Water management model in Bodri River Basin, Province of Central Java

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Abstract. Basically, in the tropics there are three sources of water, namely rainwater, surface water (river and lake water), and groundwater. From the existing water sources, almost all human daily water needs, such as drinking, bathing and washing, are sourced from groundwater. Uncontrolled extraction of groundwater can cause a variety of consequences on the environment, such as groundwater degradation, seawater intrusion and even land subsidence. Groundwater management efforts need to be carried out so that availability is maintained. The first step in this effort is to formulate a management model as a basis for determining policy. For this reason a dynamic modeling simulation is carried out using the Powersim 2.5c Program. The results showed that the priority of groundwater management efforts in the Bodri River Basin was to reduce groundwater use for the domestic sector which could be done through reducing the rate of population growth and saving groundwater use. Another result of this study is that the recharge of groundwater in the Bodri River Basin is relatively low, so efforts to find alternative sources of water other than groundwater need to be considered.

1. Introduction

Groundwater is part of the most important water resource [1]. According to Waikar and Nilawar [2], groundwater is also one of the natural resources that plays a very important role in supporting human health, economic growth and biodiversity.

It is not surprising that most people use groundwater as a source of water for everyday life. The main reason is because this water is clearer or better quality than river water or rainwater. Availability of groundwater is also more sustainable, unlike rainwater which is very seasonal [3].

The presence of groundwater is highly dependent on the geological conditions of an area [4][5]. Besides not all places have rock formations called aquifers, the system, its characteristics and productivity also vary, so naturally the distribution of groundwater on the earth's surface is also not always the same. There are areas with very high potential for groundwater, but there are also those with very low potential [6]. Apart from depending on the amount of rainfall and the type of rock, much of the minimum groundwater in an area can also be affected by the presence of vegetation and the slope of the slope. An area with dense vegetation and a flat topography has the potential to be able to absorb rainfall that falls on its surface as groundwater recharge [7][8]. In addition to these natural factors, the amount of groundwater availability also depends greatly on the rate of extraction, especially for various purposes of human life.

The Bodri River Basin is located between 6°51'20" to 7°18'6" South Latitude and 109°55'20" to 110°20'48" East Longitude. Looking at the topography, the Bodri river basin has a steep slope until the slope is indicated by variations in elevation from the coast to an altitude of 2,400 meters above sea level. The area of the Bodri river basin itself is approximately 649.68 km².
Downstream, the Bodri River Basin is composed of Holocene alluvium deposits. These deposits consist of clay and sand which have different thicknesses. On either side of the river, they have a thickness of 1 to 3 meters, consisting of gravel, sand, and silt. In coastal areas, there is a clay layer thicker than an area farther from the sea.

To the south of the alluvium deposits, there is the Damar Formation which is composed of types of Pleistocene sedimentary rocks such as sandstone tuff, conglomerates, volcanic breccias, and tuffs. Furthermore, there is a Miocene-Pliocene marine which consists of alternating claystones, marbles, sandstones, conglomerates, volcanic breccias, and limestones.

Upstream, there is the Panjatan Formation which is stratigraphically similar to the Marin Formation. This Miocene rock formation is composed of sandstones, breccias, tuffs, claystones, and lava flows. The Panjatan Formation is the main supplier of Bodri Delta sedimentary material, because it is a type of weathered sedimentary rock. The Bodri River flows result from erosion or sediment from upstream to downstream. If the river flow is high, the transported sediment will also be high. Sediments transported by the Bodri River flow, if they arrive at calm waters, will be deposited in the mouth of the river [9].

The sources of the Bodri River water come from Mount Perahu, Mount Sindoro, Mount Base, Mount Tengkik, and Mount Ungaran [10]. Bodri River itself includes perennials, namely rivers whose water flows throughout the year. In the rainy season, the discharge is high enough so that it often causes flooding in the downstream area (in the plains). The highest discharge generally occurs in January, while the lowest discharge generally occurs from June to October.

For irrigation purposes, water from rivers can be utilized. Juwero Dam was made to deflect the river as an irrigation source for agricultural areas around the Bodri River. However, during the dry season, irrigation water needs cannot be met from Bodri River.

