WATER RESOURCES MANAGEMENT MODEL BASED ON REGIONAL DEVELOPMENT: CASE STUDY OF MAGETAN REGENCY, INDONESIA †

[MODELO DE GESTIÓN DE RECURSOS HÍDRICOS BASADO EN EL DESARROLLO REGIONAL: ESTUDIO DE CASO DE REGENCIA DE MAGETAN, INDONESIA]

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SUMMARY

Background. The need for water in Magetan Regency, Indonesia, continues to increase along with regional development. **Objective.** To identify the condition of the water balance and water critical index in Magetan Regency; and forming a regional development-based water management model in Magetan Regency. **Methodology.** Formation of a water management model based on regional development, both demographically and regional economic development (agriculture, livestock, fisheries, industry, and tourism), and the environment (river and lake maintenance). This study uses water availability data from seven watersheds. The water management model uses a dynamic system model, with an analysis coverage throughout the Magetan Regency area. The annual water balance of Magetan Regency shows that the water balance and water critical index of Magetan Regency are in near critical condition. Integrated water management is needed to avoid critical water conditions in Magetan Regency in the future. **Results.** Based on the results of model simulations with the application of policy simulations, the water balance in Magetan Regency during the period 2016 to 2030 is still in a near critical condition, but critical water conditions only occur during the 2018-2020 period. **Implications.** Critical water conditions in the future can be avoided by implementing policy scenarios. The policy scenarios include: (1) reforestation, planting 500,000 tree seedlings each year, (2) maintenance of rivers and lakes twice a year, (3) construction of a reservoir with a capacity of 5000 m^3 each year. However, water availability is still fluctuating because the main factor for water availability is rainfall. **Conclusion.** the policy scenario is proven to be able to increase the availability of water in Magetan Regency.
Key words: water balance; water critical; dynamic system; reforestation; reservoir.

RESUMEN

Antecedentes. La necesidad de agua en Magetan Regency, Indonesia, continúa aumentando junto con el desarrollo regional. **Objetivo.** Identificar la condición del balance de agua y el índice crítico de agua en Magetan Regency; y la formación de un modelo de gestión del agua basado en el desarrollo regional en Magetan Regency. **Metodología.** Formación de un modelo de gestión del agua basado en el desarrollo regional, tanto demográfico como económico regional (agricultura, ganadería, pesca, industria y turismo), y el medio ambiente (mantenimiento de ríos y lagos). Este estudio utiliza datos de disponibilidad de agua de siete cuencas. El modelo de gestión del agua utiliza un modelo de sistema dinámico, con una cobertura de análisis en toda el área de Magetan Regency. El balance hídrico anual de Magetan Regency muestra que el balance hídrico y el índice crítico de agua de Magetan Regency se encuentran en una condición casi crítica. Se necesita una gestión integrada del agua para evitar condiciones críticas de agua en Magetan Regency en el futuro. **Resultados.** según los resultados de las

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simulaciones de modelos con la aplicación de simulaciones de políticas, el balance hídrico en la regencia de Magetan durante el período 2016 a 2030 todavía se encuentra en una condición casi crítica, pero las condiciones críticas del agua sólo ocurren durante el período 2018-2020. **Implicaciones.** Condiciones críticas del agua en el futuro pueden evitarse mediante la implementación de escenarios de políticas. Los escenarios de política incluyen: (1) reforestación, plantando 500.000 plántulas de árboles cada año, (2) mantenimiento de ríos y lagos dos veces al año, (3) construcción de un embalse con una capacidad de 5000 m3 cada año. La disponibilidad de agua todavía fluctúa porque el factor principal para la disponibilidad de agua es la lluvia. **Conclusión.** se ha demostrado que el escenario de la política puede aumentar la disponibilidad de agua en Magetan Regency.
Palabras clave: balance hídrico; agua crítica; sistema dinámico; repoblación forestal; reservorio.

INTRODUCTION

The aspect of water resources has always been a major issue in environmental management (Ahmadov, 2020; Luo *et al.*, 2020). The trend that often occurs is an imbalance between the availability and demand for water. Therefore, management of water resources is needed starting from a water resources management model. All forms of activity are regulated so that there is no water crisis (Thoma *et al.*, 2020; Huang, Yuan and Liu, 2021; Lv *et al.*, 2021).

The critical phenomenon of water (commonly called water crisis) during the dry season often occurs in Indonesia; one of them is in the Magetan Regency area. Magetan Regency is located at the western tip of East Java Province. The area of Magetan Regency is 688.85 km^2, at an altitude of 60 to 1660 m.a.s.l.

The availability of water in Magetan Regency during the dry season decreases drastically. The large number of developments in the water catchment area has resulted in a lack of water absorption in the soil (Lopes *et al.*, 2021). The water level of Sarangan Lake drops drastically in the dry season.

On the other hand, the need for water in Magetan Regency continues to increase. This is in line with regional development in Magetan Regency, both demographically (population growth), and regional economic development (agriculture, livestock, fisheries, industry, and tourism) (Sanchez *et al.*, 2020; Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Halli *et al.*, 2022). This is a major research issue.

Water balance analysis is a fundamental analysis in water management in a region. The water balance is the difference between the amount of water available and the demand for water in an area. A simple method of analyzing the water balance is by calculating the availability and demand for water (Naderi, 2021; Rusli *et al.*, 2021; Juma *et al.*, 2022).
Water availability is the volume of water contained in the hydrological cycle in an area. The main variables in water availability are rainfall, surface water (rivers, lakes, reservoirs, reservoirs, etc.), and subsurface water (wells, springs, etc.) (Naderi, 2021; Jayanti *et al.*, 2023). Water availability is strongly influenced by rainfall and ecological conditions (Juma *et al.*, 2022).
Meanwhile, water demand is the volume of water needed for consumption and/or must be available in an area. Regional development causes the need for water to continue to increase in line with regional development. The main variables in water availability are domestic water demand, agricultural sector water demand, industrial sector water demand, tourism sector water demand and water demand for river maintenance needs (Boldt *et al.*, 1999; Gossling *et al.*, 2012; Restrepo A, Kettner and Brakenridge, 2020; Sanchez *et al.*, 2020; Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Halli *et al.*, 2022; Pierrat *et al.*, 2023).

Evaluation of the water balance in Magetan Regency can be used to identify how critical or vulnerable water is in an area. The water critical index describes the percentage ratio of water demand and water availability in an area (Huang, Yuan and Liu, 2021; Salehi, 2022).

Water balance analysis and water critical index in Magetan Regency can be continued with projections or forecasts of water balance conditions in the future. Integrated water management is needed to achieve a balance between water demand and water availability in the future of Magetan Regency. Current and future water balance conditions and water critical indexes are the main indicators of water management (Ahmad *et al.*, 2021; Huang, Yuan and Liu, 2021; Motschmann *et al.*, 2022; Salehi, 2022).

Conservation and preservation of water resources in Magetan Regency are needed to maintain a rational and adequate management of the water balance. Conservation scenarios can be carried out to improve water balance conditions (Singha *et al.*, 2022).

The novelty of this research is the establishment of a water management model in Magetan Regency based on regional development, both demographically and regional economic development (agriculture, livestock, fisheries, industry, and tourism), and the environment (river and lake maintenance). The model is a description of the real world, which is followed by water management scenarios. Formation of a water management model in Magetan Regency based on water balance.

