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RESEARCH ARTICLE

Groundwater Potential in The Confined Aquifer Cibeureum Formation Using The Jacob Method Pump Test, Bandung – Soreang Groundwater Basin, Bandung City, West Java Province

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Abstract

High population growth increases demand for clean water. The greater the demand for clean water, the greater the extraction of groundwater. This large-scale extraction of groundwater is not balanced with the rate of groundwater recharge in aquifers, resulting in a decline in the water table. Groundwater subsidence is an ongoing problem in some areas of Indonesia, especially in densely populated areas. Bandung is one of the areas experiencing a decline in groundwater levels. The confined aquifer in the Cibeureum Formation of the Bandung-Soreang Groundwater Basin is one of the aquifers that is a source of clean water for the people of Bandung. Currently, the groundwater level in the aquifer continues to decline. The amount of potential groundwater discharge in this basin must be known, to limit the amount of groundwater withdrawal. This study aims to determine the amount of groundwater reserves, and ways to reduce the decline in groundwater levels in the basin. In this research, pumping test well data is used, which will be processed using the Jacob Method to obtain the value of groundwater reserves in the Bandung-Soreang Groundwater Basin. The amount of groundwater reserves in this basin is 67.50 L/sec. Meanwhile, the amount of groundwater is 43.87 L/sec.

Keywords: Groundwater Subsidence, Cibeureum Formation, Confined Aquifer

1. Introduction

Water is one of the natural resources that is very important for human life. Based on where it is found, water is divided into two types, namely surface water and groundwater. Rivers, lakes, and reservoirs are included in surface water, while groundwater is stored in the subsurface rock layer and the subsurface rock layer. This rock layer is referred to as the aquifer layer, where groundwater in this layer will later accumulate at one point in the subsurface called the Water Basin. Beneath the surface, which is referred to as the Groundwater Basin.

The Bandung-Soreang Groundwater Basin is one of the basins that has experienced a decrease in groundwater level, one of the factors for this decline in groundwater level is the excessive groundwater extraction (Purwoarminta, et al., 2019). In addition, the Bandung area is also a growing urban and industrial area, which results in a decrease in the area of infiltration areas which resulting in a reduction in the infiltration process in the Bandung area. The decrease in forest area (infiltration area) in the Bandung area reached 688 ha, and the increase in industrial area by 38,619 ha occurred from 1976 to 1992 (Wibowo, 2005). In addition, the decline in the area of infiltration areas can also be seen in the 2004 Groundwater Infiltration Criticality Map of the Bandung - Soreang Basin, where based on the map it is explained that the area of infiltration areas in the Bandung Soreang Groundwater Basin that is still functioning properly and normally is only 22.9% where 77% of the basin area has experienced critical groundwater conditions caused by the conversion of infiltration areas into industrial areas, so that the area can no longer absorb rainwater into the ground (Narulita, et al., 2008). Groundwater withdrawal in this basin was carried out in the shallow aquifer layer to the deep aquifer layer (depressed aquifer), where this large amount of groundwater withdrawal resulted in a decrease in groundwater level of 0.12 m/yr – 8.76 m/yr in the shallow aquifer layer, while for the depressed aquifer experienced a decrease in groundwater level of 1.44 m/yr – 12.48 m/yr, this occurred from 1994 to 1995 (Wibowo, 2005).

The amount of groundwater level declines and the amount of groundwater flow in the aquifer layer can be seen in the pump test well. In this research, the Jacob Method will be used to determine the amount of groundwater reserves in the aquifer layer. This aims to find out how to overcome and reduce the decline in groundwater levels. This research is located in Bandung City, precisely in the Cibeureum Formation, Bandung-Soreang Groundwater Basin (CAT), Bandung Municipality, West Java Province. The basin has an area of 1716 km^2 (**Figure 1**).

