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RESEARCH ARTICLE

Unregistered Artesian Well Management in Pasuruan, Indonesia: an Attempt to Protect Groundwater Resources

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Abstract The number of unregistered artesian wells increases every year in the northern slopes of Bromo Volcano, Pasuruan. Artesian wells are used for domestic needs and agricultural irrigation but are not followed by environmentally sound groundwater use. The purpose of this study is to assess the potential for groundwater, groundwater use, wasted groundwater, and recommendations for groundwater management. The groundwater potential was obtained by measuring the depth of the groundwater table, piezometric surface of artesian wells, and geoelectrical data. Water uses were obtained from calculations based on the Indonesian National Standard. The amount of wasted groundwater was obtained by comparing the groundwater potentials, groundwater uses, and groundwater discharges from unregistered artesian wells. Water transfer was assessed by selecting unregistered artesian wells with discharges able to fulfill the water demands of each village. Groundwater in the Sub-Districts of Gondang Wetan and Winongan has high potential consisting of 1 unconfined aquifer group and two confined aquifer groups. Gondang Wetan and Winongan Sub-Districts are characterized as wasting groundwater potential through unregistered artesian wells. The discharge flow of unregistered artesian wells exceeds the water needs (>100%) in Winongan and Gondang Wetan Sub-Districts. Groundwater can be managed by water transfer, closure of artesian wells, and regulation of artesian wells use. Water can be transferred to areas not covered by Artesian wells in 20 villages. The number of artesian wells used for water transfer is 20 with a discharge of 5-20 liters/s.

1. Introduction

Deep Groundwater has been widely used as a main water source globally (Hebig et al., 2012; Msassuel et al., 2017; Habermehl, 2020; Hendrayana et al., 2021). One type of deep groundwater often used is water flowing from artesian wells. Artesian wells can be made by deep drilling until they penetrate confined aquifers. Water from artesian wells has several good characteristics; it is protected from contamination, especially that leaks from the ground surface (Cloutier et al., 2006; Yan et al., 2019). The water also has natural pressure to flow to the surface without being pumped (Shrestha et al., 2017; Velasco & Capilla, 2019). However, currently, the number of artesian wells is increasing; this lowers the groundwater level and reduces the availability of groundwater (Medellín-Azuara et al., 2015; Luo & Illman, 2016).

This problem also occurs in the northern slopes of Bromo Volcano in Pasuruan, especially in Gondang Wetan and Winongan Sub-Districts. The number of artesian wells in these Sub-Districts continues to increase every year. Without any permit and proper well construction, groundwater continuously goes to the wells to waste groundwater (Toulier et al., 2019). Many people use artesian wells because the area has limited surface water sources. Both Sub-Districts are classified as very dry based on the Standard Precipitation Index (SPI) (Khairani et al., 2018). Gondang Wetan and Winongan Sub-Districts are affected by the drought (Nahar, 2016). In addition, the two Sub-Districts do not have access to the Regional Drinking Water Company (PDAM) network. (Subekti, 2012). Although many have artesian wells in the two Sub-Districts, the water is not evenly distributed, so there are still dry areas.

It is necessary to study groundwater management in Gondang Wetan and Winongan Sub-Districts to achieve sustainable use of water resources. This study investigates the efficiency of groundwater use from artificial wells, so that groundwater is not wasted and can be distributed evenly in dry areas. This study was carried out by calculating community water use, groundwater potential, total artesian wells discharge, and groundwater use efficiency. The next target of this research is to recommend water transfer from

