Evaluation of water supply alternatives for mineral water teaching factory

M Sarosa¹, R I Hapsari²*, D Moentamaria³, S Adhisuwignjo¹, R I Putri¹, H P Buwono⁴, E Rohadi⁵, S Wibowo¹

¹ Department of Electrical Engineering, State Polytechnic of Malang
² Department of Civil Engineering, State Polytechnic of Malang
³ Department of Chemical Engineering, State Polytechnic of Malang
⁴ Department of Mechanical Engineering, State Polytechnic of Malang
⁵ Department of Informatics Technology, State Polytechnic of Malang

*corresponding author: ratih@polinema.ac.id

Abstract. The teaching factory (TEFA) in State Polytechnic of Malang (Polinema) attempts to address the replication of the real industrial process inside the traditional educational setting. In Polinema, the TEFA deals with the bottled mineral drinking water, and its supply chain starts from the water purifying until the marketing. A key aspect of achieving an economically and technically feasible production is the selection of wellspring as the source of raw material. The potential water sources are located at Wringinsongo, Ampeldento, Prigen, and Ngijo in Malang area. A decision support system is required to select the suitable source by integrating weighted tangible and intangible criteria, namely water quality, distance, and willingness to pay. Multicriteria decision-making by analytical hierarchy process is applied to assign criteria weight and select the source. The results demonstrate that Ngijo wellspring is recommended, followed by Wringinsongo, Ampeldento, and Prigen according to the performance value. The system could serve as a tool for the selection, instead of intuitive judgment with a better compromise for improving the TEFA productivity.

keywords: drinking water, water resources, teaching factory, AHP, water quality

1. Introduction

Teaching factory (TEFA) is a learning concept oriented towards production and business to answer the challenges of current and future industrial developments. This type of teaching methodology is suitable for vocational education services. The TEFA in State Polytechnic of Malang (Polinema) attempts to address the replication of the real industrial processes inside the traditional educational setting. In Polinema, the TEFA deals with the bottled mineral drinking water and its supply chain starts from the water purifying until the marketing.

The existing facilities in Polinema exist from 2015 consist of a water tank, macro filtration, microfiltration, ozonation, ultraviolet irradiation, and packaging. The product is bottled drinking water packed in a 330 ml plastic bottle. The customer of the water is mainly internal users for campus activities. The manufacturing is based on the order. The sales pay off the cost of the manufacturing for every production cycle.
So far, the water resources for the production are obtained from Prigen spring, a local community. The weakness of the utilization of this source is related to the cost and the quality issues. The cost of water supply is regarded as high because the provider fully commercializes it. Regarding the quality, this source contains a little bacterium. Therefore, it is necessary to search for other sources as an alternative. There are several potential water sources in the Malang area, i.e. Wringin Songo, Ampeldento, Prigen, and Ngijo, each having its advantages and disadvantages. The criteria of a recommended source include water quality requirement, the distance, the transportation cost, the treatment cost, the feasible product unit price, amenity, and further collaboration prospects with local people. A decision support system is required to select a suitable source by integrating weighted tangible and intangible criteria. Several methods have been used as a tool in decision support. Multicriteria Decision-making Methods (MCDM) is a method that refers to the process of screening, prioritizing, ranking, or selecting alternative sets (in this case, it can be "candidate") with independent, conflicting criteria. MCDM is appropriate for water resource problems where all alternatives have several criteria, each of which has a nominal value. Each criterion has a weight that can be used to compare [1][2]. The Analytic Hierarchy Process (AHP) method is a method that models complex and unstructured problems into the form of problems in stages/tiers. The elements at each level will be given a subjective qualitative assessment [3]. This method is quite widely used to solve problems related to decision-making or the feasibility of water resources management [4], water resource vulnerability assessment [5], and evaluation of sustainable water resource utilization [6]. Although extensive research has been carried out on water resources decision-making, very limited writers draw on any systematic research into the decision-making in the water resources business context.