The water management model uses a dynamic system model, with an analysis coverage throughout the Magetan Regency area. System dynamic models can explain and reconstruct real-world behaviors. Thus, the variables to be used in the model are representative of important variables in the hydrological cycle and water balance of Magetan Regency. The dynamic system model is a closed system that can dynamically respond to various feedbacks. This feedback can include regional developments in Magetan Regency, or designs of conservation policies for the management of water resources (Simonovic, 2002; Tianhong, Songnan and Mingxin, 2019).

The purpose of this study is to identify the condition of the water balance and water critical index in Magetan Regency; and forming a regional development-based water management model in Magetan Regency. The objectives of establishing a dynamic system model for water management based on regional development in Magetan Regency are to: (1) predicting the condition of the water balance and critical water conditions in Magetan Regency in the future; (2) designing water management policies in Magetan Regency based on conservation and infrastructure development to prevent critical water conditions in Magetan Regency in the future.

MATERIAL AND METHODS

Research Location

The research location is in Magetan Regency. Magetan Regency in the context of hydrology is divided into 10 watersheds. The river flow map in Magetan Regency is shown in Figure 1. This study only uses data from seven watersheds, namely:

1. Plosotinil watershed,
2. Purwodadi watershed,
3. Ulo watershed,
4. Gandong watershed,
5. Bringin watershed,
6. Kenteng watershed,
7. Gonggang watershed.

Data Types and Sources

This study uses secondary data on seven watersheds of Magetan Regency. This research was conducted in February 2023, with data sources coming from the water balance report of the Government of Magetan Regency and Brawijaya University for 2015 calculations, the water balance report of Municipal Waterworks of Magetan Regency, and the Central Bureau of Statistics for Magetan Regency. The data collected then goes through data processing, according to the needs of the research variables. Availability of data on each research variable is also a limitation and scope of research.

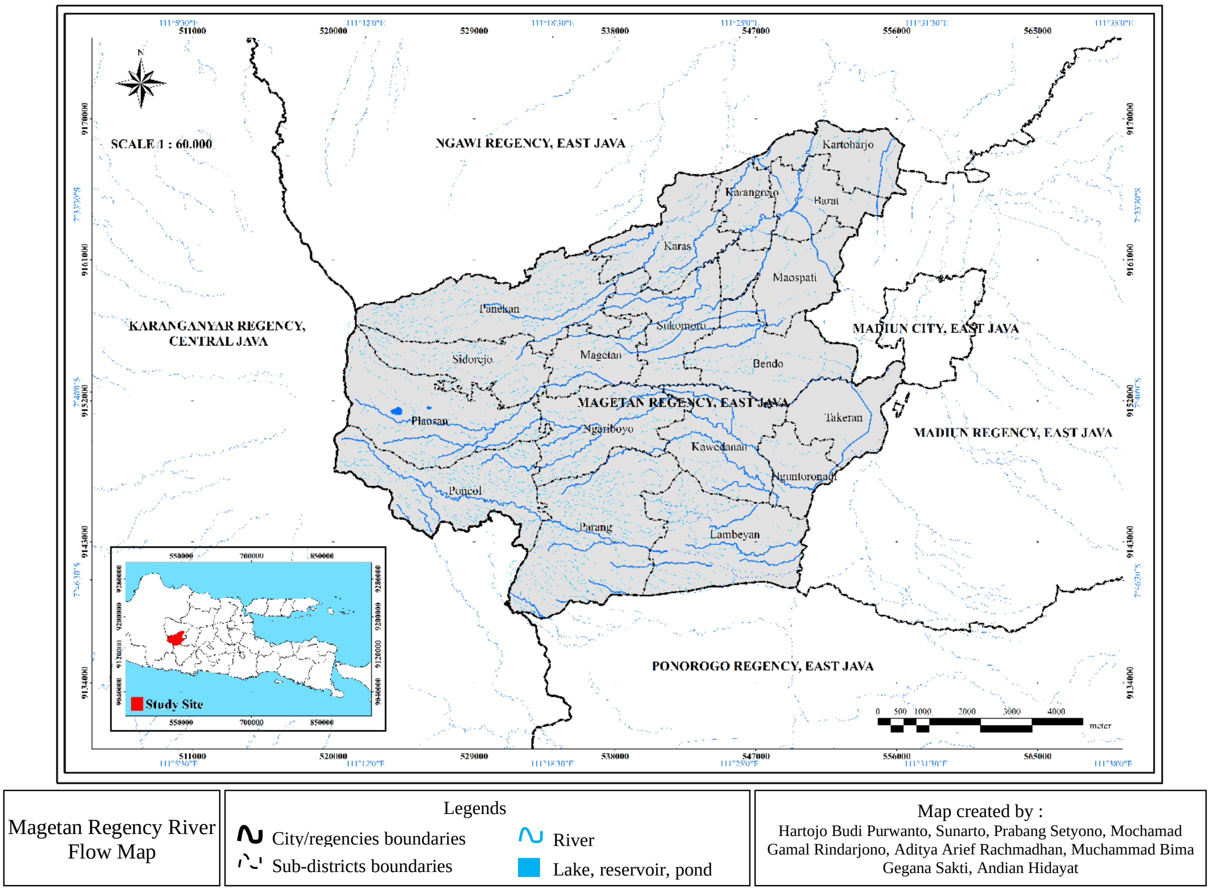


Figure 1. Map of the Magetan Regency river flow.

Research Variables

Research variables and data availability become the limitations and scope of the research. In general, the variables in this study are divided into four main groups, namely: (1) the water availability variable for Magetan Regency, (2) the water demand variable for Magetan Regency, (3) water balance variable for Magetan Regency, and (4) the development variable for the Magetan Regency area. The details of the research variables are shown in Table 1.

Water Balance Calculation Method

The water balance in Magetan Regency is the difference between the amount of water availability and water demand in Magetan Regency. The calculation of the water balance can be formulated mathematically as follows (Sanchez *et al.*, 2020; Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Naderi, 2021; Rusli *et al.*, 2021; Halli *et al.*, 2022):

water balance = water availability – water demand
water availability = surface water + subsurface water
surface water = rivers + lakes, reservoirs, ponds
subsurface water = springs + wells
water demand = domestic + agriculture, livestock, fishery + industry + tourism + river maintenance

Rainfall is not included in the calculation directly; because the rainfall that falls undergoes a process of infiltration and runoff so that it experiences discharge towards surface water (rivers, lakes) and/or subsurface water (springs and wells). Calculation of rainfall on water availability will lead to double calculations. Domestic water needs include domestic water needs from Municipal Waterworks customers and residents who are not Municipal Waterworks customers.

Table 1. Research variables, measurement units, and year of data collection.

Variable	Unit	Year
Water availability in Magetan Regency		
1. Surface water		
a. River	m^3	2016
b. Lake, reservoir, ponds	m^3	2016
2. Subsurface water		
a. Water springs	m^3	2016
b. Wells	m^3	2016
Water demand in Magetan Regency		
1. Domestic needs	m^3	2016
2. The needs of agriculture, farm, fisheries	m^3	2016
3. Industrial needs	m^3	2016
4. Tourism needs (Sarangan Lake)	m^3	2016
5. The needs for maintenance of rivers and lakes	m^3	2016
Magetan Regency water balance	m^3	2016
Magetan Regency water critical index	%	2016
The development of Magetan Regency		
1. Total population of Magetan Regency	people	2016
2. Population growth rate in Magetan Regency	%/year	2016-2020
3. Absorption of labor in the industrial sector	people	2016
4. Industrial growth (labor)	people/year	2017-2018
5. Agricultural land area	ha	2016
6. Growth of irrigated fields	ha/year	2017-2018
7. Total of cattle livestock	cows	2016
8. Growth in the number of cattle	cow/year	2016-2020
9. Total of fishery area	ha	2016
10. Growth of fisheries area	ha/year	2017-2020
11. Total of tourist (Sarangan Lake)	people	2016
12. Growth in the number of tourist (Sarangan)	people/year	2016-2019
13. Reforestation[1]	tree/year	2016-2020
14. Construction of reservoir[1]	m^3	2016-2020
15. Rainfall	mm	2016
16. Growth of rainfall	mm	2017-2019
17. River and lake sediments[1]	meter	2016
18. Sedimentation of rivers and lakes[1]	meter/year	2016-2020
19. Maintenance of rivers and lakes[1]	times/year	2016-202

Note: [1]assumption/hypothesis value

The calculation of the water balance is followed by an analysis of the water crisis index. The water crisis conditions indicate the low availability of water to meet water needs. The water critical index is calculated using the following equation (Pedro-Monzonis *et al.*, 2015):

$$\text{water critical index }(\%) = \frac{\text{water demand}}{\text{water availability}} \times 100\%$$

with the classification of water critical index as shown in Table 2.