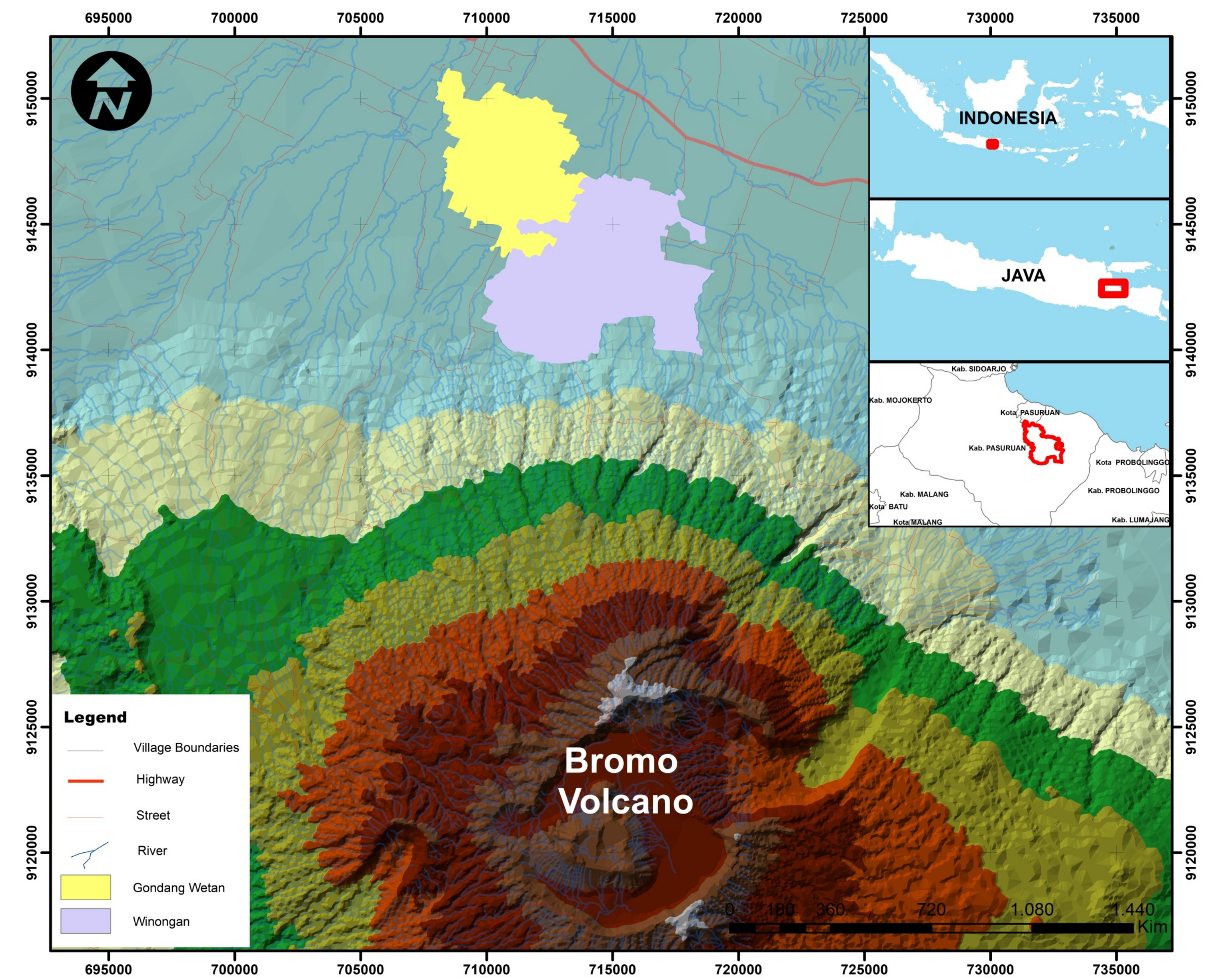

Figure 1. Study Area
(Basemap Source: Geospatial Information Agency(BIG), 2004)

artesian wells to dry areas in Winongan and Gondang Wetan Sub-Districts. Inefficient transfer of water from artesian wells is based on consideration of the discharge factor of each artesian well, the need for water, and the accessibility of the artesian wells from dry areas. This research is essential to conserve groundwater in Winongan and Gondang Sub-Districts and can be used as a pilot project to study water transfer for arid regions.

Gondang Wetan and Winongan Sub-Districts are located at the foot of the Bromo-Tengger Volcano with UTM coordinates 710000-720000 mU and 9140000-9150000 (Figure 1). The study area has an area of 69.87 km2. Rainfall in the study area ranges from 1,800-2,500 mm/year with an average temperature of 23-25°C (Husniah et al., 2009). Gondang Wetan and Winongan Sub-Districts have two geological units: Rabano Tuff (Qvtr) and Middle Quarter Ringgit Volcanic Rocks (Qpv (t))(Santosa and Suwarti, 1992). Gondang Wetan and Winongan Sub-Districts are divided into three aquifer system units: productive aquifer with flow through inter-grain spaces, high productive aquifer, and medium productive aquifer with flow through gaps inter-grain pores (Puspowardojo, 1984).

2.Methods

This study used primary data (from field measurements) and secondary data (Table 1). Field measurements resulted in a water table and piezometric surface. The number of measured shallow wells was 158. The 353 artesian wells were measured and observed. Geoelectric surveys were carried out at 82 points. The secondary data used in this study were the Geological Map of Malang Sheet (Santosa and Suwarti, 1992), Hydrogeological Map of Kediri Sheet (Puspowardojo, 1984), Land Use Map from the Geospatial Information Agency (BIG), and water use data (BPS, 2021).

Water table and piezometric surface data were processed using interpolation in ArcGIS 10.8. The selected interpolation method has the lowest RMSE error value (Ohmer et al., 2017). Water table and piezometric surface data were essential to calculate groundwater potential at factor i (Equation 1) (Todd and Mays, 2005). The analysis of geoelectrical data was used to interpret the distribution of rock layers horizontally and vertically, especially relating the nature of rocks to the water. The results of the stratigraphic interpretation were significant to calculate K value (Telford et al., 1990).

Q : K x i x A (1)

Q : groundwater discharge (m^3/day)

K : permeability coefficient (m/day)

i : hydraulic gradient

A : area of aquifer (m^2)

To analyze water use, we employed the number of populations, area of irrigated rice fields, number of livestock, number of office employees, number of school students, number of health facilities, number of places of worship, number of restaurants, and number of industrial employees. Water use was calculated according to the Indonesian National Standard (Table 2). The water use results were then compared with the groundwater potential to determine whether the groundwater balance of the study area was surplus or deficit (Hendrayana & Vicente, 2013; Hendrayana et al., 2020). In addition, a percentage of wasted groundwater was obtained from comparing the amount of water used with the total discharge of the artesian wells. Another percentage of wasted groundwater was also obtained by comparing the total discharge of the artesian wells with the amount of groundwater flow. The last stage was the buffering process of artesian wells with 400 m to obtain areas not covered by the artesian wells network. The unreachable areas need water transfer, so they are not dry. The water transfer process considered the location of the closest artesian wells and the water discharge that exceeded the water use. The analysis unit of this study is the village administration, both on the amount of groundwater flow, water use, wasted groundwater, and water transfer.

Table 1. Study Parameters

Parameters	Tools	Scales	Sources	Analysis
Water Table	GPS and Measuring Tape	1 : 100.000	Field Survey	Interpolation
Piezometric Surface	GPS and Measuring Tape	1 : 100.000	Field Survey and secondary data	Interpolation
Artesian Well Discharges	Pipe and Bucket (Volumetric Method)	1 : 100.000	Field Survey	Table and map
Statigraphy	Geoelectric VES (1D) and dipole-dipole (2D)	1 : 100.000	Field Survey	3D statigraphy model
Geology	Geology Map	1 : 100.000	Field Survey and Secondary Data	Geoelectric interpretation validation
Hydrogeology	Hydrogeology Map	1 : 250.000 with Modification	Secondary Data	Geoelectric interpretation validation
Borehole Data	Boreholes Report	1 : 100.000	Secondary Data	Geoelectric interpretation validation
Topography	Shape File	1 : 100.000	Secondary Data	Map
Water use	Statistic Data	1 : 100.000	Secondary Data	SNI 2015
Landuse	Shape File	1 : 25.000	Secondary Data	Water Transfer Map

Table 2. Estimated Regression Function Heteroscedasticity Model

Category	Standard	Category	Standard
Domestic	60 liters/day/person (rural residents)	Worship	3.000/ liters/ m^2
	120 liters/day/person (urban residents)	Hospital	3000/liters/day/unit
Livestock	6 liters/day (sheep and pork)	Office	10 liters/day/person
	40 liters/day (cow/buffalo)	Industry	10 liters/day/person
	0.6 liters/day (Poultry)	Restaurant	10 liters/day/chair
Agriculture	1 liters/second/ha	Education	10 liters/day/person

Source : (BSN, 2015 with modification)

3. Results and Discussion

The geoelectrical interpretation shows that the Gondang Wetan and Winongan Sub-Districts have four aquifer groups: aquifer 1, aquifer 2, aquifer 3, and aquifuge (Figure 3). Aquifer 1 is a free aquifer at 0-30 meters from the surface with alluvial deposits and tuff sandy clay materials. Aquifer 2 is a confined aquifer with tuff sandy clay materials at 50-80 meters. Aquifer 3 is a confined aquifer with gravelly sand materials at a depth of > 90 meters. Aquifuge is between aquifers 1, 2, and 3 with the materials of tuff clay. The results of the geoelectrical interpretation are following drill log data and geological maps. The top layer is predominantly pyroclastic deposits, tuff, and the lower layer is mostly medium or coarse volcanic sand (Santosa and Suwarti, 1992; Toulier et al., 2019).

