Utilization of groundwater for the bottled water industry by minimizing fixed and variable cost

Mirani Oktavia1, Amril Aman2 and Farida Hanum3

1Department of Industrial Engineering, Universitas Indraprasta PGRI, East Jakarta, 13760, Indonesia
2Department of Mathematics, IPB University, Bogor 16680, Indonesia

*E-mail: miranioktavia1510@gmail.com

Abstract. Water is a class of renewable natural resources. The main source of water is the rain that will always come during its season along the year. The water flows and moves (on the ground and underground) and then will stay at a retention (storage) area. There are two kinds of the retention that are natural retention (such as concave areas, lake, and low places) and artificial retention (such as saving water, well, basin, and watershed). The presence of the watershed in a region will affect the availability of water resources. A region which has watershed could use groundwater resources to fulfill the water requirements for household, agriculture, industries, tourism, and electric power station sectors. The bottled water industry (BWI) is normally built around a watershed area so that it can use the resource of water from the spring. But a problem would arise whenever the industry decided to increase the production capacity. This research addressed the problem of determining an optimal composition on water resources for the above-mentioned industry in order to minimizing the total cost. There are four alternatives to utilized groundwater around the watershed. Each water resource alternative has different cost characteristics. The cost can be classified to fixed and variable cost. This problem is modeled as a mixed integer linear programming problem and solved using a branch and bound method. This model is implemented at PT Tang Mas Cidahu in Kampung Bojong Pari Desa Jaya Bakti Kabupaten Sukabumi, West Java.

1. Introduction

Water is an important part of natural resources that have unique characteristics because water is renewable and dynamic. This means that the main source of water in the form of rain will always come by the time or season throughout the year. Water naturally flows from upstream to downstream, from higher areas to lower areas. Water flows not only in above but also in the bottom surface of the soil [6]. In the earth, water flows and moves in various ways and will stay for some time in retention. The existence of the watershed in a region greatly influence the wealth of available water resources [1]. Areas that have a watershed can utilize groundwater as much as possible to fulfill the water requirements of all sector. Each region that has a watershed can allocate their water not only to the main user sectors such as the household sector and the agricultural sector at large but also can also supply the requirements of the industrial sectors, the tourism sector, power plant, etc.

Practical lifestyles that are currently practiced by most of the urban community, one of which is marked by the increasing demand for bottled water. An area around the watershed has the potential to produce groundwater which is abundant as a source of clean water that meets the criteria to be used as the bottled water.
Four alternatives to utilized groundwater by the bottled water industry (BWI), that are plastering springs, making boreholes, stake wells, and dug wells. According to the Indonesian Dictionary, plastering is mixing cement, water, and sand used to attach bricks to become walls. The plastered springs is an activity to change the natural form of springs, such as increasing the surface of the springs, pumping, and flowing water according to their needs.

In this research, we made a formulation of groundwater utilization technique to anticipate water shortages that might occur if the demand for groundwater increases or if BWI plans to increase their production. The differences in utilization techniques inflect the variations and amount of costs that must be incurred. This utilization problem can be categorized as one of the cases of mixed integer programming in operations research, that has been applied in PT Tang Mas Cidahu Bojong Pari Jaya Bakti Cidahu Sukabumi.

2. Materials
To obtain groundwater, it requires at least three main components [3], such as:
- Making well or plastering
- Water pump
- Distribution network

2.1. Fixed costs for utilizing groundwater
Components that makeup fixed costs are drilling permits (IP) and taking permits (IPA). The following tables present IP and IPA from each source. This data we got from the Department of Mining in 2001 [2].