The water quality and the distance are the common criteria of water resources selection. The water quality associates with the cost of production. However, suppose the selection of the criteria is merely based on the unit price of production. In that case, the decision tends to direct to the closest wellspring. Essentially, it is necessary to evaluate all the benefits for intangible benefits that do not have a market price. Contingent valuation [7] using willingness to pay (WTP) techniques [8] have been developed to calculate the economic value of natural resources that do not have market prices. This study will give an account of WTP for quantifying the benefit of each water resource. The WTP of Polinema decision makers is investigated by showing the benefit of further collaboration sustainability.

The major objective of this study was to find out the suitable water resources as a raw material of commercial Mineral Water produced in Polinema TEFA. In particular, this research will examine five main research questions, i.e., the quality of water wellspring according to the standard, the distance of the wellspring, the criteria of the technically feasible wellspring, and the economic valuation of TEFA policymaker willingness. Finally, based on those multicriteria with better compromise for improving the TEFA productivity, the selected spring is decided.

2. Material and Methods

2.1 Profile of Polinema Teaching Factory
Polinema has a teaching factory (TEFA) facility of fruit juice drinks since 2008 in collaboration with alumni. In addition to the fruit juice drink unit, the previous TEFA was the biodiesel unit, and in 2010 it was increased by the establishment of the mineral water beverage unit. From 2008, TEFA involved students in quality control through learning in the Basic Chemistry and Bioprocess Laboratory. The bottled drinking water is produced under the TuyoQu trademark. The experiment was conducted in Polinema Teaching Factory, particularly in TuyoQu fabric located at Polinema campus (-7.948, 112.615).
Initially, the implementation of TEFA only involved some students as additional activities (extracurricular) outside of regular learning hours in the TEFA Club (TEFAC) community. TEFAC students are involved in the product development research process and other research to improve the quality of existing products. Gradually, students began to be involved in the production process. The beverage products got a good response from the community, especially at certain moments (peak season). The implementation of an increasing production process requires more skilled workers to meet consumer demand. Therefore, the full involvement of students in the production process through production-based learning at TEFA, is the answer to the need for skilled workers.

The Competition Grant Program – Improving the Quality of Polytechnic Education (PHK-PMPP), which POLINEMA received from 2013, further strengthens the learning process at TEFA, leading to competency certification for Chemical Engineering students. TuyoQu is one of the breakthroughs conducted by the Chemical Engineering Department of the Polinema to improve student competency in the food industry. In this production activity, students immediately jumped in as production operators and quality testing laboratories personnel.

2.2 Research Methodology
The development of TEFA requires stages in the production infrastructure and facilities to start operating manually, semi-automatically, and integrating process automation. This product has several advantages, namely the use of RO (Reverse Osmosis) and UV. Reverse osmosis, or what is often referred to as RO, is a relatively new technology, but it has a very efficient application of scientific processes. RO systems have many types, with the capacity to meet a family scope or as large as the capacity of industrial needs that require thousands of gallons per day. With the advantages of this system and membrane design that has improved efficiency and reliability, reverse osmosis can be used for many types of water treatment applications for a long time. At the same time, Ultraviolet Rays function as a germ killer and germs, such as coli bacteria, coliform, and other microbes. Figure 1 shows the photo of the drinking water plant in TEFA and the product.

2.3 Water Sources for Raw Material
The study is conducted in Malang area. The water sources candidates are Wringinsongo (-7.999, 112.744), Ampeldento (-7.911, 112.597), Prigen (-7.660, 112.674), and Ngijo (-7.903, 112.610). Figure 2 illustrates the location of the sampling points. The distance of each place to the factory for material transportation is given in Table 1. Wringinsongo was chosen because this village has a partnership collaboration with Polinema for community service activities. Ampeldento and Ngijo are located relatively near the TEFA. The local communities manage these wellsprings for village recreational facilities such as fishing ponds and swimming pools. Prigen spring, which a local private company owns, is chosen for its reliability of the service.