Aquifer 1 is shallow groundwater with a water table ranging from 80 – 10 meters above sea level (masl) (Figure 4). Aquifer 1 has groundwater flowing from south to north. Aquifer 1 is measured from dug wells with depths of 10-30 meters. The water table mapping shows that the upstream has tight equipotential lines because they are close to the groundwater recharge area of the Bromo-Tengger Volcano. The equipotential lines are increasingly tenuous towards the north as the elevation declines and are an area for groundwater use. Aquifer 2 is a confined aquifer with a piezometric surface ranging from 60 to 22 masl. Aquifer 2 has groundwater flowing from south to north. Aquifer 2 was measured in dug wells 40-60 meters deep. The piezometric surface density of aquifer 2 is denser than that of water table aquifer 1, due to the difference in hydrostatic pressure in the two different types of aquifers. Aquifer 3 is also a confined aquifer with a piezometric surface ranging from 56 to 16 masl. Aquifer 3 has the same relative direction of groundwater flow as aquifers 1 and 2, from south to north. Aquifer 3 is measured from artesian wells 70-80 meters deep. The piezometric surface pattern of aquifer 3 is similar to aquifer 2 because it is a confined aquifer. Groundwater level, piezometric surface, and groundwater flow patterns are in accordance with groundwater conditions on the existing hydrogeological map. And the aquifers belong to the aquifers in medium and high productivity (Puspowardojo, 1984).

Based on the calculation, groundwater potential in Winongan Sub-District is 32,363,137 m3/year (Figure 5) with confined aquifers 1 and 2 greater than unconfined aquifer 1. The highest groundwater potential is in Kedungrejo Village with 3,487,351 m3/year, and the lowest is in Winongan Kidul Village with 659,497 m3/year. The discharge distribution for unconfined, confined 1, 2, and total discharge are predominantly distributed in the western part of Winongan Sub-District. The calculation of groundwater potential in Gondang Wetan Sub-District showed that it has a real potential of 20,831,097 m3/year groundwater (Figure 6), with potentials for confined aquifers 1 and 2 greater than unconfined aquifer 1. The highest groundwater potential is in Brambang Village with 2,011,673 m3 /year, and the lowest is in Sekarputih Village with 465,688 m3/year. The discharge distribution for unconfined, confined 1, 2, and total discharge is predominantly distributed in the western part of Gondang Wetan Sub-District.

The calculation of the total groundwater use in Winongan Sub-District shows that the annual total groundwater use is 2,267,400 m3 (table 3). The highest use is in Gading Village of 228,168 m3/year, and the lowest is in Sidepan Village of 64,934 m3/year. In all villages in Winongan Sub-District, the percentage of water use is below 30% and is classified as low and safe (Hendrayana & Vicente, 2013; Hendrayana et al., 2020). All villages in Winongan Sub-District have a surplus groundwater balance.

The total use of groundwater in Gondang Wetan Sub-District is 2,490,353 m3/year (table 4), with the highest in Karangsentul Village (329,661 m3/year) and the lowest in Kersikan Village (78,823 m3/year). In all villages in Gondang Wetan Sub-District, the percentage of water use is below 30%. The rate of water use is classified as low and safe (Hendrayana & Vicente, 2013; Hendrayana et al., 2020). All villages in Gondang Wetan Sub-District have a surplus groundwater balance.

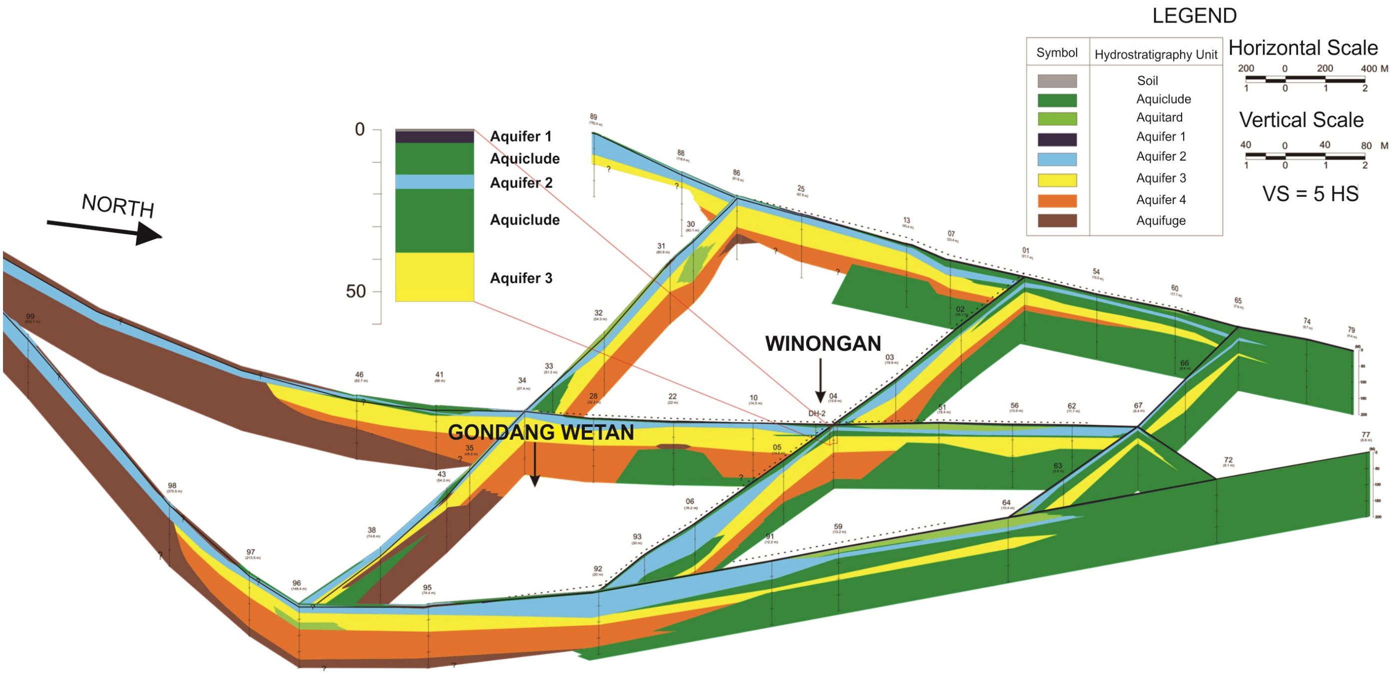

Figure 3. Hydro-stratigraphy Unit in Study Area (Hendrayana, et al., 2008)