Table 2. Water critical index classification.

Water Critical Index	Classification
< 50%	Not critical
50% - 75%	Close to critical
75% - 100%	Critical
> 100%	Very critical

Designing Water Management Model in Magetan Regency Based on Regional Development

The regional development-based water management model in Magetan Regency is based on the balance designed water using the system dynamic method. The model emphasizes the description of how water management is based on the interaction between variables in the water balance with the development of the Magetan Regency area (Simonovic, 2002; Tianhong, Songnan and Mingxin, 2019; Maswanganye *et al.*, 2022; Salehi, 2022). The main stages of designing a water management model using the system dynamic method sequentially are (Sterman, 2000):

1. Problem Formulation

The main issue in this research is the need for integrated water management to achieve a balance between water availability and water demand due to regional development in Magetan Regency, both demographically (population growth) and regional economic development (agriculture, industry, and tourism). and the environment (maintenance of rivers and lakes) (Boldt *et al.*, 1999; Gossling *et al.*, 2012; Restrepo A, Kettner and Brakenridge, 2020; Sanchez *et al.*, 2020; Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Halli *et al.*, 2022; Pierrat *et al.*, 2023). The goal of integrated water management is to avoid a water balance deficit and avoid critical water conditions in the future (Ahmad *et al.*, 2021; Huang, Yuan and Liu, 2021; Motschmann *et al.*, 2022; Salehi, 2022). The problem formulation is based on the main research issues (problems) in Table 3.

2. Model Identification and Formulation

The regional development-based water management model in Magetan Regency is divided into 2 main sub-systems, namely: (1) water supply sub-system, and (2) water demand sub-system. Based on the problem formulation, identification and model formulation are then carried out; namely (1) *causal loops diagram* formulation, (2) identification of variables and *black box* diagram, and (3) *stock and flows map* formulation.

The research variables (Table 1) are connected in *causal loops diagram* between variables, with a sign of the polarity of the relationship (positive or negative). *Causal loops diagram* of the Magetan Regency water management model based on regional development is shown in Figure 2. Based on *causal loops diagram*, to identify the variables in the *black box* diagram (shown in Figure 3).

Furthermore, based on *causal loops diagram* and *diagram black box*, formulations are then carried out in *stock and flows maps*. The water management model based on regional development in Magetan Regency is divided into 2 subsystems, namely the water supply subsystem and the water demand subsystem; and connected to the water balance of Magetan Regency. The regional development-based water management model in Magetan Regency uses the initial value of 2016.

a. **Water availability subsystem**

The availability of water comes from the availability of surface water and subsurface water (Naderi, 2021). Calculation of surface water is the sum of the volume of water in lakes and reservoirs (calculated from the volume of Sarangan Lake, Wahyu Lake, and the Gonggang Reservoir) and the volume of river water (calculated from river discharge). Meanwhile, subsurface water is the sum of the volume of water from springs and wells (calculated from spring and well debits).

Rainfall is the factor that most influences water availability (Juma *et al.*, 2022). However, rainfall is a macro variable that cannot be controlled. Controlled micro factors in the water availability subsystem are reforestation, maintenance of rivers and lakes, and construction of reservoirs.

b. **Water demand subsystem**

The need for water in Magetan Regency is the volume of water needed: (1) domestic water needs, (2) water needs for agriculture, livestock, fisheries, (3) industrial water needs; (4) tourism water needs, and (5) water needs for river maintenance. The need for water in Magetan Regency is influenced by regional development factors, both demographically (population) and economically (industrial sector growth, agricultural sector growth, and tourism sector growth) (Boldt *et al.*, 1999; Gossling *et al.*, 2012; Restrepo A, Kettner and Brakenridge, 2020; Sanchez *et al.*, 2020; Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Halli *et al.*, 2022; Pierrat *et al.*, 2023). These factors are micro factors (within Magetan Regency) which cannot be controlled because the variables that influence them are *excluded* variables in this study.

Table 3. Problem formulation of water resource management

Variable	Problem formulation
Water availability	Common conditions that occurred include: 1. Rainfall has decreased by an average of 23.80% (2017-2019); 2. The development of infrastructure and deforestation conditions in the recharge area reduce infiltration rates and increase water runoff rates; 3. Sedimentation in rivers and lakes. So it is hypothesized to cause problems in water availability including: 1. The river debit is suspected to have decreased; 2. The volume of lake water is suspected to have decreased; 3. The debit of springs is suspected to have decreased; 4. It is suspected that the discharge of wells has decreased.
Water demand	Common conditions that occur include: 1. The average population growth rate is 1.7% annually (2016-2020); 2. The average GRDP growth rate is 3.8%; 3. The rate of increase in the number of workers in the industrial sector was 7.83% (2015-2018); 4. Tourism growth in Magetan Regency after the Covid-19 pandemic. So that it is hypothesized to cause problems with water demand in Magetan Regency including: 1. Domestic water demand is suspected to have increased. 2. The need for water for agriculture, livestock and fisheries is suspected to have increased. 3. The need for industrial water is suspected to have increased. 4. The need for allocation of water needs for river maintenance in Magetan Regency.

