Determining water price for public water supply from Jatigede Reservoir

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Abstract. The “user pays” principle is one of the principles of Integrated Water Resource Management. Water price should be set optimally, high enough to complement subsidies, but within the ability of users to pay for the water. This paper discusses the optimization of the water price for public water supply by considering the dominant parameters related to operational costs, government subsidies, and the ability to pay. The study location is the Jatigede reservoir, located in the Province of West Java with an effective reservoir volume of 877 million m³, and supplying public water supply at a rate of 3.5 m³/s. To investigate the feedback loop of the complex system of water price optimization, the system dynamics approach was applied. The study results showed that the water tariff for raw water reaches a numerical balance and can meet the annual operation and maintenance costs by up to 100%. The results of the analysis of the system dynamics model showed that the optimal price for raw water supply is lower than the price of raw water in other river basins.

Keywords: water price, water supply, dynamic system, sustainable management.

1. Introduction

The development of water resource infrastructures is the effort of the government to supply raw water, strengthen national energy security, and support food security, while also reducing flood losses. The Jatigede Dam project is one of the strategic projects in the field of water resources. By investing in development costs and other related matters, the Jatigede Reservoir is calculated to be able to provide benefits throughout its operating life. The sustainability of the function of the irrigation infrastructure determines the success of water resource management. To achieve sustainability, the operation and maintenance (O&M) aspects of irrigation infrastructure are very important to guarantee the benefits of water services and protect the people from water-related damages, in addition to meeting the return on investment that was allocated at the time of development.

Water Cost, Value and Price

Cost can be divided into several components: a) O&M costs; b) capital costs; c) opportunity costs; d) costs of economics; and e) environmental externalities. The value of water is the benefits and returns for users, as well as indirect benefits and intrinsic values. Water price is the amount set by the political and social system for cost recovery, equity, and sustainability [1].
Pricing is an economic tool to improve the efficiency of water allocation among different users and to mainstream rational water usage [2].

**Sustainable Water Pricing**

Sustainable water price balancing has multiple objectives: 1) Efficient water production and consumption behaviours; 2) Optimal solutions for safe and reliable water service; 3) Promotion of equity, the ability to pay, and cost-sharing; and 4) Viability of water utilities in the long-term financial, managerial, and technical capacities [3].

**Objectives**

The purpose of this paper is to find optimal raw water tariffs by considering various dominant parameters. The obtained raw water tariffs must be well received by water users, be fair, and support the sustainable overhead and profit (O&P) of Jatigede Dam.

2. **Materials and Methods**

Jatigede Reservoir is the second-largest reservoir in Indonesia, located in Sumedang Regency, Province of West Java. This reservoir was built by damming the flow of the Cimanuk River in the area of Jatigede Sub-District of Sumedang Regency, with a capacity of 979.5 million cubic meters of water. Jatigede Reservoir has the main function as an irrigation facility for 90,000 hectares of fields in Cirebon Regency, Indramayu Regency, and Majalengka Regency, and to power a hydroelectric power plant of 110 megawatt (MW) capacity. It also functions as a facility for freshwater aquaculture, water sports, recreation, and others. This reservoir also supplies clean water to local residents with a capacity of up to 3,500 cubic meters per second and also serves to reduce flooding in 14,000 hectares of land in West Java. The location map of Jatigede Reservoir is presented in the figure below.

![Figure 1. Map of Jatigede Reservoir Location and Service Locations](image)

2.1. **Concept of Sustainable Tariffs**

Sustainable tariffs balance optimality, viability, fairness, and efficiency. The tariff must be made low enough so that it is affordable and the community of water users can jointly participate in supporting the running of the Jatigede Reservoir management system. However, the tariff must also be efficient,
and the tariff calculations must be based on the annual operation and maintenance costs in order to guarantee the viability of the Jatigede Reservoir management system.

2.2. System Dynamics in Sustainable Tariffs
The heart of system dynamics is system analysis. A system is defined as a set of elements that interact with each other, with patterns of interaction that influence one another and determine one another. Problems with a dynamic nature and feedback structure will be resolved if system dynamics analysis is carried out [4].