Base on the availability of groundwater, the Bandung Directorate of Environmental Geology states that almost 67.59% of the Bodri River Basin has low groundwater content and rare groundwater areas. Besides that, in terms of water quality, not all of them have good quality. Saline groundwater is often found in coastal areas, with during the dry season, groundwater salinity is more pronounced.

Looking at this data, groundwater management in this river basin is a necessity that must be realized immediately. With good management, optimal hydrological conditions will be realized, namely obtaining water products according to their needs and requirements. With good groundwater management, it will also have a good impact on overall water management. One of the things that can be done in formulating groundwater management is to make a model and do a simulation model, as a basis for policy determination.

2. Method of research
2.1. Data Analysis
The availability of groundwater is determined by overlaying the Groundwater Basin Map with the Topographic Map and completing it with groundwater discharge data sourced from the Directorate of Geology. Potential evapotranspiration in the study area was calculated by the Thornthwaite Method, using the formula:

\[ E_{px} = 16\left(10^{T_f}/i\right)^2 \text{mm/month} \]  

(1)

with \( f \) is the latitude factor, \( T \) is the air temperature (°C), \( I \) is \( \sum_{i=1}^{12} i \) with \( i = (T/5)^{1.514} \) and \( a = 0.000000675 \times -0.000077 I^3 + 0.01792 I^2 + 0.49239 \)

Water requirements are calculated based on water demands for non-agricultural purposes, namely domestic, industrial, hotel and livestock. This is carried out because these sectors majority use of groundwater, while the agricultural sector uses river water. Water requirements for domestic are determined according to the population and the amount of water demand per capita per day. According to the results of a survey conducted by the Directorate of Drinking Water Development, Directorate General of Human Settlements, Ministry of Public Works and Public Housing, every Indonesian person consumes an average of 144 liters of water/person/day.

Water requirements for industry are calculated based on the number of industrial employees and consumption of water use per employee per day and water requirements for the industrial process itself [11]. Standard water requirements for medium industries are 20,000 liters/unit/day. Water requirements
for hotels are determined by the number of rooms and hotel occupancy rates. The standard water requirements for hotels are the same as water requirements per person per day, which is 144 liters/day/person.

Water requirements for livestock are calculated according to the number of livestock and water consumption per animal per day. The types of livestock that are calculated for their water needs are large livestock (buffalo-horse) of 40 liters/animal/day, medium livestock (sheep, pigs) of 5 liters/animal/day and small livestock (poultry) of 0.6 liters/animal/day [11].

Because the Bodri River Basin area does not always correspond to the administrative boundaries, the determination of water requirements in the Bodri River Basin is carried out through the multiplication of population, industry and livestock in the area that falls into the river basin area with the percentage of area within the river basin per area as a whole.

2.2. Dynamic Modeling
The stages in preparing the groundwater management model begin by determining the parameters that affect the availability of groundwater [12][13]. Conceptually, the availability of groundwater is determined by the rate of usage and the recharge rate. The usage rate includes the use of water for domestic, hotel, industrial and livestock demands while the recharge rate includes the addition of water from rain.

The next step is to process and sort primary data and secondary data that are related and considered important in influencing groundwater availability. The data will determine the rate of change in the amount of groundwater from year to year. Secondary data that is very important is data on population, number of livestock, number of industries and land use. The population, number of livestock, number of hotels and the number of industries influence the amount of groundwater used, while changes in land use play a role in determining the level of water infiltration or groundwater supply.

Based on the model obtained, simulations can be made for a variety of different circumstances with the help of the Powersim 2.5c program [14][15]. The models and simulations obtained can be used as basic data to determine the selection of priority groundwater management in the study area. The model obtained, then will also be used to carry out groundwater resource modeling activities in other regions, after the value of each model parameter is adjusted to the characteristics of the area.

3. Result and discussion
3.1. Water Availability and Demand
Based on figure 1, almost 50% of the Bodri River Basin area has low groundwater content (<0.1 liters/sec). In fact, around 114.28 km² or 17.59% of the Bodri River Basin is a rare area of groundwater. High groundwater potential (5-10 liters/sec), and very high (>10 liters/sec), only covers 35.96 km² or about 16.48% of the entire river basin area. Furthermore, based on figure 1, it can be determined that the availability of groundwater for the entire Bodri River Basin is 183,878,000 m³/year.
The main source of groundwater recharge is from rainfall [17-18]. Based on the analysis of monthly rainfall data from six rain stations in the Bodri River Basin, the amount of rainfall in the Bodri river basin is 2,464 mm/year. With a river basin area of 649.68 km², the amount of rainwater in the Bodri River Basin is 1,600,811,520 m³/year.