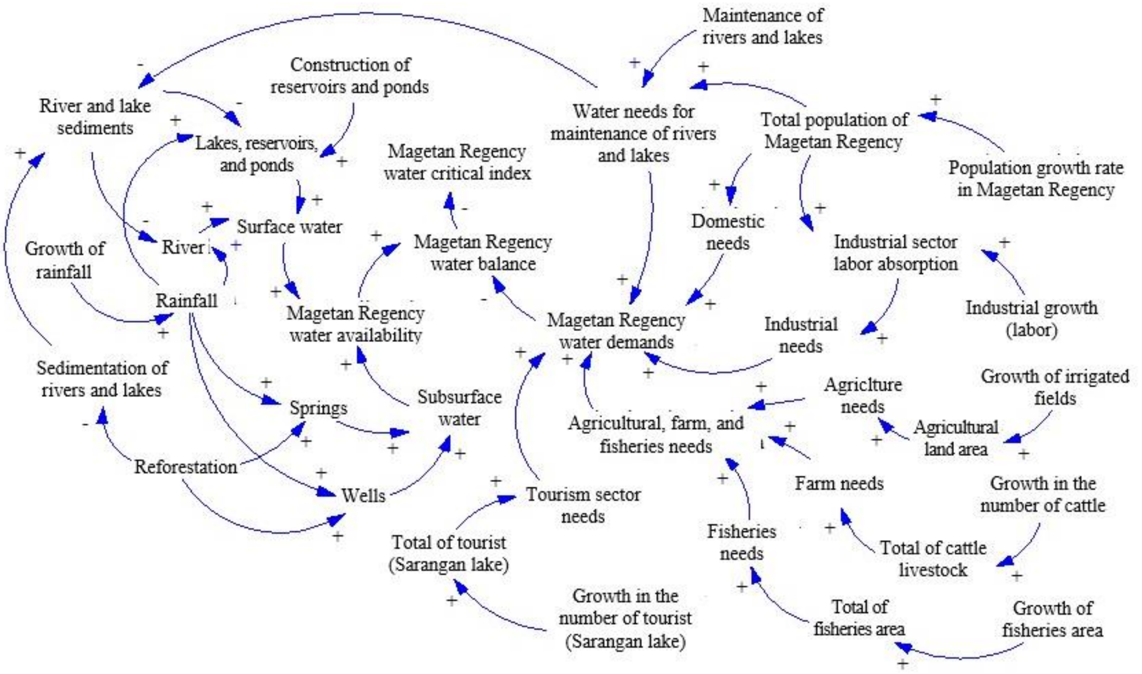


Figure 2. *Causal loops diagram* of the Magetan Regency water management model based on regional development

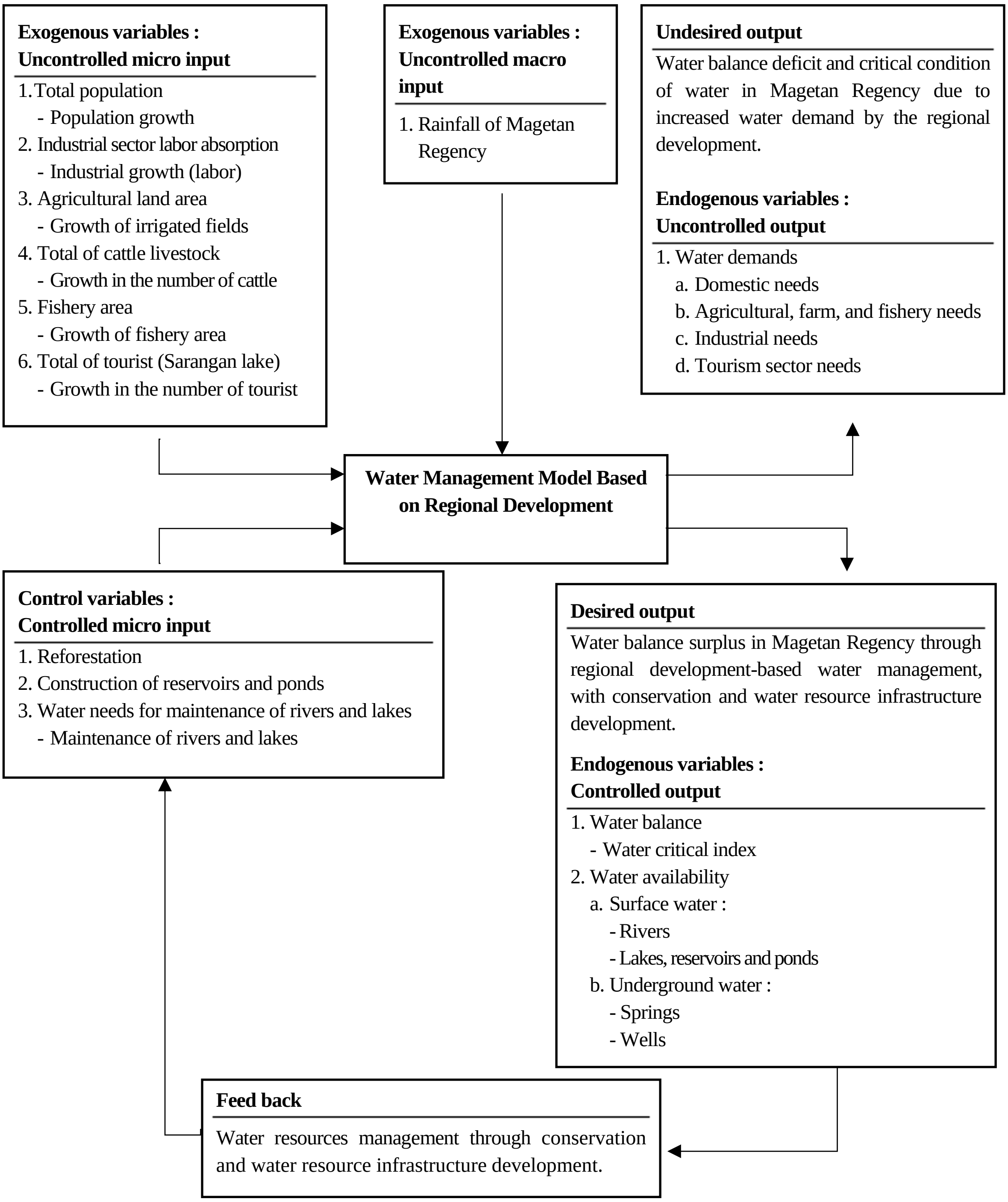
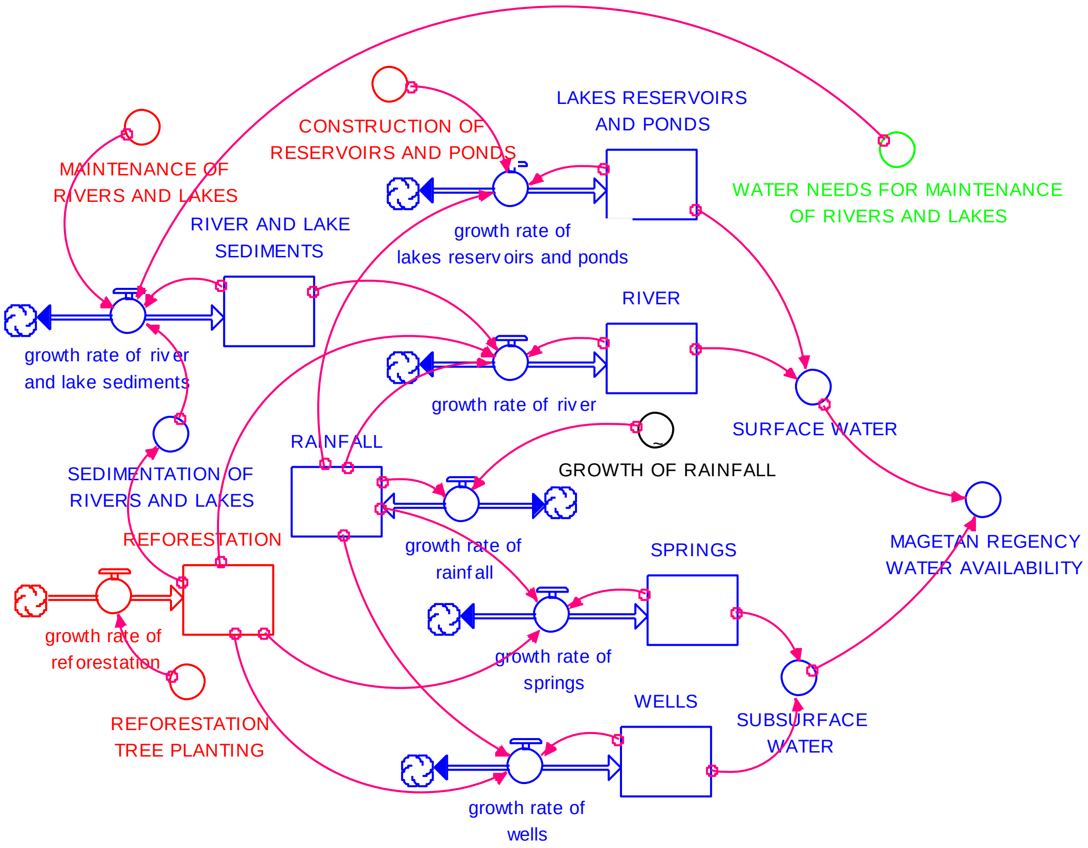


Figure 3. *Black box* diagram of Magetan Regency water management based on regional development.

c. **Magetan Regency water balance**

The Magetan Regency water balance is a confluence between the water supply and water demand subsystems of Magetan Regency; and identifying how critical or vulnerable water is in an area. Magetan Regency's water balance is an important indicator of Magetan Regency's water management (Huang, Yuan and Liu, 2021; Naderi, 2021; Rusli *et al.*, 2021; Juma *et al.*, 2022).