The benefit of this approach is to explain the structure of the system, as the elements of the system that are interrelated. The link between structure and behaviour depends on the concept of information and control feedback [5]. Causal loop diagrams represent the feedback mechanism, which amplifies (positive feedback loop) or negates (negative feedback loop) [6].

The causal or fishbone diagram was first introduced by Professor Kaoru Ishikawa from Tokyo University, and therefore a causal or fishbone diagram is also called an Ishikawa diagram. The purpose of making this causal diagram is to be able to show the root causes and the quality characteristics that are caused by those causal factors. Generally, a causal diagram shows five factors that are called the causes of an effect. The five factors are human or labour, method, material, machine, and environment. This diagram is usually arranged based on information obtained from brainstorming. According to Ariani (2003), cause and effect diagrams are used for the following needs: 1) to identify the root cause of a problem, 2) to generate ideas for solutions to problems, and 3) to assist in a further investigation or search for facts.

The determining of tariffs is a causal process that can be simulated in a system dynamics model. There are three cycles: 1) higher rates charged to the people results in greater obtained funds from the people; 2) higher tariffs charged to the people results in greater reluctance by the people to pay, causing smaller amounts of public funds to be obtained, and resulting in a swelling of the required subsidies; 3) lower availability of O&M funds means that the annual O&M will not be optimal, thus causing greater periodic maintenance costs and resulting in greater total costs in the long run.

The created system dynamics model utilized Powersim 8 software to obtain an optimal domestic water tariff to achieve an annual cost of operation and maintenance with specified subsidies. Powersim is a tool for modelling and simulation of dynamic systems. It can be used to study time-continuous progress in many subjects, for example biology, economics, physics, and ecology. The modelling was performed by constructing a Powersim diagram. This was made by choosing from the set of defined graphical symbols and placing them in suitable places. Elements influencing each other are then connected with arrows. Powersim is easy to understand and use, even for people without great knowledge in mathematics, programming, and simulation. The integration is based on the “bathtub analogy”, which does not demand knowledge of differential calculus.

![Figure 2. Bathtub Analogy](image-url)
The state $L$ (Level) in figure 2 is affected by an inflow $R_{in}$ (Rate) and an outflow $R_{out}$. This corresponds to a bathtub where the water level is affected by two taps, one that runs water into the bath and one that lets water out of the bath. Note that the state $L$ is not entirely determined by the flows, but also by the initial value $L_0$. Note also that the state does not depend on the current flows, but on the accumulated flows from the past.

Mathematically, $L$ is determined by the equation

$$\frac{dL}{dt} = R_{in}(t) - R_{out}(t)$$

$$L(0) = L_0$$

$$L(t) = L_0 + \int_0^t R_{in}(t) - R_{out}(t) dt$$

In Powersim, first-order systems of differential equations are modelled and simulated.

3. Results and Discussion

3.1. Costs for Water Resources Management and Value of Economic Benefits

In calculating the cost of water resource management, the main principle that must be taken into account is the value of real needs, not the value or amount of the budget that has been provided. As for activity data and nominal amounts, these can be used as references.

The calculation of management costs consists of calculating the costs of the water resource information system, planning, construction related to conservation, operating and maintenance, and community empowerment and evaluation monitoring.

After calculating all the components of management costs, the results of these calculations are recapitulated to become the total management costs. The total management costs for the Jatigede Reservoir are IDR 52,784,010.00 per year.

The second parameter from the calculation of the cost of managing natural resources is the value of economic benefits. A general understanding of this value is the benefit obtained from the use of water in a river area for business activities or water usage.

The types of businesses that take into account the value of economic benefits are
1. Social Affairs: agriculture, flood control, and flushing
2. Commerce: drinking water, hydropower, industry, and agriculture

3.2. External Factors

Water pricing is affected by social and political conditions, in addition to supply and demand [7]. The value of water should also consider the external effects of water resource usage. Externalities can be defined as the costs (or benefits) associated with the provision of water services, but are outside the system and are not included in the costs (or benefits) of a service [8].