2. Regional Geology

The Bandung–Soreang Groundwater Basin research area is part of the Bandung region. This area is surrounded by natural features, including volcanoes, mountains, and hills. As a result, volcanic rocks are commonly found in this area. The volcanoes in the Bandung region are generally of Quaternary age. This area is rich in volcanic products,

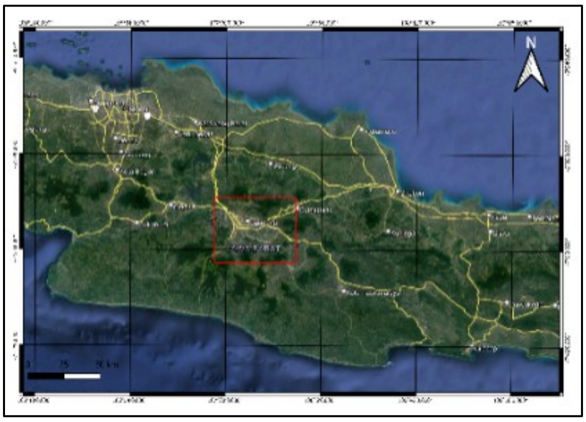

Fig 1. Location of research area

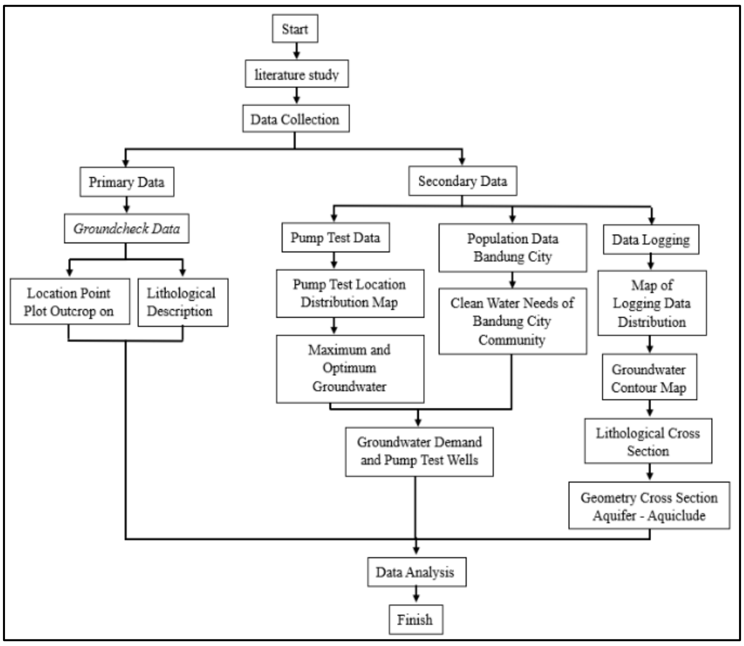

Fig 2. Research workflow

including alluvial deposits and young volcanic rocks. The Bandung-Soreang Groundwater Basin is classified as a volcanic environment (Lesmana et al., 2021). The Bandung-Soreang Groundwater Basin is located in the Bandung Zone, which has experienced significant depression, resulting in the Bandung region being surrounded by mountains, active volcanoes, and ancient volcanoes (Ikhram et al., 2021). This zone borders the Bogor Zone to the north and the Southern Mountains on the northern slope (Tohari et al., 2015).

The geological structure of the Bandung-Soreang Groundwater Basin, located in the Bandung Region of West Java Province, was formed as a result of tectonic plate activity, specifically the collision between the Indian-Australian Plate and the Eurasian Plate. Additionally, this tectonic activity has led to the formation of several geological structures in the Bandung Region, West Java, such as faults, trenches, non-volcanic arcs, forearcs, magmatic zones, back-arcs, and the Sunda Shelf (Katili, 1975). In the Bandung region of West Java, there are three active faults: the Cimandiri Fault, the Baribis Fault, and the Lembang Fault. The Cimandiri Fault is the oldest in the Bandung region, dating back to the Cretaceous period, with a fault movement direction parallel to the rock strata, namely northeast-southwest. The Baribis Fault is the main fault located in the northern part of West Java. This fault has a movement direction of Northwest–Southeast. The Lembang Fault is also located in the northern part of Bandung, where it extends for 30 km through the Bandung Soreang Groundwater Basin.

