Potential environmental pressures on water availability in Gembong reservoir in Pati District for the development of agropolitan area

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Abstract. Land-use management is the key parameter in developing an agropolitan area. The Spatial Plan of Pati District 2010-2030 contains plans for the Gembong Subdistrict to be developed into an agropolitan area. The Gembong Reservoir is one of the reservoirs in the region that has a vital role in supporting the area development. The main problem in managing the Gembong reservoir is the decreasing availability of reservoir water. Increased sedimentation affects the availability of reservoir water, which is used as a supply of irrigation areas. Management of water availability must be based on optimization analysis, because the volume of storage is limited and increasing inflow to the reservoir to increase the water level requires a long time. Therefore, the optimization model of reservoir water management is urgent to be formulated, so that the reservoir operator can be utilized to determine the allocation of supplementary water. This article presents a study of the results of observations in the field and secondary data, as well as reviews of related scientific articles, to be able to identify potential environmental stresses on reservoir water availability and its management.

1. Introduction
Freshwater availability in the world has been decreasing in terms of quantity as well as quality, plays a fundamental role in support of the environment, society and economy [1]. Water resources management is also a strategic issue in the context of water security as stated in target Number 6 of the Sustainable Development Goals (SDGs). Java Island has been in the category of water insecurity [2].

The natural and man-made reservoirs can function as reservoirs of river water or rain; consequently, sedimentation appears as the main problem in reservoir management. Factors that trigger sedimentation include eutrophication [3-4], flow of sediment carried by river flow or erosion along river bodies due to land-use change [5-8] and heavy metal distribution [9-10].

Sediment material affects the function of reservoir ecosystem as a whole. Reservoir water availability is reduced by the sediment collected in the reservoir making assessment of sediment deposition is an important factor in the operational management of a reservoir. Climate uncertainty causes erratic rain, and at certain time intervals, it can reach an extreme condition [11]. Rainwater is a water source that determines the availability of reservoir water. When rain intensity is very high, the reservoir can no longer accommodate it, causing overflow or flooding. In contrast, the volume of
reservoir water will decrease when the dry season comes; therefore, a sustainable management of reservoir water is required.

The Gembong Reservoir in the Gembong Subdistrict, presented in Figure 1, is one of the artificial reservoirs existing in Pati District, built in 1930-1933 by the Dutch Colonial Government and used as a provider of irrigation water collected from rainwater. Such existence is very much needed in line with the development plan of the Gembong Subdistrict as an agropolitan area outlined in the Spatial Plan of Pati District 2010-2030[12].

An agropolitan area is an area that is formed by the functional relationship of space and its hierarchy from the centers of agricultural production system activities and management of natural resources in a rural area [13]. Management of land use becomes the key factor to prevent the development of agropolitan area from causing environmental degradation in the region.

Agricultural sector is the focus of development in an agropolitan area, as a result, greater pressures on the environment come together with the increasing human activities in agriculture. Reservoir water availability is essential in the development of agricultural sector. Since reservoir volume is limited and it takes time for reservoir inflow to raise the water level, the management must be based on optimization analysis. The current reservoir operation is concentrated on regulating the allocation of irrigation water since the volume of water decreases due to increasing sedimentation.

![Gembong Reservoir, February 2018](image)

**Figure 1.** Gembong Reservoir, February 2018

2. Study results

2.1. Impact of anthropogenic activities on water availability

Increasing population and activities of land use around reservoirs for settlement, agriculture and livestock, industrialization, as well as deforestation in the catchment area contribute to the acceleration of reservoir sedimentation [4, 6, 14-16]. Land-use change through deforestation by local inhabitants to expand settlement areas as well as other activities have increased the number of critical lands, reduced water catchment areas, and had the potential to cause landslides and erosion [17].