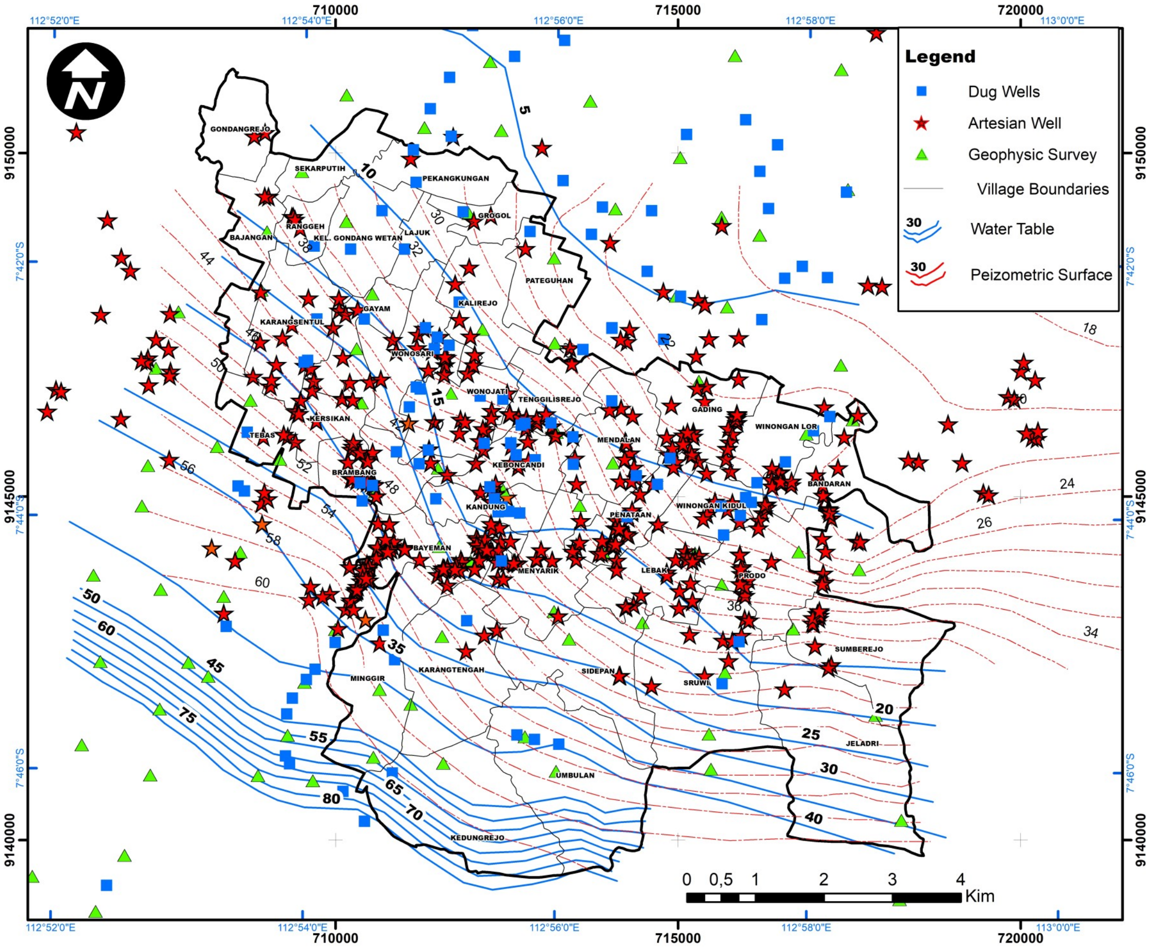

Figure 4. Water Table and Piezometric Surface in Study Area
(Basemap Source: Geospatial Information Agency (BIG), 2004)