3. Data and Methods

In this research, two types of data were used, namely primary and secondary data. Primary data is obtained based on direct inspection in the field. This data is obtained by describing rocks and outcrops directly in the field. Secondary data used in this research is divided into several types, namely pump test well data and logging data obtained from the Office of the Ministry of Energy and Mineral Resources (ESDM), data on the population of Bandung City obtained from the Bandung City Statistics Agency website, and Digital Elevation Model (DEM) data obtained from the DEMNAS website of Tanah Air Indonesia.

Figure 2 shows the research workflow. The method used in this study is the Jacob Method. This method is used to analyze pump test data in the field (Sikdar, P.K., 2019). This method is also often referred to as a time-influenced straight-line method, in which the rate of groundwater level decline is directly proportional to time, so that the value of groundwater level decline is obtained (Charly et al., 2017). Based on this, the hydraulic properties of the aquifer layer will be known, namely hydraulic conductivity, transmissivity, and storativity. Pump-test well data obtained in the field will later be processed using this method to get maximum and optimum groundwater discharge values.

Maximum groundwater discharge $Q_{\max}$ is defined as the maximum rate at which groundwater can flow to the ground surface (Kruseman & Ridder, 1994), as described in the following equation:

$$Q_{\max} = 2\pi r_e b \sqrt{\frac{K}{15}} \quad (1)$$

where $Q_{\max}$ is the maximum groundwater discharge rate (m^3/s), r_e is the effective radius of the well (m), b is the saturated thickness of the aquifer (m), and K is the hydraulic conductivity of the aquifer material (m/s).

Optimum groundwater flow Q_{opt} is defined as the amount of groundwater flow that can be utilized or extracted from the aquifer layer.

$$Q_{\text{opt}} = 0.65 \times Q_{\max} \quad (2)$$

4. Results and Discussion

4.1 Geology of Research Area

The geology of the research area can be known directly in the field in order to obtain information such as lithology, morphology, geological structure, and geological conditions of the research area. In this research, direct surveys have been carried out at three different locations in the research area (**Figure 3**).

The first site (STA01) is a location in the Dago area, Coblong District, Bandung City. This location is at coordinates 107.613868 and -6.867716. In this area, the lithology found is volcanic breccia rock (**Figure 4**). The second location (STA02) is in Ciumbuheluit, Cidadap District, Bandung City. The coordinates of this location are 107.609829 and -6.874454. At this location, volcanic breccia rocks can be found. The third location (STA03) is around the tourist site of Bandung Zoo, Coblong District, Bandung City, at coordinates 107.605993 and -6.891986. Tuffaceous silt lithology can be found at this location.

4.2 Analysis of Groundwater Flow Direction

The topographic shape of an area will affect the direction of river flow in the area. The Bandung-Soreang Groundwater Basin has a relatively North-South and South-North groundwater flow pattern, where groundwater will accumulate in the central part of the region, which tends to have a sloping topographic shape (**Figure 5**). Meanwhile, the northern and southern parts of the basin consist of mountains and volcanoes, so the northern and southern parts tend to have steep topography

4.3 Aquifer - Aquiclude Geometry Analysis

The depth and thickness of the Cibeureum Formation aquifer layer can be determined in two ways. The first is by performing lithological correlation based on logging data. This correlation is done to obtain information about the

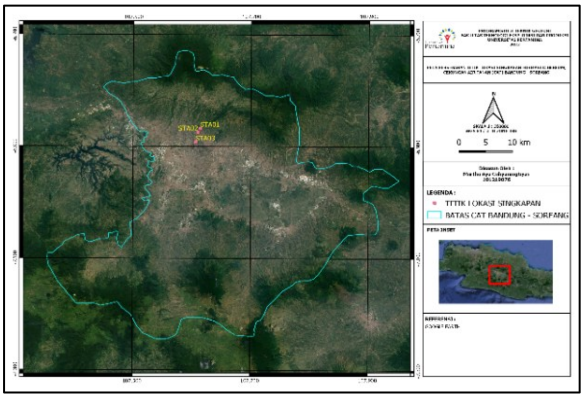

Fig 3. Location map of the outcrop point of the research area


Fig 4. Volcanic Breccia (SAT01)