Thus, the models are fully interconnected in the stock and flow model diagram shown in Figure 7.



Note : The macro variable cannot be controlled
Controlled micro variables (control variables)
Influential variables from other subsystems

Figure 4. *Stock and flow* diagram of the water availability subsystem in the Magetan Regency water management model based on regional development

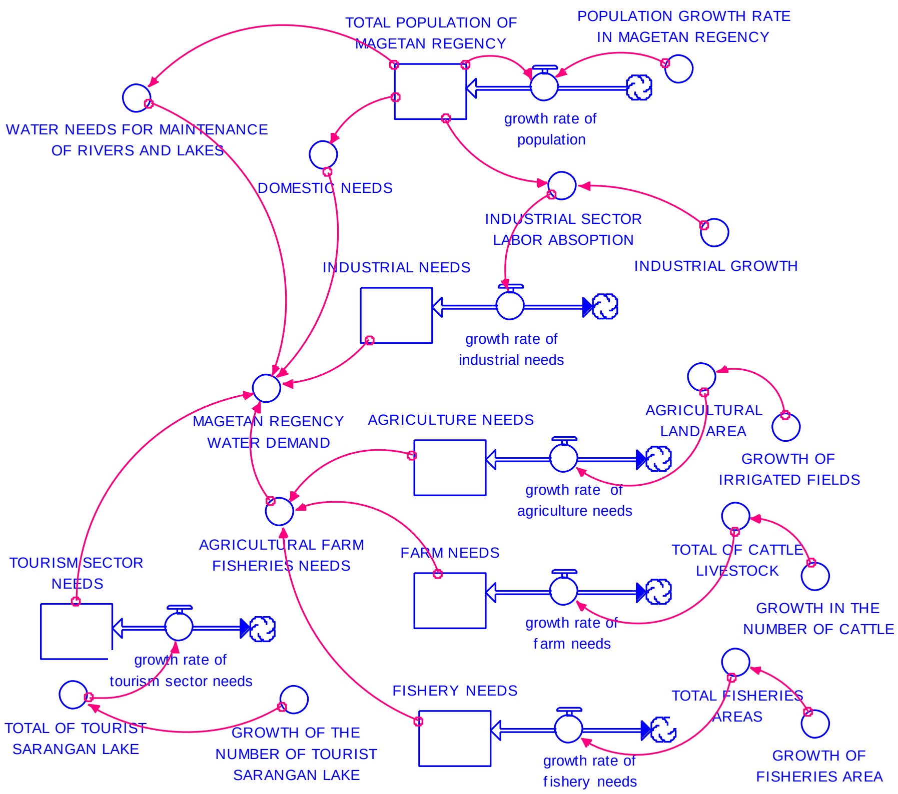


Figure 5. *Stock and* diagram of the water demand subsystem in the Magetan Regency water management model based on regional development.

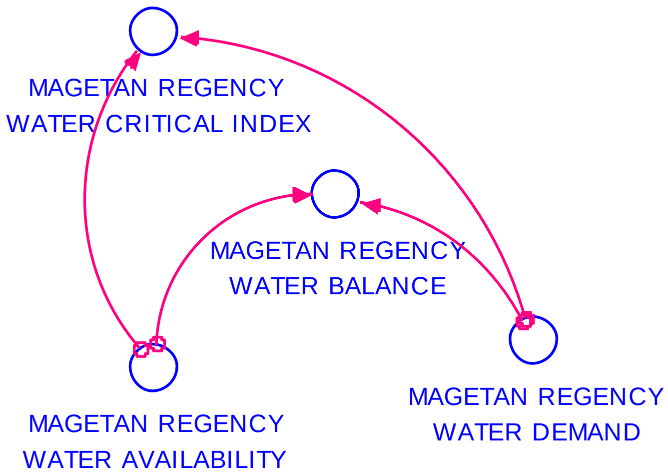


Figure 6. *Stock and flow* diagram in the Magetan Regency water management model based on regional development

3. Model Simulation and Validation

The model simulation was carried out ex-ante with an initial database of 2016 using the following two scenarios:

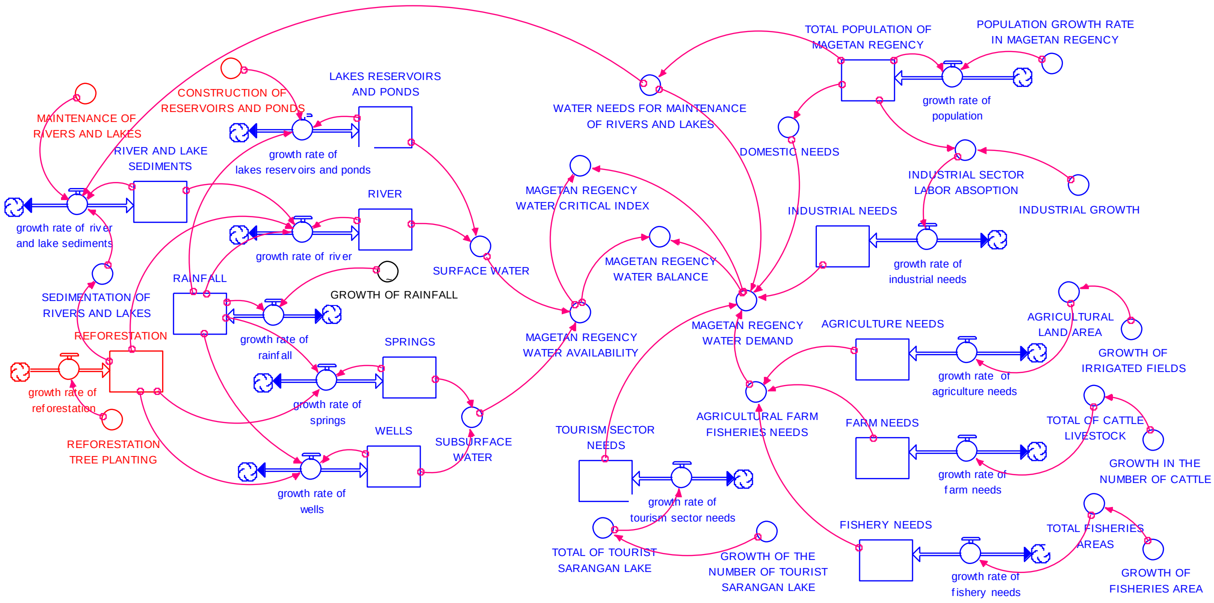
a. Model simulation without policy scenarios

Model simulations without policy scenarios are ex-ante simulations without any changes to the variables and policy scenarios. Model simulations without policy scenarios are used to:

- Ex-ante simulation for 2016 to 2020, used for model validation (feasibility).
- Ex-ante simulation for 2016 to 2030, used to determine the water balance and water critical index of Magetan Regency until 2030 (with a validated model).

b. Model simulation with policy scenarios

The model simulation with policy scenarios is an ex-ante simulation for 2016 to 2030 with changes to the control variables and policy scenarios (with a validated model).