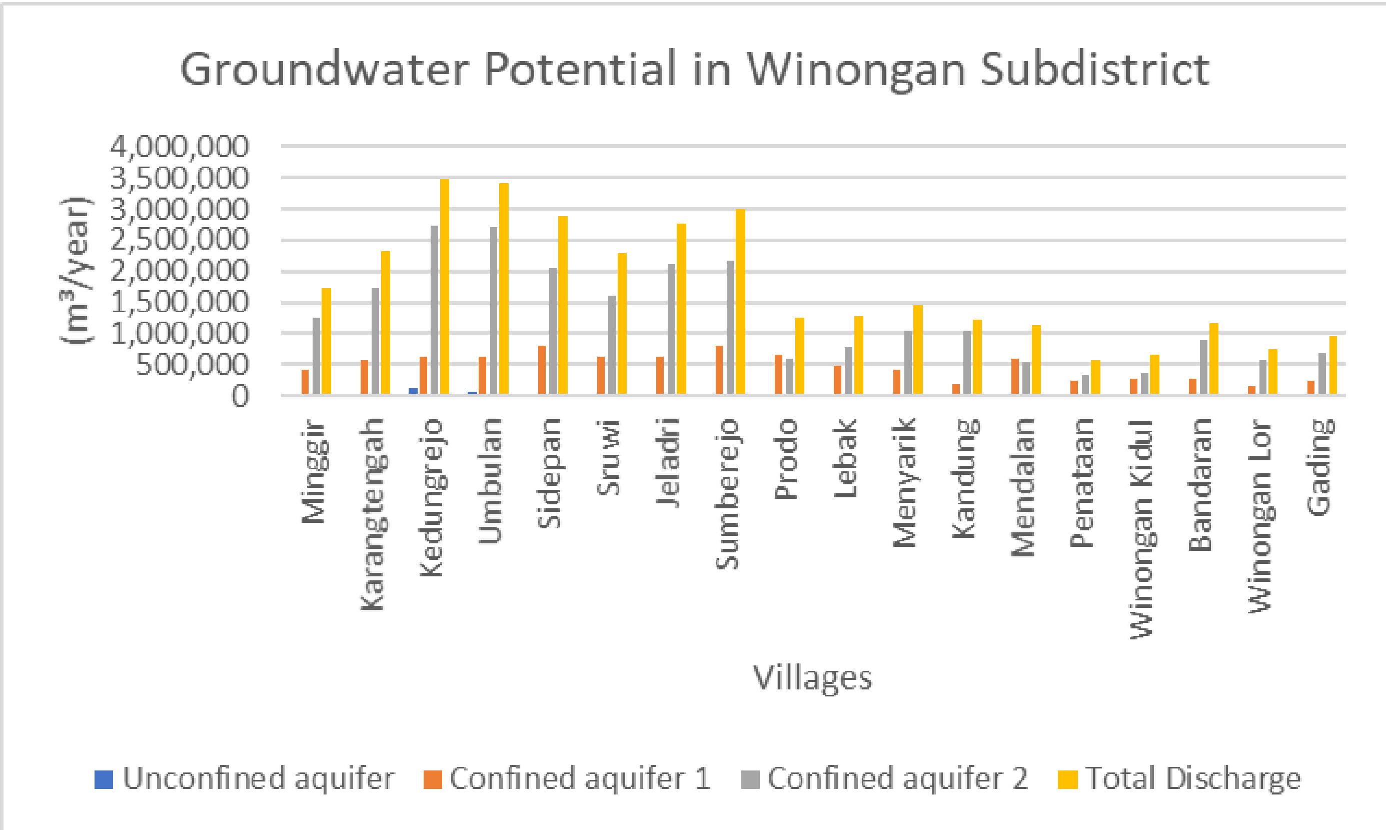

Figure 5. Calculation of Groundwater Potential in Winongan Sub-District

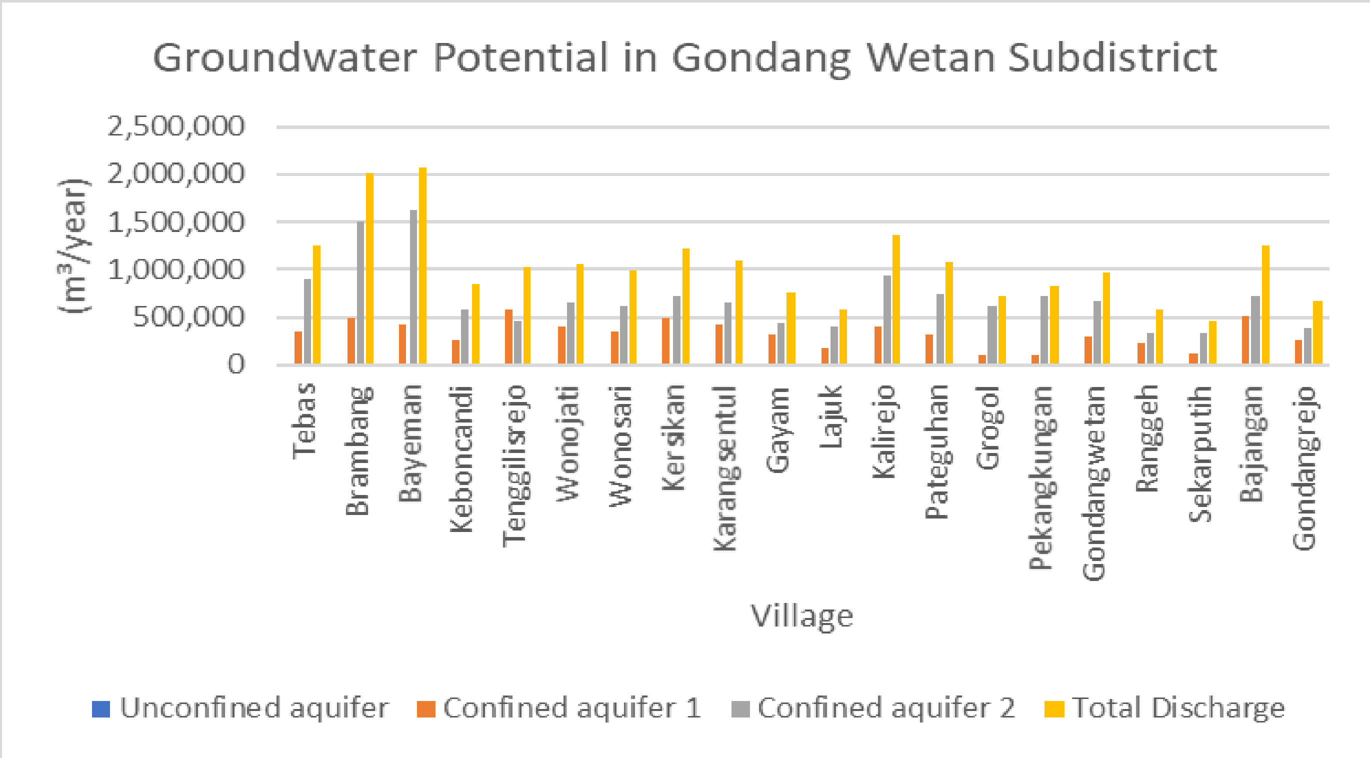

Figure 6. Calculation of Groundwater Potential in Gondang Wetan Sub-District

Table 3. Groundwater Use Rate in Winongan Sub-District

Village	Groundwater Discharge (m3/yr)	Total Groundwater Use (m3/yr)	Balance (m3/yr)	%
Minggir	1,720,235	124,123	1,596,112	7.22
Karangtengah	2,327,318	106,117	2,221,200	4.56
Kedungrejo	3,487,351	151,682	3,335,669	4.35
Umbulan	3,407,205	115,707	3,291,498	3.40
Sidepan	2,895,499	64,934	2,830,565	2.24
Sruwi	2,278,048	100,354	2,177,694	4.41
Jeladri	2,768,839	108,346	2,660,493	3.91
Sumberejo	2,995,601	175,858	2,819,742	5.87
Prodo	1,264,142	122,182	1,141,959	9.67
Lebak	1,275,134	104,358	1,170,776	8.18
Menyarik	1,472,277	139,316	1,332,961	9.46
Kandung	1,235,829	71,734	1,164,095	5.80
Mendalan	1,121,028	168,635	952,393	15.04
Penataan	582,231	139,181	443,049	23.90
Winongan Kidul	659,497	101,533	557,964	15.40
Bandaran	1,171,102	127,895	1,043,207	10.92
Winongan Lor	742,163	117,276	624,887	15.80
Gading	959,639	228,168	731,471	23.78
Total	32,363,137	2,267,400	30,095,737	-