| Source | Drilling Permits | Plastering springs | Boreholes | Stake wells | Dug wells |
|--------|------------------|---------------------|-----------|-------------|-----------|
| 1      |                  | $1 \times 10^6$     | $1 \times 10^6$ | 400         | 200       |
| 2      |                  | $2 \times 10^6$     | $1,5 \times 10^6$ | 500         | 250       |
| 3      |                  | $2,5 \times 10^6$   | $2 \times 10^6$  | 600         | 300       |

| Source | Taking Permits | Plastering springs | Boreholes | Stake wells | Dug wells |
|--------|----------------|---------------------|-----------|-------------|-----------|
| 1      |                | $2 \times 10^6$     | $1,5 \times 10^6$ | 500         | 250       |
| 2      |                | $2,5 \times 10^6$   | $2 \times 10^6$  | 600         | 300       |
| 3      |                | $3 \times 10^6$     | $2,5 \times 10^6$ | 700         | 500       |

2.2. Variable costs for utilizing groundwater
Collection and utilization tax of groundwater is categorized as variable costs. This tax is collected by the local government for the collection and utilization of groundwater by BWI or other commercial industries.

The following are details of elements that affect the amount of tax that must be issued by BWI.

The basic price of water (HDA) is calculated by multiplying the water value factor (FNA) with the price of raw water (HAB). So it can be stated

\[ HDA = FNA \times HAB \]

Water acquisition value (NPA) is calculated based on the multiplication between HDA and retrieval volume (progressive volume). NPA can be stated

\[ NPA = HDA \times V \]
NPA = Progressive Volume × HAD

The collection and utilization tax of groundwater is calculated based on the multiplication of the NPA with the percentage of the tariff. So, the tax can be stated

\[ Tax = \text{NPA} \times \% \text{Tariff} \]

the percentage of the tariff is determined by the local Mining Agency or BPSDA.

3. Methods

BWI those are built around the watershed mostly do plastering of springs because they considered that is a very practical of groundwater utilization technique and judged that a source of water had been proven its clarity quality. However, problems may arise when the industry decides to increase the amount of production because the requirements of water will increase. Therefore, it is needed an alternative water source by making boreholes, stake wells, and dug wells.

The solution to this problem can be solved by using a mixed integer programming model [10]. The following formulations must be defined.

Set
- \( i \) = plastering springs index \( i = 1,...,I \).
- \( j \) = boreholes index \( j = 1,...,J \).
- \( k \) = stake wells index \( k = 1,...,K \).
- \( l \) = dug wells index \( l = 1,...,L \).

Parameter
- \( MA_i \) = the water capacity of plastering springs \( i \) (m\(^3\)).
- \( SB_j \) = the water capacity of boreholes \( j \) (m\(^3\)).
- \( SP_k \) = the water capacity of stake wells \( k \) (m\(^3\)).
- \( SG_l \) = the water capacity of dug wells \( l \) (m\(^3\)).
- \( D \) = the water requested by the BWI industry as a whole (m\(^3\)/month).

\( FC_{MA_i} \) = total fixed cost to obtaining the water from plastered springs \( i \) (rupiah/month).
The fixed cost of obtaining the water from the plastering springs could be calculated by adding up the following costs:

\[ FC_{MA_i} = IP_{MA_i} + IPA_{MA_i} + MP + P_i \]  \hspace{1cm} (1)

\( IP_{MA_i} \) = the cost of drilling permits retribution at plastering springs \( i \) (rupiah/month).
\( IPA_{MA_i} \) = the cost of taking permits retribution at plastering springs \( i \) (rupiah/month).
\( MP \) = the cost of purchasing a pump machine at plastering springs \( i \) (rupiah/month).
\( P_i \) = the cost of purchasing the pipes at plastering springs \( i \) (rupiah/month), when \( P_i = J_i \times H \).
\( J_i \) = the distance of the industry to plastering springs \( i \) (meter).
\( H \) = the price of pipes (rupiah/meter).