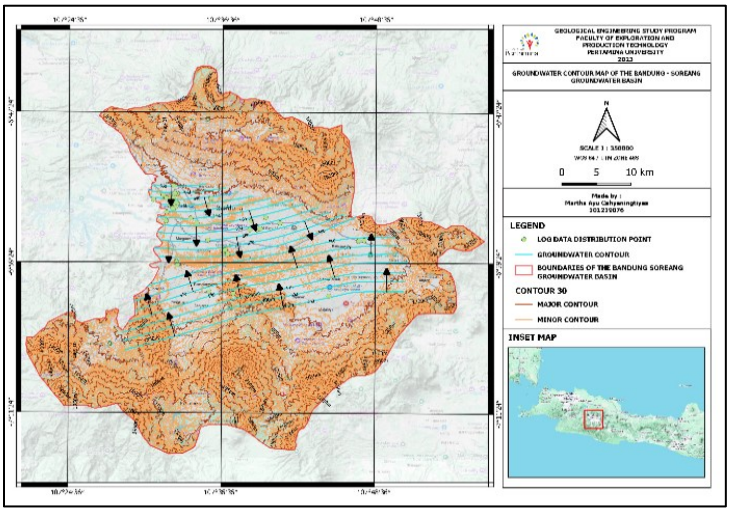

Fig 5. Groundwater Flow Contour Map of Bandung - Soreang Groundwater Basin

subsurface conditions, such as rock lithology, that have the potential to become an aquifer layer. Rocks that have the potential to become aquifer layers are rocks that have low resistivity values (Nadhowi et al., 2022). The second way to determine the depth and thickness of the aquifer layer is to make a cross-section of the aquifer geometry. Geometry based on logging data and pumping test well data. Based on this, a grouping of rock layers can be used as an aquifer and aquiclude.

At the research site, Cibeureum Formation, Bandung - Soreang Groundwater Basin, there are three cross-section lines of aquifer-aquiclude geometry: cross-section lines A-B, C-D, and E-F (**Figure 6**). Logging data and pump test well data are located around each of these cross-section lines have a very close relationship in determining the depth point of the aquifer layer, the thickness of the aquifer layer, and the amount of groundwater discharge in the aquifer layer. The thickness of the aquifer layer will affect the thickness of the pump test well screen, where, in general, the thickness of the aquifer layer will be thicker than the thickness of the pump test well screen. The thickness of the pump test well screen will affect the amount of groundwater discharge that the pump test well can deliver to the surface. The thickness of the pump test well screen, which is designed to be smaller than the thickness of the aquifer layer, aims to prevent excessive groundwater extraction in the aquifer layer.

North-South Cross Section (A-B). The correlation of the aquifer geometry cross-section line A extends from the North-South direction from Cimahi to Banjaran. This cross-section line consists of several logging data namely M9, M39, M17, M21, M19, M30, M35, and M18, and two pumping test well data namely SL10 and SL09 (**Figure 7**). The groundwater flow pattern in this section line tends to be in the North-South and South-North directions. This is influenced by the height of the water table in each aquifer layer. The different groundwater levels are caused by the amount of groundwater withdrawal in each area. Where the greater the groundwater withdrawal in the area, the lower the groundwater level in the area. This can later have a negative impact on the people in the area such as land subsidence to the exhaustion of clean water reserves. One of the efforts to reduce land subsidence is to use PDAM water as a source of clean water.

North-South Cross Section (C-D). The geometry cross-section line of the C- D aquifer extends from the North-South direction from South Cimahi to Majalaya. This section line comprises several logging data, namely M38, M43, M26, and M4, and pump test well data, namely SL10, SL04, SL01, SL06, SL03, and SL09 (**Figure 8**). The groundwater flow pattern in this section line is North-South and South-North. Groundwater flow in this cross-section line will accumulate in areas that have sloping topographic contours such as Cimahi with Cibereum and Turangga with Buahbatu (**Figure 9**). The low groundwater level in some areas can adversely impact the community such as land subsidence and depletion of clean water reserves. This can be mitigated by constructing recharge wells to restore groundwater levels.