Note : The macro variable cannot be controlled
Controlled micro variables (control variables), policy priorities

Figure 7. Stock and flow diagram of the Magetan Regency water management model based on regional development

Dynamic model validation was performed using *mean percentage error* (MPE) analysis; namely the average percentage deviation value between the simulated value and the actual data value (Sterman, 2000; Carpentras and Quayle, 2022). The MPE equation is as follows:

$$\text{MPE} = \bar{\Sigma}\ \frac{(\text{actual value} - \text{simulated value})}{\text{actual value}} \times 100\%$$

with the following criteria:

MPE < 5% = very precise; valid and usable model.
5% < MPE < 10% = exact; valid and usable model.
MPE > 10% = not correct; the model is invalid and cannot be used

A valid dynamic system model can be used to simulate various feedback.

4. Water Management Model Policy Design

The policy design of the water management model is carried out through *ex-ante* simulations for 2016 to 2030 by making changes to the control variables as feedback. These changes form the basis for determining policy scenarios which include:

a. Reforestation planting 500,000 tree seedlings every year

Reforestation cannot directly impact the hydrological cycle in Magetan Regency; Thus, there is a delay of two years. Reforestation has a direct positive impact on the availability of water in springs and wells; and indirectly has a positive impact on the availability of river water and lake water (Ellison *et al.*, 2017; Rosas, Viveen and Vanacker, 2023).

b. Maintenance of rivers and lakes twice a year

River maintenance is encouraged to be carried out more frequently than before, with maintenance of rivers and lakes, ponds, reservoirs for each watershed being carried out twice a year. River maintenance aims to clean river sediments (Boldt *et al.*, 1999; Rosas, Viveen and Vanacker, 2023).

c. Construction of reservoirs with a capacity of 5000m^3 annually
The construction of reservoirs is carried out with a target of building an additional volume capacity of 5,000 m^3 each year. The construction of reservoirs aims to increase the capacity of surface water reserves for agriculture, livestock and fisheries in Magetan Regency (Jayanti *et al.*, 2023).

Furthermore, a comparison of the value of the ex-ante simulation in the absence of a policy scenario is carried out with the value of the ex-ante simulation in the presence of a policy scenario.

RESULTS AND DISCUSSION

Magetan Regency Water Balance

Analysis of the water balance in Magetan Regency is the difference between the amount of water availability and water demand in Magetan Regency. Calculation of the water balance is also followed by analysis of the critical index of water. Evaluation of the water balance in Magetan Regency can be used to identify how critical or vulnerable water is in an area. The water balance and annual water critical index in Magetan Regency are shown in Table 4.

Table 4. Magetan Regency water balance.

Variable	Volume (m^3)
Water availability in Magetan Regency	
1. Surface water	
a. River	107.090.174
b. Lake, reservoir, ponds	26.500.000
2. Subsurface water	
a. Water springs	1.797.552
b. Wells	131.091.368
Water demand in Magetan Regency	
1. Domestic needs	34.104.166
2. The needs of agriculture, farm, fisheries	58.023.460
3. Industrial needs	15.468.281
4. Tourism needs (Sarangan Lake)	3.090.528
5. The needs for maintenance of rivers and lakes	68.748.480
Total water availability	266.479.094
Total water demand	179.434.914
Water balance	87.044.180
Water critical index (%)	67,335
Water critical condition	Close to critical

Note: based on the calculated value of 2016.

Rivers are the main source of surface water, with a volume of availability in one year of 107,090,174 m^3 (based on seven watersheds). Lake water is a supporting component of water availability in Magetan Regency, with a volume capacity of up to 26,500,000 m^3. The availability of lake water in Magetan Regency refers to three large (main) lakes, namely the Gonggang Poncol Reservoir, Sarangan Lake, and Wahyu Lake. Surface water is mainly used for agricultural irrigation needs in Magetan Regency (Halli *et al.*, 2022; Maswanganye *et al.*, 2022; Jayanti *et al.*, 2023).

Even so, the largest source of water in Magetan Regency is from well water, with a volume of supply in one year of 131,091,368 m^3. There are 145 recorded well points in Magetan Regency, which are spread over 12 sub-districts. Wells can generally be in the lowlands to the highlands. Meanwhile, the volume of water availability from springs is only

1,797,552 m^3. There are 23 springs in Magetan Regency, spread across Panekan, Poncol, Sidorejo and Plaosan Districts. Springs are generally located in the highlands. Subsurface water sources are sources of clean water primarily for the domestic needs of the community (Rusli *et al.*, 2021; Ha *et al.*, 2022; Bhunia, Shit and Brahma, 2023).

The need for water for maintenance of rivers is the largest, but the need for water for maintenance of rivers is not the need for used water. The need for water for river maintenance is the flow of water needs that must be available to keep flowing in the river; as an effort to maintain the condition of the river ecosystem to remain sustainable (Restrepo A, Kettner and Brakenridge, 2020; Pierrat *et al.*, 2023).

The largest demand for used water is from the agricultural, livestock and fisheries sectors of 58,023,460 m^3. This is due to the large demand for water for agricultural irrigation, with a total water requirement of 50,757,565 m^3. The area of irrigated rice fields in Magetan Regency is equivalent to 40.6% of the area of Magetan Regency. The irrigation water needs of the agricultural sector and the water needs for river maintenance depend on the availability of rivers and lakes (Halli *et al.*, 2022; Maswanganye *et al.*, 2022).

The calculated amount of water requirement for irrigation has been converted based on the assumption of plant raw water needs; i.e. water experiencing evapotranspiration, with a coefficient value of 0.11574. This means that only 11.574% of the water flowing into irrigated rice fields experiences evapotranspiration through plants. While the rest becomes runoff water back into the river and some of it enters the soil (infiltration) (Anapalli *et al.*, 2019).

The water demand for the livestock sub-sector in one year is 4,493,880 m^3. The water needs of the livestock sub-sector are the need for clean water for livestock drinking water, feed processing, cage sanitation, and post-harvest processing in the livestock sector. The need for clean water for livestock depends on the number of livestock population and the type of livestock. Fulfilling the need for clean water in the livestock sub-sector is mainly met from well water (Burkhardt *et al.*, 2022).

The need for water in the fisheries sub-sector in one year is 2,772,014 m^3; with a water requirement per hectare of fishery area of 25,494 m^3. The total fishery area in Plaosan District is 36.33 ha; with a general fishery area of 35 ha and a pond fishery area of 1.33 ha. The need for water in the fisheries sub-sector is for pond water, cleanliness and rinsing of ponds for freshwater fish farming. Fulfilling the water needs of the fisheries sub-sector can be met from the availability of water from rivers and lakes; however, wells are the main source of water for fisheries, especially for aquaculture ponds and nurseries (Kwon *et al.*, 2022).

Domestic water demand is the need for clean water for drinking water, sanitation, and other domestic activities. Domestic water demand in Magetan Regency in one year is 34,104,166 m^3, with a per capita water requirement of 54.31 m^3. The amount of domestic water demand is very dependent on the population in the region. The more numerous and densely populated an area is, the higher the demand for domestic water. The need for clean water in Magetan Regency is obtained from springs and well water. Meeting the needs of clean water from springs is obtained directly, or indirectly through Municipal Waterworks (Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Rusli *et al.*, 2021; El Shinawi *et al.*, 2022; Ferencz, Dawidek and Bronowicka-Mielniczuk, 2022; Halli *et al.*, 2022).

