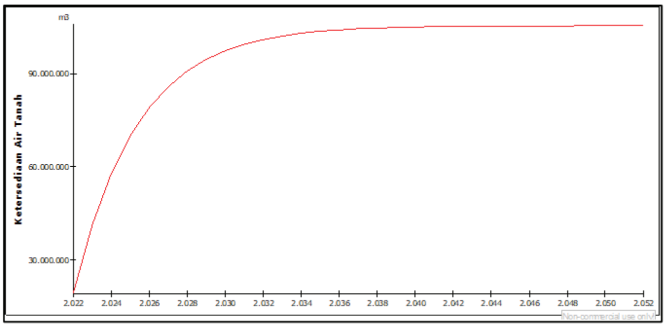

Figure 7. Graph of water demand rate for population 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Industrial

Medium to large industrial activities in the Cimandiri Watershed in Sukabumi District are mostly located in 15 sub-districts in the north of Sukabumi District. These industrial activities are activities that are taken into account in their water needs because these industrial activities use water for raw materials or supporting materials in relatively large quantities. The number of medium and large industrial activities in Sukabumi District from 2017 - 2021 fluctuated in line with the economic conditions affecting these industrial activities. In 2021, the number of industrial activities located in Sukabumi District (15 sub-districts in the Cimandiri

Watershed) amounted to 102 companies with a total water demand of 8,038,045 m^3 per year. The water demand in industrial activities is calculated using data on the amount of water consumed in one year. The rate of industry and industrial water usage parameters are also considered when calculating the water demand for industrial operations. For a 1% industrial growth rate, with an average water usage of 78,804.36 m^3. Water requirement for industrial purposes rises till 2052. The overall water consumption in 2052 was 10,834,069.86 m^3. The rate of water demand for industry 2022 - 2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 8.

West Java, Indonesia, has a diverse industrial landscape that significantly influences water demand. The primary industries include agriculture, mining, and manufacturing, each contributing uniquely to the region's economic growth and water usage patterns. The mining sector, particularly for industrial minerals, plays a crucial role in West Java's economy, with a notable output multiplier effect (Soelistijo et al., 2015). Mining operations require significant water for processing and dust suppression, contributing to the overall water demand in the region (Juwana et al., 2009). The manufacturing industry, including food, textiles, and construction, accounts for a large share of the regional GDP (Falatehan & Bahtiar, 2019). This sector's water consumption is high due to processes such as cooling, cleaning, and product formulation, exacerbating water scarcity issues (Juwana et al., 2009).

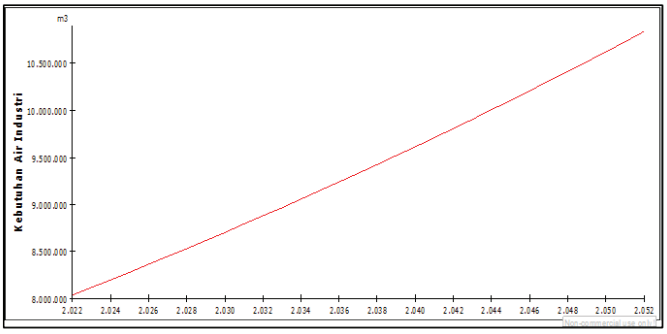

Figure 8. Graph of water demand rate for industry 2022 - 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Tourism

Hotels, homestays, restaurants, and swimming pools (or water booms) are among the tourism-related businesses in the Cimandiri Watershed of Sukabumi District's 15 subdistricts. According to data from the Sukabumi District Tourism Office, the number of tourism-related economic activity has grown between 2017 and 2022. The total water consumption in tourism business activities fluctuates in response to tourist visits. Tourism business activity declined significantly between 2020 and 2021 as a result of the COVID 19 epidemic. The calculation of water demand in tourism activities accounts for a 3% tourism growth rate, with an average water demand of 775.96 m^3. According to the calculation of water consumption for tourism activities till 2052, it increased each year. In 2052, the water required to support tourism facilities and infrastructure totaled 88,522.55 m^3 (Figure 9).

The high average water consumption in Indonesia's tourism sector is primarily driven by several interrelated factors, including increased tourist demand, inadequate water management, and competition for water resources among various sectors. Hotels in Denpasar, Bali, for instance, are significant water consumers, relying on deep groundwater and municipal supplies, necessitating improved management practices to mitigate future shortages (Setiyono, 2018). Despite improvements in water supply coverage, the tourism sector still faces a significant gap between supply and demand, indicating reliance on alternative sources like groundwater (Yamamoto et al., 2021).