West-East Cross Section (E-F). The aquiclude aquifer geometry cross section line (E-F) extends from the West - East from Margaasih to Cicalengka. This cross-section line

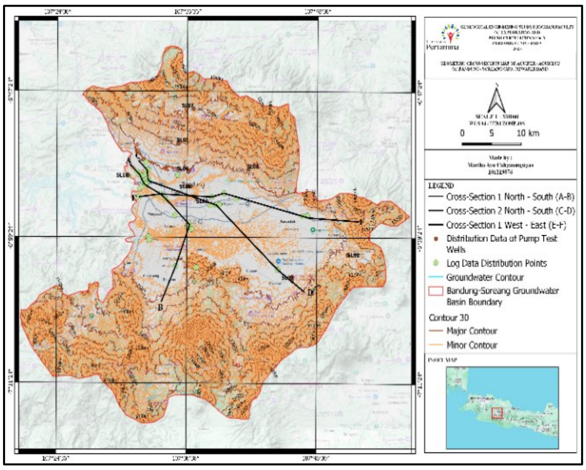

Fig 6. Aquifer Geometry Cross Section Map of Bandung-Soreang Groundwater Basin

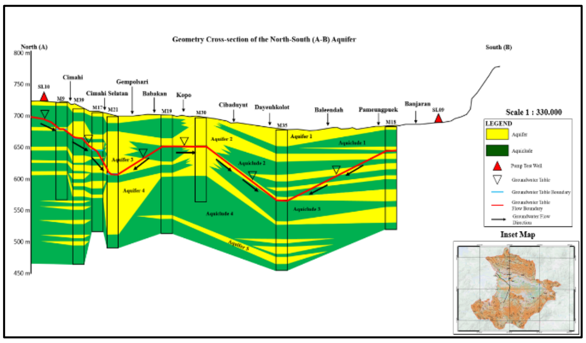

Fig 7. North-South Cross Section Correlation (A-B)

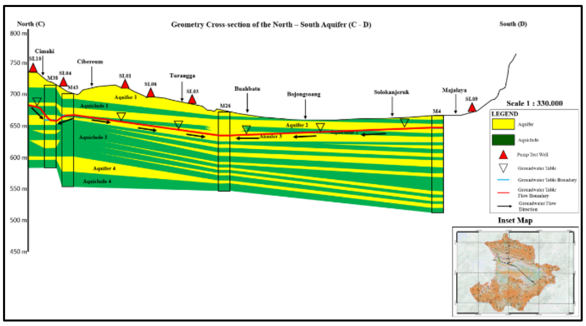

Fig 8. North-South Cross Section Correlation (C-D)

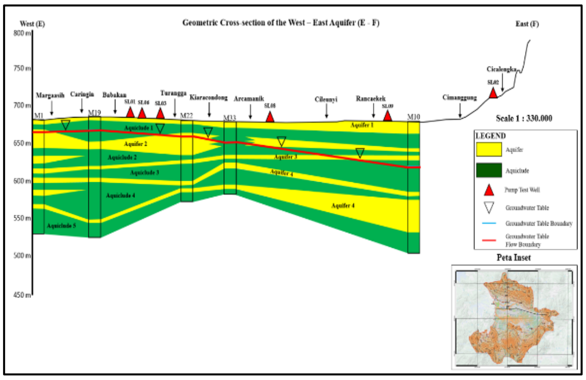

Fig 9. West-East Cross Section Correlation (E-F)

consists of several logging data namely M1, M19, M22, M33, and M10, and several pump test well data namely SL01, SL06, SL03, SL08, SL09, and SL02 (**Figure 9**). Based on the cross-sectional line drawing, it can be seen that around the area of Rancaekek and Cimanggung, there has been a large amount of groundwater withdrawal. This is indicated by the lowest groundwater level in the area (M10) compared to the groundwater level in other areas. This decrease in groundwater level can cause the community to lack clean water, so other alternatives are needed to reduce groundwater extraction, such as using lake water and PDAM water. In addition, the construction of recharge wells or infiltration wells in areas with low groundwater levels is also one of the ways to reduce groundwater extraction areas that have low groundwater levels, and it is also an effort to restore groundwater levels in these areas.