Industrial sector water needs are water needs for production and non-production activities in the industrial sector; with a total water requirement of 15,468,281 m^3. The need for water for the industrial sector is the need for clean water. As the number and size of industries increase, the demand for water in the industrial sector also increases (Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Halli *et al.*, 2022).

The largest industrial sector's water demand is for the sugar industry. There are two sugar factories in Magetan Regency, namely Rejosari Sugar Factory and Purwodadi Sugar Factory; with a total water volume requirement of 14,843,520 m^3.

The industry with the second largest demand for water is the leather tanning and leather craft industry, with a total volume requirement of 471,744 m^3 of water. The greatest need for water in the leather industry is during the leather tanning process. The leather tanning industry and leather crafts are carried out by micro and small businesses. The leather craft industry in Magetan Regency includes 188 leather tanning business units and 333 leather craft business units; which is centralized in Magetan District.

The need for clean water for other industries in Magetan Regency is not as large as that for the sugar industry and the leather craft industry. Other industries that are developing in Magetan Regency are micro and small business scale industries; in the types of business of food and beverage, convection, construction and building materials, printing, and other business sectors.

The need for water in the tourism sector is the need for water with the lowest volume, namely 3,090,528 m^3. Magetan Regency is famous for its Sarangan Lake tourist destination. Sarangan Lake is one of the favorite tourist destinations in East Java Province. The total water demand for the tourism sector is calculated based on the number of tourists; with an estimated water requirement for each tourist of 3.61 m^3. The need for water includes the need for water for domestic and non-domestic purposes in the tourism sector; both at tourist sites, and hotels that support the tourism sector (Gossling *et al.*, 2012).

The annual water balance of Magetan Regency shows a surplus of water volume of 87,044,180 m^3. The annual critical water index for Magetan Regency shows a value of 67.335%. So, it can be concluded that the water balance and water critical index of Magetan Regency are close to critical condition.

The condition of the water balance of Magetan Regency must receive special attention, both from the Magetan Regency government and the East Java Provincial Government; as well as the academic community, environmental activists, and various related stakeholders. The water balance in Magetan Regency will get worse if attention, supervision, and repressive actions are not received (Singha *et al.*, 2022).

Furthermore, to better understand the condition of the water balance in Magetan Regency, it is necessary to detail the water balance. This breakdown of the water balance is also a novelty in this study. The condition of the water balance in Magetan Regency can be detailed, by calculating the net water balance and surface water balance.

1. Clean Water Balance of Magetan Regency

The clean water balance is an analysis of the balance between the availability of water from clean water sources suitable for consumption (springs and wells) and the demand for clean water (domestic water needs, industry, livestock, fisheries, and tourism). The annual water balance and critical index of clean water in Magetan Regency are shown in Table 5.

Magetan Regency's annual clean water balance shows a surplus of water volume of 72,960,051 m^3. The water critical index for Magetan Regency shows a value of 45.097% (not critical). Furthermore, the annual clean water balance can also be broken down based on the source of clean water for the people of Magetan Regency; namely from Municipal Waterworks sources and well water sources.

Clean water balance from Municipal Waterworks Magetan Regency

Municipal Waterworks water source is water from springs. Municipal Waterworks water sources are assumed to be used only for the domestic needs of the people of Magetan Regency.

The water balance and the critical index of clean water for Municipal Waterworks sources are shown in Table 6.

Table 5. Magetan Regency clean water balance.

Variable	Volume (m^3)
Water availability in Magetan Regency	
1. Subsurface water	1,797,552
a. Water springs	131,091,368
b. Wells	
Water demand in Magetan Regency	
1. Domestic needs	1,485,630
a. Municipal Waterworks	32,618,535
b. Domestic non-Municipal Waterworks	15,468,281
2. Industrial needs	4,493,880
3. The needs of agriculture, farm, fisheries	2,772,014
	3,090,528
a. Farm	
b. Fisheries	
4. Tourism needs (Sarangan Lake)	
Total water availability	132,888,920
Total water demand	59,928,869
Water balance	72,960,051
Water critical index (%)	45.097
Water critical condition	Not critical

Note: based on the calculated value of 2016.

Magetan Regency's annual clean water balance based on Municipal Waterworks water sources shows a surplus of water volume of 311,922 m^3; with a critical index value of 82.647% (water critical). The condition of the water balance from Municipal Waterworks sources shows the condition of the water balance from springs. It is concluded that the water balance and critical index of clean water from Municipal Waterworks sources (springs) are in critical water conditions.

Table 6. Magetan Regency clean water balance for Municipal Waterworks sources.

Variabel	Volume (m^3)
Water availability in Magetan Regency	
1. Subsurface water a. Water springs	1,797,552
Water demand in Magetan Regency	
1. Domestic a. Municipal Waterworks	1,485,630
Water balance	311,922
Water balance	82.647
Water critical index (%)	Critical

Note: based on the calculated value of 2016

Spring water is a crucial water source and is closely related to environmental sustainability. Excessive exploitation of springs can have a negative impact on the environment. Efforts to manage and conserve spring water sources must be a top priority. Environmental conditions and natural water resources will get worse if they do not get attention, supervision, and repressive actions (Ferencz, Dawidek and Bronowicka-Mielniczuk, 2022; Singha *et al.*, 2022; Bhunia, Shit and Brahma, 2023).

1. Clean water balance of wells in Magetan Regency

Most people in Magetan Regency use well water as a source of clean water for domestic needs. Industrial, livestock, fishery, and tourism water needs are also assumed to come from well water sources. The water balance and criticality index of well water are shown in Table 7.

Magetan Regency's annual well water balance sheet shows a surplus of water volume of 72,648,129 m^3; with a water critical index of 44.582% (not critical). Thus, it is concluded that the water balance and critical index of water from well water sources in Magetan Regency are not critical.

Table 7. Magetan Regency clean water balance for wells.

Variable	Volume (m^3)
Water availability in Magetan Regency	
1. Subsurface water	131,091,368
a. Wells	
Water demand in Magetan Regency	
1. Domestic needs	32.618.535
a. Domestic non-Municipal Waterworks	15,468,281
2. Industrial needs	4,493,880
3. The needs of agriculture, farm, fisheries	2,772,014
a. Farm	3,090,528
b. Fisheries	
4. Pariwisata	
Total water availability	131,091,368
Total water demand	58,443,238
Water balance	72,648,129
Water critical index (%)	44.582
Water critical condition	Not critical

Note: based on the calculated value of 2016

Even so, the use and exploitation of well water sources needs attention. This is due to the large level of community demand for clean water sources; and well water is the main source of water availability for the people of Magetan Regency.

Over-exploitation of well water can have a negative impact on the environment. Excessive exploitation can have an impact on lowering the ground level. In addition, environmental conditions and the availability of subsurface water resources will decrease if attention, supervision, and repressive measures are not received (Ty *et al.*, 2021; El Shinawi *et al.*, 2022; Singha *et al.*, 2022; Bhunia, Shit and Brahma, 2023).

2. *Surface Water Balance of Magetan Regency*

Surface water balance is a calculation of water availability from surface water sources (rivers and lakes) and surface water demand (agricultural irrigation water needs, and river maintenance water needs). Surface water needs are divided into used water needs, namely for agricultural irrigation water needs, and available water needs, namely water needs for river maintenance. Surface water balance and water critical index are shown in Table 8.

Table 8. Magetan Regency surface water balance.