\( FC_{SB_j} \) = total fixed cost to obtaining the water from boreholes \( j \) (rupiah/month).
The fixed cost of obtaining the water from the boreholes could be calculated by adding up the following costs:

\[ FC_{SB_j} = IP_{SB_j} + IPA_{SB_j} + MB + P_j \]  \hspace{1cm} (2)

\( IP_{SB_j} \) = the cost of drilling permits retribution at boreholes \( j \) (rupiah/month).
\( IPA_{SB_j} \) = the cost of taking permits retribution at boreholes \( j \) (rupiah/month).
MB = the cost of purchasing a pump machine at boreholes \( j \) (rupiah/month).
P\(_j\) = the cost of purchasing the pipes at boreholes \( j \) (rupiah/month), when \( P\(_j\) = D\(_j\) \times H \).
D\(_j\) = the distance of the industry to boreholes \( j \) (meter).
H = the price of pipes (rupiah/meter).
FC\(_{SPk}\) = total fixed cost to obtaining the water from stake wells \( k \) (rupiah/month).
The fixed cost of obtaining the water from the stake wells could be calculated by adding up the following costs:

\[
FC_{SPk} = IP_{SPk} + IPA_{SPk} + SP + P_k
\]  

(3)

IP\(_{SPk}\) = the cost of drilling permits retribution at stake wells \( k \) (rupiah/month).
IPA\(_{SPk}\) = the cost of taking permits retribution at stake wells \( k \) (rupiah/month).
SP = the cost of purchasing a pump machine at stake wells \( k \) (rupiah/month).
P\(_k\) = the cost of purchasing the pipes at stake wells \( k \) (rupiah/month), when \( P\(_k\) = D\(_k\) \times H \).
D\(_k\) = the distance of the industry to stake wells \( k \) (meter).
H = the price of pipes (rupiah/meter).
FC\(_{SGl}\) = total fixed cost to obtaining the water from dug wells \( k \) (rupiah/month).
The fixed cost of obtaining the water from the dug wells could be calculated by adding up the following costs:

\[
FC_{SGl} = IP_{SGl} + IPA_{SGl} + MG + P_l
\]  

(4)

IP\(_{SGl}\) = the cost of drilling permits retribution at dug wells \( k \) (rupiah/month).
IPA\(_{SGl}\) = the cost of taking permits retribution at dug wells \( k \) (rupiah/month).
MG = the cost of purchasing a pump machine at dug wells \( k \) (rupiah/month).
P\(_l\) = the cost of purchasing the pipes at dug wells \( k \) (rupiah/month), when \( P\(_l\) = D\(_l\) \times H \).
D\(_l\) = the distance of the industry to dug wells \( k \) (meter).
H = the price of pipes (rupiah/meter).
P\(_{MAi}\) = collection and utilization tax of groundwater by plastered springs \( i \) (rupiah/month).
P\(_{SBj}\) = collection and utilization tax of groundwater by boreholes \( j \) (rupiah/month).
P\(_{SPk}\) = collection and utilization tax of groundwater by stake wells \( k \) (rupiah/month).
P\(_{SGl}\) = collection and utilization tax of groundwater by dug wells \( l \) (rupiah/month).

3.1. Decision Variables

\( W_{MAi} \) = the water that is utilized by the BWI industry from plastered springs \( i \) (m\(^3\)/month).
\( W_{SBj} \) = the water that is utilized by the BWI industry from boreholes \( j \) (m\(^3\)/month).
\( W_{SPk} \) = the water that is utilized by the BWI industry from stake wells \( k \) (m\(^3\)/month).
\( W_{SGl} \) = the water that is utilized by the BWI industry from dug wells \( l \) (m\(^3\)/month).

Other decision variables in the form of binary variables include:

\[
\delta_{MAi} = \begin{cases} 
1 ; & \text{if water is utilized by BWI industry from plastering springs } i \\
0 ; & \text{otherwise}
\end{cases}
\]

\[
\delta_{SBj} = \begin{cases} 
1 ; & \text{if water is utilized by BWI industry from boreholes } j \\
0 ; & \text{otherwise}
\end{cases}
\]

\[
\delta_{SPk} = \begin{cases} 
1 ; & \text{if water is utilized by BWI industry from stake wells } k \\
0 ; & \text{otherwise}
\end{cases}
\]