Water quality parameters include chemical, physical, and biological properties. They are tested based on the drinking water standard from Ministry of Health Indonesia no. 492/Menkes/Per/IV/2010. Parameters examined for water quality include pH, Ammonia Total, E. Coli, Total Coliform, Arsenic, Fluor, Cadmium, Nitrite, Nitrate, Cyanide, Odour, Colour, Total Dissolve Solids, Aluminium, Iron, Hardness, Chloride, Zinc, Sulphate, Cuprum. From the result analysis, the parameters are reclassified to represent chemical, physical, and biological parameters.
Figure 2. Location of raw water source

Table 1. Distance of wellspring

| No | Wellspring      | Distance | Photo | No | Wellspring      | Distance | Photo |
|----|----------------|----------|-------|----|----------------|----------|-------|
| 1  | Wringinsongo   | 20.1 km  | ![Photo](image1.png) | 3  | Prigen          | 49.1 km  | ![Photo](image3.png) |
|    | A catchment area is a conserved vegetated area with very low anthropogenic impact |          |       | 4  | Ngijo           | 8.8 km   | ![Photo](image4.png) |
|    |                |          |       |    | The catchment area is the vegetated area with moderate anthropogenic impact |          |       |
| 2  | Ampeldento     | 7.6 km   | ![Photo](image2.png) |          |                |          |       |
|    | The catchment area is agricultural land with high anthropogenic impact |          |       |    |                |          |       |

2.4 Intangible Benefit Valuation

The contingent valuation approach [9] is employed since Polinema as an institution and TEFA managers also consider the non-market value in selecting the suitable wellspring. It was decided that the best source is the one that is beneficial for extensive collaboration. To measure the intangible benefit, a question set asking the WTP to the Polinema policymakers, TEFA managers, lecturers, and researchers of TEFA is administered. The range of the WTP for purchasing one 330 ml bottle of TuyoQu is Rp0-1500, Rp1200-1500, Rp1500-2000, Rp2000-2500, Rp2500-3000, Rp2500-3000, and Rp3500-4000. For comparison, the market price of a similar size of commercially bottled water is Rp900-2300.
2.5 Drinking Water Quality

2.5.1 Analytical Hierarchy Process

In this study, a multicriteria decision-making framework assists in deciding the most feasible and sustainable water source out of three sources that maximize the multiple advantages. Upon an in-depth discussion and literature review, five criteria are taken as top indicator aggregation, namely physical quality parameter, chemical quality parameter, biological quality parameter, the distance of the source, and WTP. AHP is a method for organizing and analyzing difficult decisions in an organized manner [3]. It reflects a decision-making dilemma through the use of a hierarchical structure composed of its constituents. In AHP, each criterion has different importance, represented by the weight of a pairwise comparison of the components. Three contributors from Polinema Integrated Applied Technology Research Centre, a practitioner from the raw water industry, and Polinema policymaker are chosen for judging the weight based on their expertise in the community drinking water business. The priority scales are derived and then analyzed by multiplying them by the parent's priority. The results of the comparisons in pairs are laid up in a matrix. The first normalized Eigen matrix vector is the dominating criteria. Afterward, the ratio scale determines those weight values.

Before the pairwise comparison, the few parameters are selected as factors representing chemical, physical, and biological properties to simplify the procedure. According to Table 2, the contributing parameters are TDS, Dissolved Cadmium as representative of heavy metals, and Total Coliform.

2.5.2 Willingness to Pay

Simple descriptive statistics are presented to assess the WTP. The number of respondents is 16 based on the purposive sampling technique. The chart in Figure 3 illustrates the number of respondents who chose each class of WTP and the average WTP from all respondents. The modus of Ampeldento, Ngijo, Wringinsongo, and Prigen is Rp1500-2000, Rp1500-2000, Rp2000-2500, and Rp1500-2000 respectively. The average of Ampeldento, Ngijo, Wringinsongo, and Prigen is Rp1843.8, Rp1875.0, Rp2031.3, and Rp1890.6, respectively.