With increasing population as well as economic and social demands, sustainable reservoir management as an irrigation source for thousands of hectares of agricultural lands becomes an important issue of reservoir water resource management. Sediment composition is controlled by anthropogenic activities and natural conditions [18-19]. Allocating water reservoirs is managed by implementing the sustainable water management and river restoration strategies through adaptation of the human hydrological system and climate change [20-21].
Result of interview with two operators of the Gembong Reservoir relating to human activities around it revealed that along with the reduced volume of reservoir water in the dry season, the extent of reservoir land converted into agricultural lands or grazing has increased. Human activities in land-use change around the drying reservoir in the dry season have the potential to improve economic condition of the surrounding community, but they have ecologically increased potential sedimentation.

2.2. Effect of climate change on reservoir water availability

Sedimentation rate and age of sediments are influenced by climate change, such as fluctuating and random temperature and rainfall [22], which can be calculated based on hydrographic survey analysis [5], radiocarbon data [23], seismographic and lithographic data [24], depth of water [14], mineral types [25], and measured using the bathymetric techniques [26-27].

The study of the impact of climate change on water resources in a water management strategy is influenced by the selected hydrological model [28]. Suripin et al. (2017) have examined the impact of climate change, the land subsidence, and the land-use change on flooding in Semarang City [29]. Long-term understanding of changes in hydrological balance in response to seasonal rainfall and temperature changes is important in planning the management of freshwater reservoirs [30]. Land-use change and its impacts are crucial factors in water management and sustainability [31], evaluated by considering the ecological, social, and economic aspects [32].

2.3. Correlation between reservoir water availability and agricultural production

In the context of food security, Indonesia needs to fulfill food production by the Medium-Term Development Plan. The climate change has an impact on changes in agricultural land use [33], [34]. Management and development of a reservoir irrigation system is required to maintain production sustainability or even to increase it.

The decreasing reservoir flow rate during the dry season and overflow turning into floods in the rainy season should be managed optimally to minimize the adverse effects on agricultural production. The decreasing availability of reservoir water will reduce the reservoir capacity to supply water for irrigation, which economically has the potential to reduce agricultural production. When production falls both qualitatively and quantitatively, the level of community welfare will also decrease. The vulnerability of water resources and drought resilience is challenge existing water management strategies [35].

2.4. Optimizing the management of reservoir water availability

Optimization is a method to find the best answer in minimizing or maximizing objective functions that are subject to various constraints. Several optimization methods are developed based on linear and nonlinear programming, generic algorithms, artificial neural networks, and multi-object optimization, and they have been used by researchers as water management methodologies [36-37]. The bio-economic optimization model is applied as an approach to simulate land-use decision making by farmers under the condition of climate uncertainty [38].

Reservoir management requires high investment costs to minimize the risk of flooding and damage. Dynamic optimization method is used as a model to analyze the dynamic behavior of optimal investment strategies [39], with a fuzzy approach [40]. Linear programming model is also developed and used to identify factors that trigger changes in landscape and agricultural land use around reservoirs [41].

The cumulative capacity of the reservoir is calculated using the geospatial remote sensing technique, which is a development of conventional methods of hydrological surveillance and inflow-outflow approaches [5]. Bathymetry technique is also used to calculate sediment accumulation, which is then used to forecast the remaining reservoir capacity [26-27, 42].

3. Conclusion

Water availability in the Gembong Reservoir which is important as the supplement for agricultural irrigation in developing an agropolitan area has been under environmental pressures due to anthropogenic activities and climate change. Management of reservoir water availability which
continues to decrease as a result of increased sedimentation should be based on optimization analysis. The results of this study provide an opportunity for further research, so that an optimal model of the management of reservoir water availability for irrigation supply is arranged. Mathematical modeling, especially forecasting methods, can play a role in predicting reservoir water availability in the future as well as in making optimal decisions in the management. Ecosystem complexity requires the development of mathematical models along with their computational methods.

The availability of reservoir water is determined by rainfall and evaporation, which depends on climate change, as well as by the supplementation of irrigation areas affected by human activities. Knowledge of future rainfall and evaporation patterns as well as the rate of change is needed to predict reservoir water availability. Climate change affects the beginning of rainy season as well as rainfall patterns, which has implications for the vulnerability and resilience of farmer communities. Development of community adaptation is a method that must be performed to restore community resilience or to face climate change.

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