External factors impact the willingness to pay. External factors might consist of a) the ratio between income and expenditure, as the indicator of purchasing power of the people; b) regional income, as the indicator of the ability of subsidies; c) surface water scarcity, which is an indicator of the amount of water in the region; and d) availability of groundwater, which is an indicator of the large needs of people for surface water. Higher values of external factors mean higher purchasing power of the people, or they may also indicate that there are no other choices, and thus the people are willing to buy water from the Jatigede reservoir. The value of external factors was determined by considering other river basins, which are Ciliwung - Cisadane (Jakarta Capital Region), Citarum (West Java), Cimanuk - Cisanggarung (West Java), Bengawan Solo (Central Java), and Brantas (East Java).
3.3. Causal Loop Diagram
From the cause-and-effect diagram above, it can be seen that there is one balancing loop, as the raw water loop.

![Figure 4. Causal Loop Diagram for This Study](image)

In this study, the tariff of the public water supply represents the interaction of the ability of the people to pay, which in this case is the operational funds and public funds that can be collected after subsidies from the government are balanced with funds collected from industry and hydropower.

From the causal loop diagram above, it is illustrated that the O&M fund is the fund generated from the amount of water given to the operator, which is expected to be the maximum of annual operation and maintenance costs. Subsidies are interventions from the government and operational costs are maintenance costs and O&M funds.

The expected tariff is the comparison between annual operation and maintenance costs minus subsidies with production water volume. A greater expected tariff will determine a greater rate. The
ability of the operator to pay is a factor of the determined tariff, which is influenced by external factors. A higher established tariff means a lower ability by the operator to pay. The ability to pay operators is directly proportional to the O&M fund, and the O&M fund is inversely proportional to maintenance costs in the sense that smaller available O&M funds will incur large maintenance costs. The amount of maintenance costs will result in high O&M costs. High O&M costs result in the expected tariffs being large, and thus the established tariffs will also be large, and this continues on and on. This cycle is a loop that will continuously proceed towards balance.

3.4. Computer Model

The input data for the model are composed of annual operation and maintenance costs to be achieved, percentage of subsidies to be provided, graphs of maintenance costs relationships that arise if existing O&M funds do not reach operation and maintenance costs, water production plans in m$^3$/year for raw water, reliability of water production, and water tariff reference taken from other selected regional tariffs. The analysed external factor is an indicator of the ability of the people to be willing to pay for water at a fixed rate, calculated from the comparison of the established tariff with the desired tariff based on external factors. The structure of the model is presented in the following figure.

The following are the data and assumptions used in this simulation. Production of water from the Jatigede reservoir for public domestic raw water supply by the water company (PDAM) was taken to be 3.5 m$^3$/s. The utilized reference rate was the rate from Jatiluhur because the reservoir tariff is classified as the smallest. The reliability of raw water production was established at 90% and the analysis was carried out with several scenarios: normal reservoir operation with 0%-10% subsidy and dry reservoir operation with 0%-10% subsidy. The structure of the computer model is presented in the figure below.

![Figure 5. Model Structure](image-url)
The simulation results for all scenarios showed that the tariff for raw water users reaches an optimal amount. The simulation results show that the O&P Fund will reach 100% of annual operation and maintenance costs. The tariff table is presented below.

| Subsidy          | Normal Reservoir Operation | Dry Reservoir Operation |
|------------------|----------------------------|-------------------------|
|                  | 0% | 5% | 10% | 0% | 5% | 10% |
| Raw Water Tariff (IDR/m$^3$) | 67.42 | 65.29 | 63.03 | 68.15 | 66.02 | 63.78 |

Compared to other regional raw water tariffs, the optimal raw water tariff from the Jatigede reservoir is the lowest water tariff. A tariff comparison chart is presented below.

Figure 6. Raw water tariff of Jatigede Reservoir compared to raw water tariffs of other regions

4. Conclusion
The modelling of system dynamics for obtaining optimal water tariffs leads to these conclusions:
• A transparent and flexible system dynamics approach has provided a comprehensive picture of water financing.
• The optimal tariffs obtained for all scenarios cover 100% of annual operation and maintenance costs, which are the lowest compared to other regional tariffs accepted by water users and can support the sustainable operation and maintenance of Jatigede Reservoir.
• The resulting water tariffs range from 63.03 IDR/m$^3$ for the scenario of normal reservoir operation with 10% subsidy to 68.15 IDR/m$^3$ for the scenario of dry reservoir operation without subsidy.
• The results of this optimal tariff analysis are expected to become input for determining government policy for the operation of Jatigede Reservoir.
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