Source: processing results (2021)

Table 4. Groundwater Use Rate in Gondang Wetan Sub-District

Village	Groundwater Discharge (m3/yr)	Total Groundwater Usage (m3/yr)	Groundwater Balance (m^3/yr)	%
Tebas	1,248,413	112,033	1,136,380	8.97
Brambang	2,011,673	88,287	1,923,386	4.39
Bayeman	2,070,081	168,878	1,901,203	8.16
Keboncandi	843,484	126,174	717,310	14.96
Tenggilisrejo	1,029,273	117,990	911,283	11.46
Wonojati	1,065,759	133,473	932,287	12.52
Wonosari	985,238	138,403	846,834	14.05
Kersikan	1,222,510	78,823	1,143,687	6.45
Karangsentul	1,086,260	329,661	756,599	30.35
Gayam	765,024	96,184	668,839	12.57
Lajuk	586,195	81,434	504,761	13.89
Kalirejo	1,358,152	133,907	1,224,245	9.86
Pateguhan	1,072,092	115,016	957,076	10.73
Grogol	725,568	79,901	645,667	11.01
Pekangkungan	829,151	99,661	729,489	12.02
Gondangwetan	969,508	136,004	833,504	14.03
Ranggeh	575,761	100,555	475,206	17.46
Sekarputih	465,688	106,406	359,282	22.85
Bajangan	1,255,878	102,598	1,153,280	8.17
Gondangrejo	665,389	144,964	520,425	21.79
Total	20,831,097	2,490,353	18,340,744	-

Source: processing results (2021)

Comparison of groundwater discharged from Artesian Wells (QAW) to Total Groundwater Flow (QG) in Winongan Sub-District shows that 7 villages have a value of more than 100% (Figure 7). The distribution pattern with more than 100% is in the north and the middle. The result indicates that a lot of groundwater in Winongan Sub-District is wasted. The wasted groundwater reduces the potential for groundwater in the surrounding villages and lowers piezometric surfaces. This result is also proportional to the rate of comparison of artesian wells discharge (QAW) to water use (QWU) in Winongan Sub-District, where the entire village is >100%. The distribution pattern with the percentage of >100% is in the middle and the south. This means that the water of the artesian well that comes out is more than the community needs.

Comparison of wasted groundwater from Artesian Wells (QAW) to Total Groundwater Flow (QG) in Gondang Wetan Sub-District shows that 8 villages have a value of more than 100% (Figure 7). The distribution pattern with more than 100% is in the middle and the north. This result indicates that a lot of groundwater in Gondang Wetan Sub-District is wasted. The wasted groundwater reduces groundwater potential in the surrounding villages and decreases piezometric surfaces. This result is also proportional to comparing artesian wells discharge (QAW) to water use (QWU) in Gondang Wetan Sub-District. Each of its 13 villages has a percentage of more than 100%.

Information: Total Groundwater Flow (QG), Artesian Well Discharge (QAW), Water Use (QWU), Percentage of Groundwater Wasted from Comparison of Artesian Wells with Groundwater Potential (QAW/QG), and Percentage of Groundwater Wasted from Comparison of Water Use with Artesian Wells (QAW/QWU).

The distribution pattern with more than 100% is in the middle and the south. This means that the water of the artesian well that comes out is more than the community needs. The results of the comparison of wasted groundwater from Artesian Wells (QAW) to groundwater potential (QG) and the comparison of artesian wells discharge (QAW) to water use (QWU) show that a lot of artesian wells water is wasted.

Groundwater from artesian wells in Winongan and Gondang Wetan Sub-Districts is wasted very significantly. This causes environmental impacts, one of which is the decreasing discharge in Umbulan Spring year to year and more artesian wells (Toulier et al., 2019). The same pattern happens in many parts of the world, such as in Queensland, Australia. An increase in the number of artesian wells from 1900-2015, followed by an increase in water use (Kent et al., 2019), has caused groundwater decline in this city. The same pattern also occurs in North Africa; the intensive use of artesian wells and artesian springs from 1940-2010 has declined groundwater levels in this area (Massuel et al., 2017). Ontario, Canada is also experiencing the same thing.