The thickness of the aquifer layer and pump test wells located on each line of the cross-sectional geometry of aquifers A-B, C-D, and E-F can be seen in the table below (**Table 1**). Each aquifer layer in the logging data has a different thickness. Based on the table below (**Table 1**), it is known that the aquifer layer has a greater thickness than the pump test well screen. Then, the pump test well screen. The thickness of the pump test well screen is made smaller compared to the thickness of the aquifer layer, which is intended so that groundwater extraction in the aquifer layer does not damage conservation aquifer layer does not damage groundwater conservation. In the table below (**Table 1**), there is an aquifer layer that is smaller than the thickness of the pump test well screen, namely in the M33 logging data, where this data has an aquifer layer thickness of 14m, while the pump test well screen has a thickness of 20m. This shows that groundwater withdrawal in the aquifer layer of the M33 logging data is smaller than the thickness of the pump test well screen. This shows that groundwater extraction around this logging data has damaged groundwater conservation in the area.

4.4 Groundwater Flow Discharge Analysis Using Jacob's Method

In this research, namely in the confined aquifer, the Cibereum Formation, the Bandung -Soreang Groundwater Basin has ten pump test wells locations with twelve pump test wells spread across the research area. The amount of groundwater discharges each pump test well can extract differs. Where to determine the maximum groundwater discharge ($Q_{\max}$) and optimal groundwater discharge (Q_{opt}) from each aquifer layer it is calculated using the Jacob Method while determining the maximum groundwater discharge ($Q_{\max}$) and optimal groundwater discharge (Q_{opt}) from the confined aquifer, Cibeureum Formation, Bandung – Soreang Groundwater Basin is by adding up all the maximum ($Q_{\max}$) and optimum (Q_{opt}) groundwater discharge from each pump test well.

Table 1. Aquifer layer thickness in each logging data area

Geometry Name	Data Logging Code	Pump Test Well Code	Aquifer Layer Thickness (m)	Thickness of Pump Test Well Screen (m)
Cross-section of the North-South (A-B) Aquifer	M9	SL10	20	20
	M39	SL10	88	20
	M17	SL10	51	20
	M21	SL10	150	20
	M18	SL09	75	40
Cross-section of the North-South (C-D) Aquifer	M38	SL10	43	20
	M43	SL10	41	20
	M26	SL03	62	24
	M4	SL09	70	40
Cross-section of the West-East (E-F) Aquifer	M1	SL06	62	20
	M19	SL06	25	20
	M22	SL03	42	24
	M33	SL08	14	20
	M10	SL09	56	40

Table 2. Large groundwater discharge of the Bandung - Soreang groundwater basin

No	Well Location Name	Well Name	Aquifer Thickness (m)	Δs (m)	T (m^2/day)	T (m^2/hour)	K (m/hour)	Qs (L/sec/m)	Qmax (m^3/sec)	Qmax (L/sec)	Qopt (L/sec)	Qopt (m^3/hour)
1	SL01	MA-01	68	9.34	5.31	0.22	0.003	0.33	0.0107	10.66	6.93	599
2	SL02	MA-01	30	27.41	3.11	0.12	0.004	0.20	0.0061	6.10	3.96	342
		MA-02	21	25.64	3.30	0.14	0.007	0.21	0.0052	5.25	3.41	295
3	SL03	MA-01	24	6.04	1.36	0.06	0.002	0.09	0.0024	2.40	1.56	135
4	SL04	MA-01	68	6.41	8.42	0.35	0.005	0.53	0.0117	11.73	7.63	659
5	SL05	MA-01	16	2.98	5.89	0.25	0.015	0.37	0.0054	5.44	3.54	306
		MA-02	16	6.97	2.84	0.12	0.007	0.18	0.0038	3.78	2.45	212
6	SL06	MA-01	20	8.65	8.10	0.34	0.017	0.51	0.0071	7.13	4.64	401
7	SL07	MA-01	8	1.68	7.91	0.33	0.041	0.50	0.0033	3.34	2.17	188
8	SL08	MA-01	20	4.22	12.45	0.52	0.026	0.79	0.0077	7.74	5.03	435
9	SL09	MA-01	40	18.75	0.50	0.02	0.001	0.03	0.0019	1.88	1.22	105
10	SL10	MA-01	20	78.45	0.52	0.02	0.001	0.03	0.0020	2.04	1.33	115
	Total Groundwater Rate								0.0675	67.50	43.87	3791
	Average Groundwater Rate										3.66	