\[
\delta_{SGl} = \begin{cases} 
1 ; & \text{if water is utilized by BWI industry from dug wells } l \\
0 ; & \text{otherwise}
\end{cases}
\]
3.2. Objective Function

\[
\text{Min } \sum_{i=1}^{I}(P_{MAi}W_{MAi} + FC_{MAi}\delta_{MAi}) + \sum_{j=1}^{J}(P_{SBj}W_{SBj} + FC_{SBj}\delta_{SBj}) + \sum_{k=1}^{K}(P_{SPk}W_{SPk} + FC_{SPk}\delta_{SPk}) + \sum_{l=1}^{L}(P_{SGl}W_{SGl} + FC_{SGl}\delta_{SGl})
\]

3.3. Constraints

Some obstacles that must be met to obtain the minimum operating costs as follows.

Capacity constraint. This constraint limits the total water that can be used by the BWI industry, which does not exceed the upper bound of groundwater capacity at each source. We could express \(W_{MAi} \leq MA_i\) for each \(i\), \(W_{SBj} \leq SB_j\) for each \(j\), \(W_{SPk} \leq SP_k\) for each \(k\), and \(W_{SGl} \leq SG_l\) for each \(l\).

Demand constraint. The total volume of water that was allocated from all sources equal to the demand of the BWI industry.

\[
\left( \sum_{i=1}^{I} W_{MAi} + \sum_{j=1}^{J} W_{SBj} + \sum_{k=1}^{K} W_{SPk} + \sum_{l=1}^{L} W_{SGl} \right) = D
\]

First logic condition constraint. This obstacle states that water from each source can still be used continuously as long as the water is still there. If water from the plastering springs \(i\) is utilized by the BWI industry, then this condition can be represented as \(W_{MAi} \geq 0 \rightarrow \delta_{MAi} = 1\). \(\delta_{MAi}\) is worth one if the water is allocated and zero if otherwise. Suppose \(M\) is an upper bound of \(W_{MAi}\), then this constraint can be expressed by \(W_{MAi} - M \times \delta_{MAi} \leq 0\). If water from the boreholes \(j\) is utilized by the BWI industry, then this condition can be represented as \(W_{SBj} \geq 0 \rightarrow \delta_{SBj} = 1\). \(\delta_{SBj}\) is worth one if the water is allocated and zero if otherwise. Suppose \(M\) is an upper bound of \(W_{SBj}\), then this constraint can be expressed by \(W_{SBj} - M \times \delta_{SBj} \leq 0\). If water from the stake wells \(k\) is utilized by the BWI industry, then this condition can be represented as \(W_{SPk} \geq 0 \rightarrow \delta_{SPk} = 1\). \(\delta_{SPk}\) is worth one if the water is allocated and zero if otherwise. Suppose \(M\) is an upper bound of \(W_{SPk}\), then this constraint can be expressed by \(W_{SPk} - M \times \delta_{SPk} \leq 0\). If water from the dug wells \(l\) is utilized by the BWI industry, then this condition can be represented as \(W_{SGl} \geq 0 \rightarrow \delta_{SGl} = 1\). \(\delta_{SGl}\) is worth one if the water is allocated and zero if otherwise. Suppose \(M\) is an upper bound of \(W_{SGl}\), then this constraint can be expressed by \(W_{SGl} - M \times \delta_{SGl} \leq 0\).