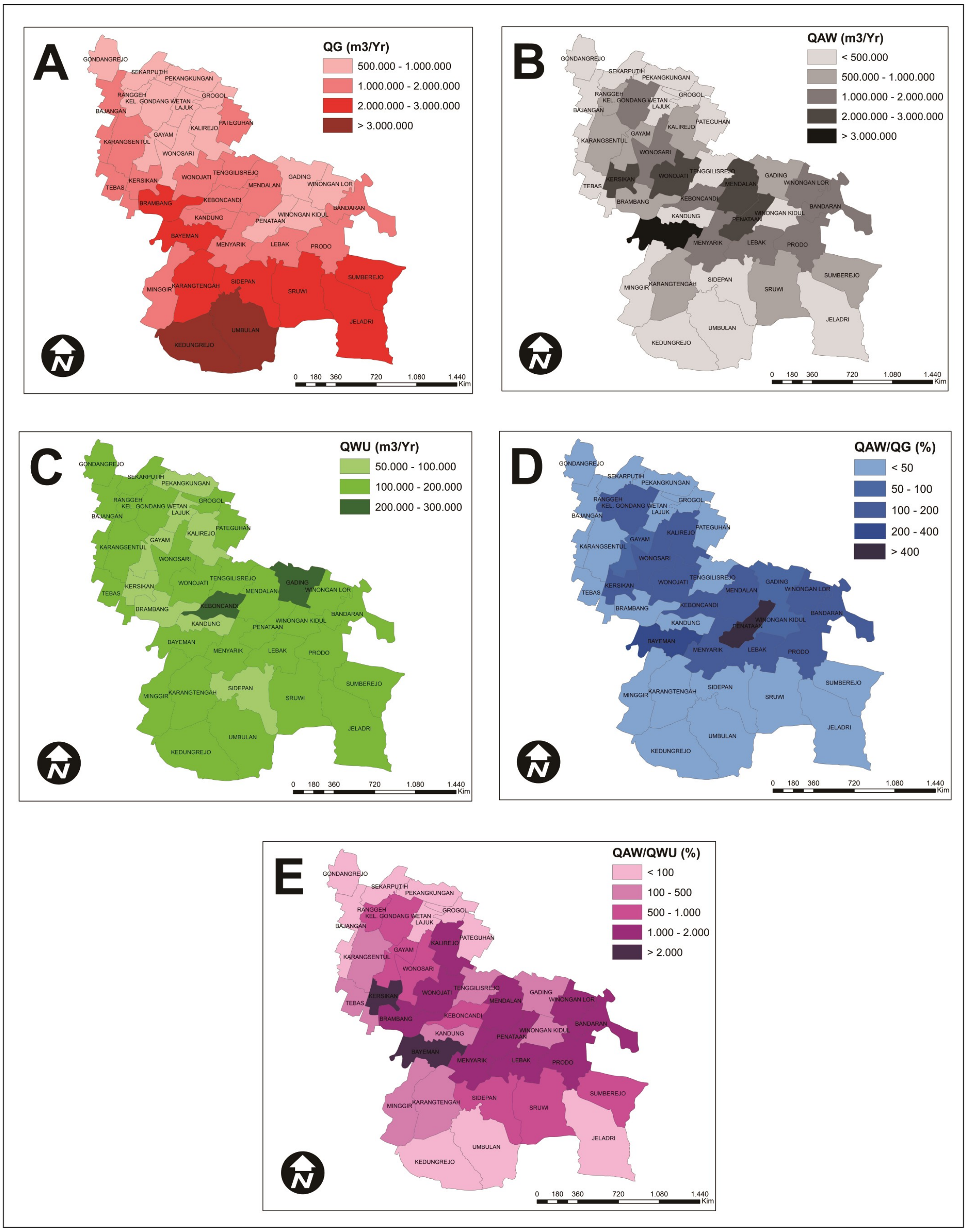

Figure 7. Comparison of QG, QAW, QWU, QAW/QG and QAW/QWU in Gondang Wetan Sub-District (Basemap Source: Geospatial Information Agency(BIG), 2004)

There is an increasing number of artesian wells in this city, followed by increasing groundwater extraction activities. This has declined the groundwater level in Ontario (Luo and Illman, 2016). On a bigger scale, such as in Australia's Great Artesian Basin, an increasing number of artesian wells and continuous groundwater extractions have depleted groundwater storage (Habermehl, 2019). This problem has caused several artesian wells and artesian springs to stop flowing.

Fortunately, in the research area, there are no artesian wells and artesian springs that have stopped flowing. Preventive measures can still be taken to prevent what has happened in Australia's Great Artesian Basin from occurring in the study area. In addition, all unregistered artesian wells are not adequately cased in the study area. If this is not taken seriously, the condition in Jordan can quickly happen in the study area. In Jordan, many artesian wells are not correctly completed with the proper casing. This problem has resulted in the groundwater mixing with salt from the salt lenses (Salameh and Tarawneh, 2017).

The artesian wells water is predominantly used for agriculture in paddy fields (Khasanah et al., 2021) (Figure 8). The artesian wells in rice fields are allowed to flow continuously to waste a lot of their water. A water transfer system can be created to allocate the water to villages not covered by the artesian wells network to reduce wasted artesian wells water. The water from the selected artesian wells can be transferred with discharges ranging from 5-20 liters/second (Table 5). The artesian wells can meet community water needs in areas not covered by the water network buffer (Figure 4). The number of villages not covered by the water network buffer is 20, and the required artesian well is 20.

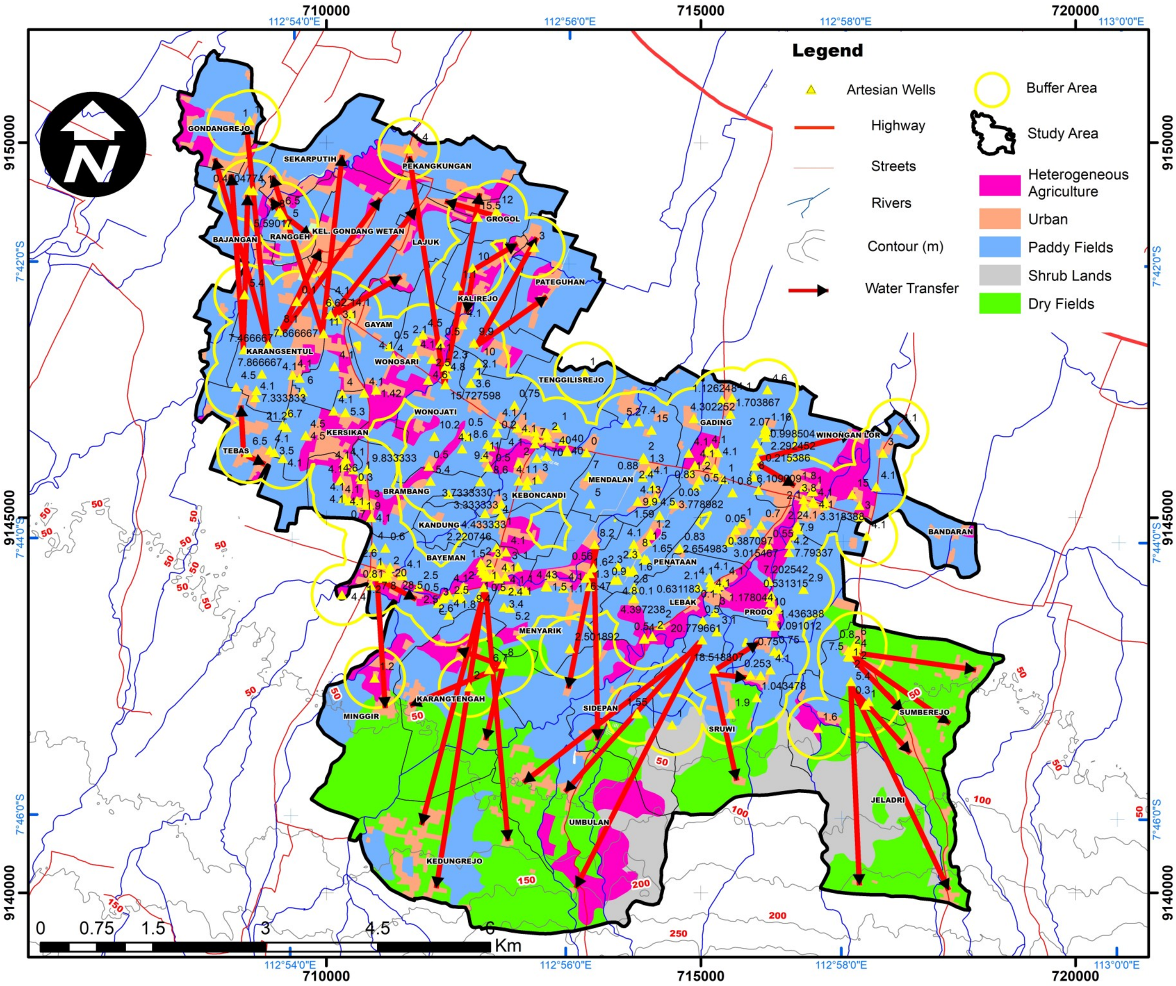

Figure 8. Water Transfer in Study Area
(Basemap Source: Geospatial Information Agency(BIG), 2004)