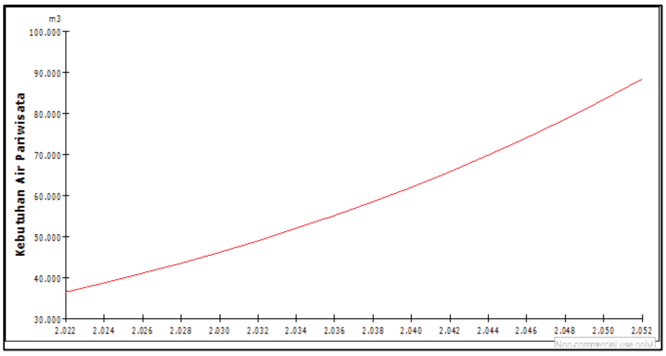

Figure 9. Graph of water demand rate for tourism in 2022 – 2052 in Cimandiri Watershed of Sukabumi District.

Water Demand for Agriculture

Sukabumi District's Cimandiri Watershed (15 sub-districts) has 20,883 hectares of irrigated agricultural land. The calculation of water demand for agricultural activities takes into account the growth and decrease of agricultural area, as well as the pace of expansion and conversion of agricultural land. According to Sukabumi District Agriculture Office data on land growth rates from 2018 to 2021, no new paddy fields were developed. The rate of conversion of paddy fields is also calculated by converting paddy fields into land other than rice fields, such as housing, industry, and road building. The rate of conversion of paddy fields is also calculated by converting paddy fields into land other than rice fields, such as housing, industry, and road building. According to data, paddy fields are converted at a rate of 9% annually. With no new agricultural area expansion and a 9% annual conversion rate, the demand for water in agriculture has declined until 2052. In 2052, agriculture will require 247,133.93 m^3 of water. The rate of of water demand for agriculture 2022-2052 In Cimandiri Watershed, Sukabumi District, can be seen in Figure 10.

Agriculture is one of the primary industries in West Java, Indonesia. The agricultural sector is vital, particularly in plantations, animal husbandry, and fisheries, which are major contributors to the local economy (Mukhyi et al., 2008). This sector's water demand is substantial, driven by irrigation needs and livestock maintenance, leading to increased pressure on water resources (Juwana et al., 2009).

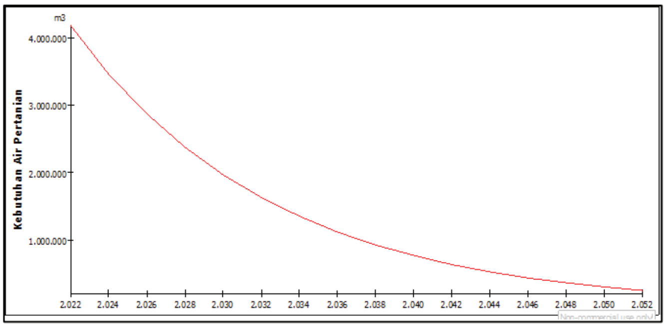

Figure 10. Graph of water demand rate for agriculture 2022-2052 In Cimandiri Watershed of Sukabumi District.

Water Demand for Livestock

Water demands for livestock production in a single year are determined using both direct water needs for livestock consumption and water needs for supporting facilities such as cage sanitation. According to data from Sukabumi District's Livestock Service Office in 2021, there are 12 types of livestock in the Cimandiri Watershed, with a total livestock population of 30,805,399 animals. The overall annual water consumption for all animals is 35,857,484.44 m^3. The rate of water demand for livestock 2022 - 2052 in Cimandiri Watershed, Sukabumi District, can be seen in Figure 11. The decline in water availability affects not only crop production but also the viability of livestock operations, necessitating a multifaceted approach to address these issues. Economic valuations indicate that cattle farming can yield greater benefits than traditional crop cultivation, especially in drought-prone areas (Widagdo et al., 2023).

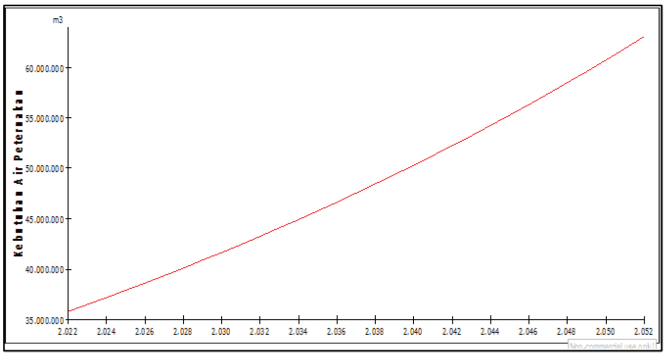

Figure 11. Graph of water demand rate for livestock 2022 - 2052 in Cimandiri Watershed, Sukabumi District.