Second logic condition constraint. This constraint states that the use of water for the same technique from the second and third sources can be done if the water from the first source has been carried out and it turns out that the capacity has not met the required water needs as a whole. If the industry decides to utilize the plastering springs \(i + 1\), then plastering springs \(i\) must be done first. This constraint can be expressed by \(\delta_{MAi+1} = 1 \rightarrow \delta_{MAi} = 1\), equivalent to the inequality \(\delta_{MAi+1} - \delta_{MAi} \leq 0\). If the industry decides to utilize the boreholes \(j + 1\), then boreholes \(j\) must be done first. This constraint can be expressed by \(\delta_{SBj+1} = 1 \rightarrow \delta_{SBj} = 1\), equivalent to the inequality \(\delta_{SBj+1} - \delta_{SBj} \leq 0\). If the industry decides to utilize the stake wells \(k + 1\), then stake wells \(k\) must be done first. This constraint can be expressed by \(\delta_{SPk+1} = 1 \rightarrow \delta_{SPk} = 1\), equivalent to the inequality \(\delta_{SPk+1} - \delta_{SPk} \leq 0\). Finally, if the industry decides to utilize the dug wells \(l + 1\), then dug wells \(l\) must be done first. This constraint can be expressed by \(\delta_{SGl+1} = 1 \rightarrow \delta_{SGl} = 1\), equivalent to the inequality \(\delta_{SGl+1} - \delta_{SGl} \leq 0\).

Non-negative constraint. This obstacle ensures that the volume of water allocated from each source to the BWI industry is greater or equal to zero. The volume of water that allocated from the plastering springs \(i\) is \(W_{MAi} \geq 0, \forall i\). The volume of water that allocated from the boreholes \(j\) is \(W_{SBj} \geq 0, \forall j\). The volume of water that allocated from the stake wells \(k\) is \(W_{SPk} \geq 0, \forall k\). The volume of water that allocated from the dug wells \(l\) is \(W_{SGl} \geq 0, \forall l\).
4. Results
In this research has been studied the utilization technique of groundwater around the Cicatih watershed which has an area of 53 thousand hectares. In recent years groundwater in that area has been widely used by the BWI industry, including by PT Tang Mas Cidahu located in Bojong Pari Jaya Bakti Cidahu Sukabumi. So far, the industry only utilizes plastering springs in length approximately 200 meters, the capacity of water is $6.4 \times 10^4 \text{ m}^3/\text{month}$.

The industry plans to increase production in the coming years due to growing demand. Because the industry does not know certainly how much water volume is needed, then we make several possible demands based on the maximum capacity of each source. The following are given several scenarios of possible groundwater demands with considering analysis by Pawitan et al. [8].

| No | Demand (m$^3$/month) | Explanation |
|----|----------------------|-------------|
| 1  | 64.000               | the demand for groundwater equals with the maximum capacity of the first of plastering springs |
| 2  | 70.000               | the demand for groundwater greater than the maximum capacity of the first of plastering springs |
| 3  | 116.600              | the demand for groundwater greater than the maximum capacity of the first and second of plastering springs |
| 4  | 149.700              | the demand for groundwater less than the total maximum capacity of all of the plastering springs |
| 5  | 27.600.700           | the demand for groundwater greater than the maximum capacity of all of the plastering springs and the first of boreholes |
| 6  | 54.960.700           | the demand for groundwater less than the total maximum capacity of all of the plastering springs and all of the boreholes |
| 7  | 82.320.700           | the demand for groundwater less than the total maximum capacity of all of the plastering springs, all of the boreholes, and the first of stake wells |
| 8  | 109.680.700          | the demand of groundwater less than the total maximum capacity of all of the plastering springs, all of the boreholes, all of the stake wells, the first of dug wells |

This following table shows the costs and capacity of each source. This data we obtain with detailing all numbers and formulas that have been presented in Section 2.

| Source      | Fixed Cost (Rp/month) | Variable Cost (Rp/month) | Capacity (m$^3$/month) |
|-------------|----------------------|--------------------------|------------------------|
| Plastering springs | 1 463.333 | 3.300 | $6.4 \times 10^4$ |
|              | 2 892.917 | 3.300 | 52.560 |
|              | 3 896.042 | 3.300 | 33.139 |
|              | 1 209.642 | 6.600 | $2,736 \times 10^7$ |
|              | 2 297.142 | 6.600 | $2,736 \times 10^7$ |
|              | 3 384.642 | 6.600 | $2,736 \times 10^7$ |
|              | 1 93.535  | 8.250 | $2,736 \times 10^7$ |
| Boreholes   | 2 111.035 | 8.250 | $2,736 \times 10^7$ |
|              | 3 128.535 | 8.250 | $2,736 \times 10^7$ |
|              | 1 89.552  | 9.900 | $2,736 \times 10^7$ |
| Stake wells | 2 98.302  | 9.900 | $2,736 \times 10^7$ |
|              | 3 108.302 | 9.900 | $2,736 \times 10^7$ |
To find out the potential of groundwater resources for PT Tang Mas Cidahu, the following is a cross-sectional picture of the area obtained from Agroklimat and Hydrology Research Association (Balitklimat) in 2008. We got this data from the Department of Agriculture at 2009 [3].