The artesian wells that can supply villages currently not covered by the water network buffer are evenly distributed in Winongan and Gondangwetan Sub-Districts. The distribution of the artesian wells is in the southern and northern areas. In the north part, in Gondang Wetan Sub-District, water can be distributed through pipes carried out by gravity, but water cannot be transferred by gravity in the north part of Winongan Sub-District. In the northern part of Winongan Sub-District, pumping is necessary because there are no springs or boreholes in the upper zone. The north zone of Winongan Sub-District is included in the low-medium groundwater productivity zone. Another option is dropping a tanker truck if developing a water pipe system is not evident in the northern part.

The smallest groundwater discharge amount of the artesian well is 157,680 m3/year, and the highest is 655,949 m3/year. While the lowest water use is 49,950 m3/year, and the highest is 135,276 m3/year. Umbulan, Kedungrejo, and Sidepan village water needs can also be met from the Umbulan Spring; However, a different artesian well is preferred because Umbulan Spring is already overburdened to meet the bulk water source of the City of Surabaya. Likewise, Banyu Biru Spring can fulfill water demands in Sumberejo and Jeladri villages; however, it is not used because it has been used for other purposes.

In addition, it is necessary to close artesian wells in agricultural areas that are rarely used. Besides, A system to open and close the artesian wells is often used, and the prohibition against constructing new artesian wells is also necessary. Artesian wells closure program is also implemented in Yemen to reduce the impact of excessive groundwater exploitation (T. Taher et al., 2012). Prohibitions and restrictions of constructions of new artesian wells have also been carried out in Iran using government regulations (Stevanovic & Iurkiewicz, 2009). This measure is possibly implemented in this research area where unregistered artesian wells increase yearly.

Another way to reduce groundwater wasting can be seen in the United States. Research for alternative water sources for irrigation demands has been carried out extensively in this country. Many farmers have switched from groundwater to surface water from extensive damming (Schlager, 2006). In the study area, irrigation from surface water is only found in Pateguhan Village, the lower part of Winongan Sub-District. In contrast, the upper parts of the Winongan and Gondang Wetan Sub-Districts are not supplied by surface water irrigation, so the farmers use artesian wells. By seeing what is implemented in the US, we can build or extend a surface water-sourced irrigation system to supply farming water needs in the study area. This measure is possibly reducing groundwater waste. Another effort can reduce the groundwater waste and add more artesian wells to mobilize local communities for more effective supervision (Taher, 2016). However, this measure is quite improbable to be

Table 5. Water Transfer Management in Study Area

Code	x	y	l/s	m³/year	Village with Drought	Water Need (m³/ years)	Sub-District
AW56	715172	9142987	18.5	583,416	Umbulan	89,005	
AW18	712358	9143054	8	252,288	Kedungrejo	116,678	
AW28	713462	9144199	6.5	204,984	Sidepan	49,950	
AW7	717065	9143335	6	189,216	Sumberejo	135,276	
AW9	717000	9142820	5.4	170,294	Jeladri	83,343	Winongan
AW15	712173	9142980	6.7	211,291	Karangtengah	81,629	
6	715016	9143375	20.8	655,949	Sruwi	77,195	
AW27	711747	9143939	6.9	217,598	Minggir	95,479	
15	715769	9145368	6.1	192,370	Winongan Lor	90,213	
AW38	708949	9145869	6.5	204,984	Tebas	86,179	
AW29	708902	9147243	7.5	236,520	Bajangan	78,921	
AW2	709387	9149073	6.5	204,984	Gondangrejo	111,511	
AW57	709365	9147498	8.1	255,442	Rangggeh	77,350	
AW4	709486	9148906	5	157,680	Sekarputih	81,851	
B16	709963	9147456	11	346,896	Gondangwetan	104,618	Gondang Wetan
AW31	712270	9149088	12	378,432	Pekakungan	76,663	
AW39	710054	9147710	6.6	208,138	Lajuk	62,641	
AW85	711971	9147332	9.9	312,206	Kalirejo	103,006	
AW30	711954	9148334	10	315,360	Grogol	61,463	
69	711588	9146774	15.7	495,115	Pateguhan	88,474	

Source: processing results (2021)

implemented in the study area as the whole community members use and dig more unregistered artesian wells for irrigation and domestic uses (Khasanah et al., 2021).

4. Conclusion

The aquifer in the study area has high groundwater potential and has three aquifer layers – 1 unconfined and two confined layers. Many unregistered artesian wells water in Winongan and Gondang Wetan Sub-Districts is wasted. All artesian wells in all villages in Winongan and Gondang Wetan Sub-Districts discharge water that exceeds village water needs (>100%). The distribution pattern with more than 100% is found in the central and southern parts of the Winongan and Gondang Wetan Sub-Districts. In addition, the distribution with the percentage of more than 100% of discharged groundwater from Artesian Wells to Total Groundwater Flow is in the central and northern parts of Winongan and Gondang Wetan Sub-Districts. Excessive artesian wells can be managed using water transfer for areas not covered by the artesian groundwater network, mainly in the central, southern, and northern parts of Winongan and Gondang Wetan Sub-Districts using groundwater more than 100%. A water transfer system through pipes using the gravity method can be applied in Gondang Wetan Sub-District. Still, for Winongan District, water transfer must be carried out using a pumping system or water dropping with tanker trucks. In addition, it is necessary to close artesian wells which are not frequently used in agricultural areas, implement an open and closing system of artesian wells, and prohibit the construction of new artesian wells.

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