Rainwater that falls in the research area, not all infiltrate into the soil as groundwater recharge. Part of the rainfall will disappear into the atmosphere as evapotranspiration, some will become runoff and directly flow into the sea. Based on runoff discharge data obtained from river flow data in Juwero Dam, it is known that the average discharge of the Bodri River is 647,420,000 m³/year. Furthermore, by referring to the Laviati study [19], it was found that changes of runoff coefficient that caused by land conversion were 6.78%.

With an average annual temperature of 25.5°C, the results of the calculation of potential evapotranspiration indicate that:

\[ i = \left(\frac{25.5}{5}\right)^{1.514} = 11.78314567 \]
\[ I = 141.397748 \]
\[ a = 1.90823236 \times 1.53 + 2.53 + 0.49239 = 3.4009 \]
so that, \( E_{px} = 16 \times \left(10 \times \frac{25.5}{156.7800892}\right)^{3.4009} \text{mm/month} = 118.87 \text{mm/month}. \]

Because the Bodri River Basin is located at latitude 6°51'20" to 7°18'6" South Latitude, it refers to the mean table possible duration of the sun light in the Northern and Southern expressions in units of 30 days of 12 hours each, the f factor is 1.02208395, so, \( E_{p} = 1.02208395 \times 147.952761 = 121.5099 \text{mm/month}. \) With an area of 649.68 km², the volume of evapotranspiration in the study area was \( 0.121509919 \times 649680000 = 78611280 \text{m}^3/\text{month} \) or \( 943,335,360 \text{m}^3/\text{year}. \)

Referring to the Kendal Regency Population and Civil Registration Office, Temanggung Regency and Semarang Regency In 2018, the population of Kendal Regency was 976,752 people, Temanggung Regency 783,551 people and Semarang District 1,014,198 inhabitants, with a population growth of 1.49%. Taking into account the percentage of the regions in the three districts that enter the Bodri river basin, the population in the Bodri River Basin is 796,139 people. A similar method was used to determine the number of livestock, so that the number of large livestock (cattle, buffaloes and horses) was 25,100, medium livestock (goats, pigs) 116,806 and small animals (poultry) 5,060,538. For the
industrial and hospitality sector, there are 27 medium-sized industrial units and 22 hotels with 492 rooms.

With domestic water needs per person of 144 liters/day, the amount of water requirements for domestic demands is 41,845,066 m$^3$/year. For livestock, the amount of water demands for large livestock is 366,460 m$^3$/year, medium livestock 213,171 m$^3$/year and small livestock 1,108,257 m$^3$/year, while for industry 197,100 m$^3$/year. For hotels with the assumption that one room is for 2 people and the occupancy rate is 60%, the water needs are 41,375 m$^3$/year.

Based on these parameters, a groundwater management model is formulated shown in figure 2. From this model it can be determined the availability and needs of groundwater and its projections as shown in figure 3.

Looking at figure 3, it is seen that the biggest water demand in the Bodri River Basin is for domestic demands, followed by hotels, livestock and industry. At present the water needs for domestic reach 41,485,066 m$^3$/year, while for hotels 11,326,670 m$^3$/year, livestock 1,687,889 m$^3$/year and industry at 197,100 m$^3$/year. Projection in 2050, domestic water demands are 66,185,840 m$^3$/year or almost one and
a half times the current water demand. The growth of hotels is relatively constant, so are the number of
industries and livestock, so that the water demands are also relatively constant.

This high water demand has an impact on the availability of groundwater. At present the recharge of
groundwater from rainwater infiltration only reaches 10,056,160 m$^3$/year, while the total water demand
reaches 55,056,524 m$^3$/year. As a result, groundwater storage is only 138,877,636 m$^3$/year and continues
to decline to reach 114,530,109 m$^3$/year in 2050 (figure 4). In 2066 the demands for water will exceed
its groundwater stored, so that water table will begin to decline.