![Cross-sectional picture of the Cicatih watershed](image)

**Figure 1.** Cross-sectional picture the watershed of Cicatih.

From the sketch of the transverse profile in Figure 1, it shows that at an altitude of 1000 to 1800 masl is a catchment area. This criterion is obtained based on the parameters used, namely land cover and soil type. Both of these parameters contain permeability information on water graduation which is in line with the West Java Regional Regulation Number 2 in 2003.

Based on measurements using a regional map obtained from the National Coordinator for Survey and Mapping Agency (Bakosurtanal) with a scale of 1: 25000 it is known that PT Tang Mas Cidahu is in the position 06046'34" LS and 106043'42" BT, so according to research from the Agroklimat and Hydrology Research Association (Balitklimat) region with the position of the depth of the well is relatively shallow which is approximately 5.35 meters.

Based on data from the Department of Settlement and Regional Infrastructure (Kimpraswil) in 2000 it was found that the potential resources of the Cicatih watershed were $2.736 \times 10^7$ m$^3$/month for each planned well.

After learning various things from the Cicatih watershed, then the solution to groundwater problems to minimize operational costs by PT Tang Mas Cidahu was obtained using a mathematical formulation that was created with the mixed integer programming software (branch and bound method). The following results are obtained.
Table 5. Results of problem-solving.

| No | Demand (m³/month) | Objective Function | Source |
|----|-------------------|--------------------|--------|
| 1  | 64.000            | $2.11 \times 10^8$ | Plastering springs 1 |
| 2  | 70.000            | $2.31 \times 10^8$ | Plastering springs 1 and 2 |
| 3  | 116.600           | $3.85 \times 10^8$ | All plastering springs |
| 4  | 149.700           | $4.94 \times 10^8$ | All plastering springs and boreholes 1 |
| 5  | 27.600.700        | $1.82 \times 10^{11}$ | All plastering springs, boreholes 1 and 2 |
| 6  | 54.960.700        | $3.62 \times 10^{11}$ | All plastering springs and all boreholes |
| 7  | 82.320.700        | $5.43 \times 10^{11}$ | All plastering springs, all boreholes, and stake wells 1 |
| 8  | 164.400.700       | $1.22 \times 10^{12}$ | All plastering springs, all boreholes, all stake wells, and dug wells 1 |

5. Conclusion

Based on the results presented in Table 5, we can make conclusions:

- If the demand is less than or equal to the capacity of the water source from the plastering springs, then the water will be obtained from that source.
- If the demand is equal to or greater than the capacity of the plastering springs, then water will be obtained from the boreholes.
- If it turns out that the demand exceeds the capacity of both the plastering springs and the boreholes, then the industry can obtain water supply from the stake wells.
- However, if the request exceeds the capacity of the three sources, the industry can utilize the dug well to the maximum capacity of the third well.
- The order of water utilization is from the plastering springs, the boreholes, the stake wells, and then the dug wells. Utilization of each source from the first, second, and third wells, respectively.

From the results of the research that has been carried out shows that the minimum cost of using groundwater by PT Tang Mas Cidahu can be obtained if the industry uses the plastering springs from three sources in sequence, then it is followed by exploring the boreholes, the stake well, and finally the dug well. By looking at groundwater abundant supply, it can be concluded that the area has the potential to produce bottled water which is currently very much needed by the Sukabumi people in particular and the Indonesian people in general.

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