Water Balance

Water balance can be analyzed up to a certain time period by calculating water availability from groundwater and surface water, as well as analyzing water demand from water needs for population, industrial activities, tourism activities, agriculture, and livestock. The results of the analysis show that the water carrying capacity of the Cimandiri Watershed in Sukabumi District can cover the water needs for various business operations as well as the fundamental needs of the present population until 2052 (Figure 12). According to the Water Balance research, there is still surplus water from 2022 to 2052, which tends to decline year after year as water demand increases. In the Table 2 can be seen that in 2052 predicted there is 186,900,997.90 m^3 of excess water.

The projected impacts of climate change on water balance in West Java, Indonesia, by 2050 are significant, with alterations in precipitation patterns, increased water demand, and extreme weather events. These changes threaten water availability and agricultural productivity, necessitating urgent adaptation strategies. Rainfall intensity and distribution are expected to shift, with projections indicating a potential increase in annual rainfall by 1,472 mm per year (Susanti et al., 2021).

Table 2. Water balance.

(m^3)			
Year	**Kebutuhan Air**	**Daya Dukung Air**	**Neraca Air**
2022	49.539.360,48	1.100.863.900,80	1.051.324.540,32
2023	49.952.507,20	841.419.096,79	791.466.589,60
2024	50.413.846,70	661.935.294,66	611.521.447,96
2025	50.920.592,90	537.877.410,75	486.956.817,86
2026	51.470.239,21	452.211.409,76	400.741.170,55
2027	52.060.534,01	393.117.875,74	341.057.341,73
2028	52.689.458,19	352.400.793,28	299.711.335,08
2029	53.355.204,82	324.380.590,32	271.025.385,50
2030	54.056.160,60	305.124.392,05	251.068.231,45
2031	54.790.889,04	291.911.005,49	237.120.116,45
2032	55.558.115,14	282.859.237,42	227.301.122,28
2033	56.356.711,43	276.669.818,43	220.313.107,00
2034	57.185.685,36	272.446.311,41	215.260.626,06
2035	58.044.167,74	269.570.907,60	211.526.739,86
2036	58.931.402,31	267.618.345,89	208.686.943,59
2037	59.846.736,20	266.296.296,88	206.449.560,68
2038	60.789.611,33	265.404.107,49	204.614.496,16
2039	61.759.556,52	264.804.275,90	203.044.719,38
2040	62.756.180,38	264.402.746,61	201.646.566,24
2041	63.779.164,80	264.135.312,26	200.356.1476,46
2042	64.828.259,14	263.958.239,88	199.129.980,74
2043	65.903.274,82	263.841.817,03	197.938.542,22
2044	67.004.080,50	263.765.914,21	196.761.833,71
2045	68.130.597,72	263.716.937,97	195.586.340,24
2046	69.282.796,86	263.685.742,30	194.402.945,43
2047	70.460.693,58	263.666.199,50	193.205.505,92
2048	71.664.345,50	263.654.224,10	191.989.878,60
2049	72.893.849,30	263.647.107,81	190.753.258,51

2050	74.149.337,99	263.643.067,42	189.493.729,43
2051	75.430.978,50	263.640.938,30	188.209.959,81
2052	76.738.969,50	263.639.967,40	186.900.997,90

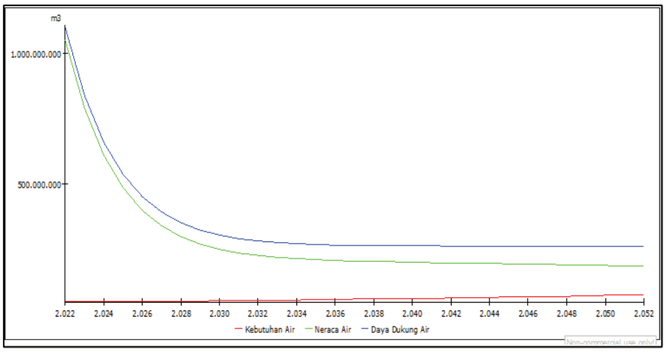

Figure 12. Graph of water demand rate with water support capacity 2022-2052.

CONCLUSION

The Cimandiri Watershed in Sukabumi District has enough surface and groundwater to meet the needs of the population, industry, tourism, agriculture, and livestock until 2052. A water balance analysis in the Cimandiri Watershed in Sukabumi district shows a water surplus of 186,900,997.90 m^3 till 2052. Thus, we must develop a strategy and take action to ensure that extra water is used effectively and responsibly, thereby establishing a buffer for future shortages while also benefiting the environment and the community.

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