Very high WTP is found for Wringinsongo spring. Strong evidence of contributors' positive value is found when this spring is employed as raw material for mass production in TEFA. Low WTP is found for Ampeldento and Ngijo sources. Some of the respondents speculated that Ampeldento and Ngijo sources' handling cost would be high due to difficult access and the lack of water reservoir and transmission facilities. Regarding Prigen spring, one individual stated that this source is unfeasible, and Rp0 WTP was given. Overall, these results suggest that Wringinsongo is preferable as a raw material source for TEFA.

The performance index of the wellspring is calculated the performance matrix. Because each of the three parameters measures the value in a different unit, it is necessary to normalize the values of each parameter before coupling to create a dimensionless variable [10]. To calculate the whole scenario's performance index, a metric computation is performed by multiplying the weights by the individual combination values [10][11].

3 Results and Discussion

3.1 Water Quality Assessment

The laboratory test is used to assess the raw water quality test. Table 2 presents the characteristic of water samples in four locations. Warm colors indicate the high content of the substance. As can be seen from the table, generally, Prigen source provides a better quality of water resources. The Prigen is located in an underground basin, and the spring itself is rather a subterranean river. Therefore, human activities and the watershed condition have less effect on the quality of water resources.
### Table 2. Results of water quality test

| Parameter       | Unit | Standard | Ampel-dento | Prigen | Ngijo | Wringinsongo |
|-----------------|------|----------|-------------|--------|-------|--------------|
| Turbidity       | NTU  | 5        | 0.32        | 0.30   | 0.61  | 0.64         |
| TDS             | mg/L | 500      | 288.0       | 156.0  | 232.0 | 263.6        |
| Taste           | -    | -        | 1*          | 1*     | 1*    | 1*           |
| Odour           | -    | -        | 1*          | 1*     | 1*    | 1*           |
| Colour          | PtCo | 15       | <0.2033     | <0.2033| <0.2033| <0.2033      |
| Temperature     | °C   | Air temp. ±3 | 27          | 27     | 27    | 27           |
| pH              |      | 6.5-8.5  | 7.20        | 7.42   | 7.04  | 7.06         |
| Dislv. Cr       | mg/L | 0.05     | <0.0100     | <0.0100| <0.0100| 0.0127       |
| Dislv. Cd       | mg/L | 0.003    | <0.0015     | 0.0018 | <0.0015| 0.0016       |
| Dislv. Se       | mg/L | 0.01     | <0.0003     | <0.0003| <0.0003| 0.0091       |
| Dislv. Cu       | mg/L | 2        | 0.0152      | 0.0131 | <0.0117| <0.0117      |
| Total NH3       | mg/L | 1.5      | 0.4006      | 0.3120 | 0.2950 | 0.2522       |
| NO2             | mg/L | 3        | <0.0012     | <0.0012| <0.0012| 0.0198       |
| NO3             | mg/L | 50       | 22.19       | 7.662  | 32.10 | 25.46        |
| CaCO3           | mg/L | 500      | 103         | 55     | 73    | 101          |
| Cl-             | mg/L | 250      | 22.2        | 10.3   | 13.8  | 12.8         |
| SO4             | mg/L | 250      | 13.84       | 8.783  | 16.95 | 19.87        |
| F-              | mg/L | 1.5      | <0.0625     | <0.0625| <0.0625| <0.0625      |
| Dislv. As       | mg/L | 0.01     | <0.0004     | <0.0004| <0.0004| <0.0004      |
| Dislv. Mn       | mg/L | 0.4      | <0.0097     | <0.0097| <0.0097| <0.0097      |
| Ca              | mg/L | 0.07     | <0.0010     | <0.010 | <0.010 | <0.010       |
| Dislv. Al       | mg/L | 0.2      | <0.0103     | <0.0103| <0.0103| <0.0103      |
| Dislv. Fe       | mg/L | 0.3      | <0.0139     | <0.0139| <0.0139| <0.0139      |
| Dislv. Zn       | mg/L | 3        | <0.0053     | <0.0053| <0.0053| <0.0053      |
| E. coli         | MPN/100mL | 0 | 2* | <2* | 2* | 5* |
| Total Coliform  | MPN/100mL | 0 | 5* | 7* | 5* | 9* |