Table 3. Clean Water Requirements and Pump Test Wells

Parameter	Value
Population of Bandung City	2,530,448
Clean water needs per person (L/day/person)	120
Clean water from PDAM Tirtawening (m^3/day)	741,988.84
Bandung community water needs before using PDAM (m^3/day)	3,036,654
Bandung community water needs after using PDAM (m^3/day)	2,294,665
Number of pump test wells required before using PDAM	9,614
Number of pump test wells required after using PDAM	7,265
Average output (m^3/day)	315.88

The maximum (Q_{max}) and optimum (Q_{opt}) groundwater discharge from each pump test well can be seen in the following table (**Table 2**). Based on this table, the maximum groundwater discharge (Q_{max}) from the Bandung—Soreang Groundwater Basin is 67.50 L/s, or around 0.0675 m^3/s, and the optimum groundwater discharge is 43.87 L/s, or around 3,791 m^3/day (**Table 2**).

4.5 Analysis of Groundwater Needs

The significant Population growth of Bandung City has resulted in this region requiring large amounts of clean water. The need for clean water is not comparable to groundwater availability in the Bandung–Soreang Groundwater Basin. Extraction of groundwater in large quantities decreases groundwater levels, which will also impact land subsidence. So, to reduce the potential for groundwater levels to decline, adjustments are needed to balance the need for clean water and groundwater availability in the Bandung–Soreang Groundwater Basin. This aims to determine whether the groundwater reserves in the Bandung–Soreang Groundwater Basin can meet the clean water needs of the Bandung Community or not and to prevent excessive groundwater extraction. Based on the Bandung City Central Statistics Agency, the Population of Bandung City has reached 2,530,448 people (Bandung City Central Statistics Agency, 2022), with the amount of clean water needed by the community amounting to 3,036,654 m^3/day (**Table 3**). Meanwhile, the groundwater reserves in the Bandung–Soreang Groundwater Basin are 67.50 L/sec. This shows that the large groundwater reserves in the basin are unable to meet the clean water needs of the Bandung community. So that groundwater originating from the confined aquifer, Cibeureum Formation, Bandung – Soreang Groundwater Basin can meet the daily clean water needs of the Bandung community, 9614 pump test wells are needed spread across this basin.

Tirtawening Regional Drinking Water Company (PDAM) is one of the PDAMs in the Bandung area. This PDAM supplies clean water to the people of Bandung, amounting to 22,568,852 m^3/month or 741,989 m^3/day. Using PDAM water as a source of clean water in addition to using groundwater will certainly reduce groundwater withdrawal in the confined aquifer of the Cibeureum Formation, Bandung – Soreang Groundwater Basin. So, the need for groundwater by the people of Bandung is reduced to 2,294,664 m^3/day, and the size of the pump test wells needed is also reduced to 7265.

5. Conclusion

The maximum potential groundwater discharge from the Bandung – Soreang Groundwater Basin is 0.0675 m^3/s or around 67.50 L/s with an optimum groundwater discharge of 3,791 m^3/s or around 43.87 L/s.

The amount of clean water needed by the Bandung community in one day reaches 303,653,760 L/day or around 3,036,654 m^3/day, which is very inconsistent with the size of the available groundwater reserves. This shows that the significant groundwater potential in the Bandung–Soreang Groundwater Basin cannot meet the clean water needs of the Bandung community.

Land subsidence can be reduced by limiting community groundwater extraction. Meanwhile, to meet clean water needs, apart from using groundwater as a source of clean water, people can also use clean water from PDAM and river water (if the river water is not polluted). Using this water can reduce the decline in groundwater levels, reducing land subsidence.

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