3.2. Groundwater Management Model By Reducing Population Increase

Looking at the results of the calculation of groundwater utilization, it is known that most of the water
utilization in the Bodri River Basin is for residents’ needs or for domestic demands. Similarly, the rate
of increase in water use is also in line with the rate of population growth. Based on this phenomenon,
the simulation of reducing water use will be emphasized in water use in this domestic sector.

There are two ways that can be done to reduce the amount of water utilization for domestic needs.
The first way is to reduce the population growth rate (for example with the family planning program or
population migration), while the second method is to reduce water use or save water.

In an effort to reduce water use by reducing the rate of population growth, a reduction of 25% was
carried out, so that if the previous population growth rate of 1.49% was changed to 1.12%, the simulation
results are shown in figure 5.

Looking at figure 5, it is known that by reducing the population growth rate, there is a very significant
phenomenon of decreasing water demand. If at present the water demand is 55,056,524 m$^3$/year, in 2050
it will only reach 72,318,979 m$^3$/year. Even up to 50 years later or in 2069, groundwater stored in
aquifers still exceed the total water requirements.
3.3. Groundwater Management Model With Water Savings

Groundwater management efforts by saving water are carried out by reducing the amount of water utilization per person per day by 25%, so that if previously the amount of water utilization was 144 liters/person/day to 108 liters/person/day. The simulation results are shown in figure 6.

![Figure 6. Groundwater management by saving water](image)

Looking at figure 6, it is known that by saving water, there is also a very significant phenomenon of decreasing water demand. If at present the water demand of the population is 44,674,882 m³/year, in 2050 it will only reach 62,983,513 m³/year. Even efforts to reduce the use of groundwater by conserving water are more effective than reducing the rate of population growth. In addition to saving water use, efforts to save groundwater use can also be done by increasing the production capacity of Regional Water Supply Companies (PDAM) by utilizing water sourced from rivers.

3.4. Groundwater Management Model By Maintaining Groundwater Recharge

One way to maintain groundwater recharge is to reduce the part of the rain that becomes runoff. The way to reduce runoff is to reduce the rate of land conversion into residential areas, because expansion of settlements will increase the runoff coefficient value.

For this reason, in this simulation the rate of conversion of land to settlements was reduced by 25%. The 25% value used as a basis for decreasing the rate of land conversion is the suitability of the simulation and the expected reality.

![Figure 7. Groundwater management by maintaining groundwater recharge](image)
Looking at figure 7, there is a slowdown in the rate of reduction in groundwater inflows that is not too significant, namely from 10,056,160 m$^3$/year to 10,056,158 m$^3$/year in 2050 (compared with the results without a decrease in settlement rate of 10,056,160 m$^3$/year to 10,056,158 m$^3$/year). Therefore, the efforts of groundwater management by maintaining groundwater recharge remain unable to avoid the occurrence of groundwater subsidence, because in 2066 the demand for water exceeded groundwater savings.

3.5. Groundwater Management Model By Reducing The Rate Of Population Growth, Saving Water And Decreasing The Rate Of Land Conversion

In this alternative groundwater management model, the parameter of population growth rate, the amount of water usage for domestic demands and the rate of conversion of land to settlements has been reduced by 25% (figure 8).

![Figure 8. Groundwater management by reduce the growth rate population, saving water and decreasing the rate of land conversion](image)

The simulation results show that there is a significant decrease in water requirements followed by constant groundwater recharge, so that the amount of stored groundwater at present is 149,338,902 m$^3$, which will only decrease to 135,290,274 m$^3$ in 2050. This can be compared if no treatment is carried out like this. Without management efforts, stored groundwater will drop to 114,530,109 m$^3$ in 2050, or a difference of 20,760,165 m$^3$.

4. Conclusion

From the simulations results it can be seen that the priority of groundwater management efforts in the Bodri River Basin is to reduce groundwater use for the domestic sector which can be done through reducing the rate of population growth and saving groundwater use. Another thing that needs attention is that the recharge of groundwater in the Bodri River Basin is relatively low, so efforts to find alternative sources of water other than groundwater need to be considered. Utilization of Sungai Bodri water as a source of water for Regional Water Supply Companies (PDAM) will be able to reduce the use of groundwater.

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