*Warmer colours indicate high amount

Contrary to the expectation, Wringinsongo spring quality is somewhat poor in terms of biological parameters. A possible explanation for these results may be the local sanitation facilities in upper Wringinsongo that may contaminate the water resources. However, in terms of chemical matter, the quality is acceptable. As for Ampeldento, the chemical parameter shows a low quality, but biologically the water is better than Wringinsongo. The upstream of Ampeldento is an active agriculture area that may contribute to some nutrient substances. Generally, compared to other springs, Ngijo source provides the second-best water quality.

#### 3.2 Multi-criteria Assessment

The individual dimensionless values of four wellspring alternatives are depicted in Figure 4. A higher score reflects higher performance. The bigger the radar pattern size indicates, the better performance. From the figure, the greatest value is likely served by Ngijo spring, while the lowest value is given by Prigen spring. By combining performance scores and the numerical priority assigned by AHP analysis to the five criteria, the optimal scenario can be selected based on the sustainability index.
Figure 3. Results of WTP survey

Figure 4. Individual alternatives scores (normalized) in terms of five criteria

Table 3. Criteria importance

| No. | Criteria             | Eigen-vector |
|-----|----------------------|--------------|
| 1   | Chemical Parameters  | 18.0%        |
| 2   | Physical Parameters  | 21.4%        |
| 3   | Biological Parameters| 9.3%         |
| 4   | WTP                  | 30.7%        |
| 5   | Distance             | 20.7%        |

Table 4. Performance index of four wellspring

| Location     | Ampeldento | Ngijo | Wringinsongo | Prigen |
|--------------|------------|-------|--------------|--------|
| Value        | 0.48       | 0.62  | 0.54         | 0.34   |
Table 3 highlights the importance analysis of five criteria using the pairwise-comparison perception of three contributors. Water chemical substance was put as a priority by the researcher over the distance. The contributor from the industrial sector mainly disregarded the intangible benefit. At the same time, the policymaker considered the intangible benefit of extensive collaboration as the important criteria for biological water quality.

Table 4 summarizes the value of four water springs from the multicriteria decision-making procedure. The comparison finds that Ngijo spring has the highest performance value. The study has not demonstrated the adequate benefit of employing Prigen spring, which has supplied the water to the current TEFA production. Wringinsongo wellspring has a slightly lower numerical value than Ngijo. Due to the existence of Coliform, the performance valuation of Wringinsongo spring results in a lower value than Ngijo.

This section suggests utilizing the Ngijo wellspring for supplying the raw water in TEFA production. Due to the water quality and the close distance, this choice provides a reasonable cost that is also beneficial in an intangible context. Nonetheless, the findings in this study are subject to at least two limitations. First, some essential criteria have not been included, e.g., the cost of a water reservoir and transmission facilities, the intangible cost of location accessibility, water quantity variables, and local people’s willingness to accept. Second, the water quality test is limited to only one sample, leading to the unrepresentative result. Notwithstanding these limitations, this framework could serve as a better approach for selecting water resources that integrate tangible and intangible criteria for improving TEFA productivity.

4 Conclusions
This paper has presented the multicriteria approach to better select the best raw water material resources for Polinema TEFA. The method allows the quantitative to effectively select the appropriate by considering multiple tangible and intangible benefits associated with water quality, distance, and willingness to pay. Analysis of AHP suggests that the rank of the criteria importance from very important to less important are willingness to pay, physical parameter, distance, chemical parameter, and biological parameter. The valuation analysis reveals that Ngijo wellspring is recommended for TEFA source, followed by Wringinsongo, Ampeldento, and Prigen. Despite the criteria limitation, the system could serve as a tool for the selection instead of intuitive judgment with a better compromise for improving the TEFA productivity.

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