Variable	Volume (m^3)
Water availability in Magetan Regency	
1. Surface water	
a. River	107,090,174
b. Lakes, reservoirs, ponds	26,500,000
Water demand in Magetan Regency	
1. The needs of agriculture, farm, fisheries	
a. Agriculture (irigation, used)	50,757,565
2. The needs for maintenance of rivers and lakes (need to be available)	68,748,480
Used water balance	82,832,609
Total water balance	14,084,129
Used water critical index (%)	37.995
Water critical index (%)	89.457
Conclusion for water critical condition	Critical

Note: based on the calculated value of 2016

Based on the balance of used water (for agricultural irrigation water needs), the surface water balance experienced a surplus of water volume of 82,832,609 m^3; with a water critical index of 37.995% (not critical). Nevertheless, based on the total water balance, the surface water balance experienced a surplus of water volume of 14,984,129 m^3; with a water critical index of 89.457% (water critical). So, it can be concluded that the water balance and critical index of surface water in Magetan Regency are in critical water condition.

The surface water balance shows a surplus because it is supported by the volume of water reserves in lakes/reservoirs. Even so, the amount of water reserves in the lake/reservoir will be exhausted if there is no inflow of water; either from the hydrologic cycle from rainwater, or from river water discharge (Maswanganye *et al.*, 2022).

However, the high critical condition of water in the annual water balance allows for a deficit of water discharge in the dry season. This shows that the need for water discharge for river maintenance cannot be fulfilled during the dry season. If the water needs for river maintenance are not met, it can have a negative impact on the physical condition and river ecosystems in Magetan Regency (Boldt *et al.*, 1999; Restrepo A, Kettner and Brakenridge, 2020; Pierrat *et al.*, 2023).

Water Management Model Analysis Based on Regional Development

Integrated water management is needed to avoid critical water conditions in Magetan Regency in the future. The design of a water management model based on regional development in Magetan Regency uses the system dynamic method (Simonovic, 2002; Pedro-Monzonis *et al.*, 2015; Tianhong, Songnan and Mingxin, 2019; Ahmad *et al.*, 2021; Maswanganye *et al.*, 2022; Motschmann *et al.*, 2022; Salehi, 2022; Bhunia, Shit and Brahma, 2023). The first step is to validate the model. Next, the results of model simulations without policy scenarios and model simulations with policy scenarios will be discussed.

1. Validation of Water Management Model Analysis Based on Regional Development

Model validation is carried out to determine whether the system model is a legitimate representative of the reality being studied. The results of the validation of water management model analysis based on regional development in Magetan Regency are shown in Table 9.

2. Simulation Validation of Water Management Model Analysis Based on Regional Development without Policy Scenario

Ex-ante model simulation by imitating real conditions (without changes to variables and policy scenarios) for 2016 to 2030. Simulation of water balance and critical water index of Magetan Regency until 2030. The results of the model simulation without policy scenarios are shown in Table 10.

The model simulation results show that water availability fluctuates from year to year, and water demand continues to grow over time. This causes fluctuations in the water balance; so is the critical index of water. In general, the condition of the water balance in Magetan Regency during the period 2016 to 2030 is close to critical; however, critical water conditions also occurred during the 2018-2020, 2023, and 2027-2029 periods.

Table 9. Validation of water resources management model based on regional development.

Variable	Year of comparison	*MPE* (%)
Water availability in Magetan Regency	2016	0.000
1. Surface water	2016	0.000
a. River	2016	0.000
b. Lakes, reservoirs, and ponds	2016	0.000
2. Subsurface water	2016	0.000
a. Springs	2016	0.000
b. Wells	2016	0.000
Water demand in Magetan Regency	2016	0.043
1. Domestic needs	2016	-0.001
2. The needs of agriculture, farm, fisheries	2016	0.504
3. Industrial needs	2016	0.000
4. Tourism needs (Sarangan Lake)	2016	0.000
5. The needs for maintenance of rivers and lakes	2016	0.000
Water balance	2016	-0.089
The Development of Magetan Regency		
1. Total population of Magetan Regency	2016-2020	2.532
2. Absorpstion of labor in the industrial sector	2017-2018	0.557
3. Agricultural land area	2017-2018	0.002
4. Total of cattle livestock	2016-2020	-8.650
5. Total of fishery area	2017-2020	0.000
6. Total of tourist (Sarangan Lake)	2016-2019	0.224
7. Rainfall	2016-2019	0.083

The validation results of the dynamic model show that the model is within the correct estimate (5% < MPE < 10%) to very precise (MPE < 5%) for the key variables. So, it is concluded that the model formed is valid, and is a legitimate representative of the reality being studied with convincing conclusions.

Table 10. The results of the simulation of the water balance model in Magetan Regency (2016-2030).

Year	Water availability (m^3)	Water demand (m^3)	Water balance (m^3)	Water critical index(%)	Water critical condition
2016*	266,479,094	179,512,570	86,966,524	67.36	Close to critical
2017	254,756,053	181,322,903	73,433,150	71.18	Close to critical
2018	223,746,879	182,069,382	41,677,497	81.37	Critical
2019	203,099,903	182,823,842	20,276,061	90.02	Critical
2020	220,957,998	183,588,980	37,369,018	83.09	Critical
2021	260,642,266	184,364,980	76,277,286	70.73	Close to critical
2022	250,418,774	185,152,026	65,266,748	73.94	Close to critical
2023	243,000,757	185,950,308	57,050,448	76.52	Critical
2024	274,744,003	186,760,019	87,983,984	67.98	Close to critical
2025	282,075,331	187,581,353	94,493,979	66.50	Close to critical
2026	267,848,484	188,414,509	79,433,975	70.34	Close to critical
2027	251,248,142	189,259,691	61,988,451	75.33	Critical
2028	241,329,638	190,117,103	51,212,536	78.78	Critical
2029	247,252,876	190,986,954	56,265,921	77.24	Critical
2030	270,652,574	191,869,459	78,783,115	70.89	Close to critical

Note: *initial value

The simulation results also show that the worst water balance conditions are in 2018-2020. The simulation results are close to real conditions, where drought was reported due to drought in Magetan Regency during the 2018-2020 period, with the peak of drought in 2019. Several sub-districts experienced drought because of a long drought; this has caused a water crisis in several sub-district locations in Magetan Regency.

This condition occurs due to fluctuations in water availability from year to year, and water demand continues to grow over time. Fluctuations in water availability are strongly influenced by rainfall conditions in Magetan Regency; while the need for water is strongly influenced by the development of the region. Rainfall is the main factor in the availability of water in Magetan Regency, which in turn affects the availability of water in rivers, lakes, springs and wells (Naderi, 2021; Juma *et al.*, 2022; Jayanti *et al.*, 2023). The graph of the development of water availability and rainfall in Magetan Regency is shown in Figure 8.

The availability of water in Magetan Regency moves along with the rainfall conditions in Magetan Regency. During the period from 2016 to 2019, rainfall in Magetan Regency decreased by an average of 26.33% annually. This condition certainly causes a decrease in water discharge from rivers, springs, and wells, as well as a decrease in the volume of lake water.

Demographic growth affects domestic water demand. The population growth rate of Magetan Regency is 1.7% annually. Demographic growth also affects the need for water for river maintenance; which is calculated based on the multiplication between the number of residents and the need for water for maintenance/flushing per capita. So that the increasing population, the higher the demand for domestic water and the need for water for river maintenance (Baggio, Qadir and Smakhtin, 2021; Huang, Yuan and Liu, 2021; Rusli *et al.*, 2021; Halli *et al.*, 2022; Pierrat *et al.*, 2023).

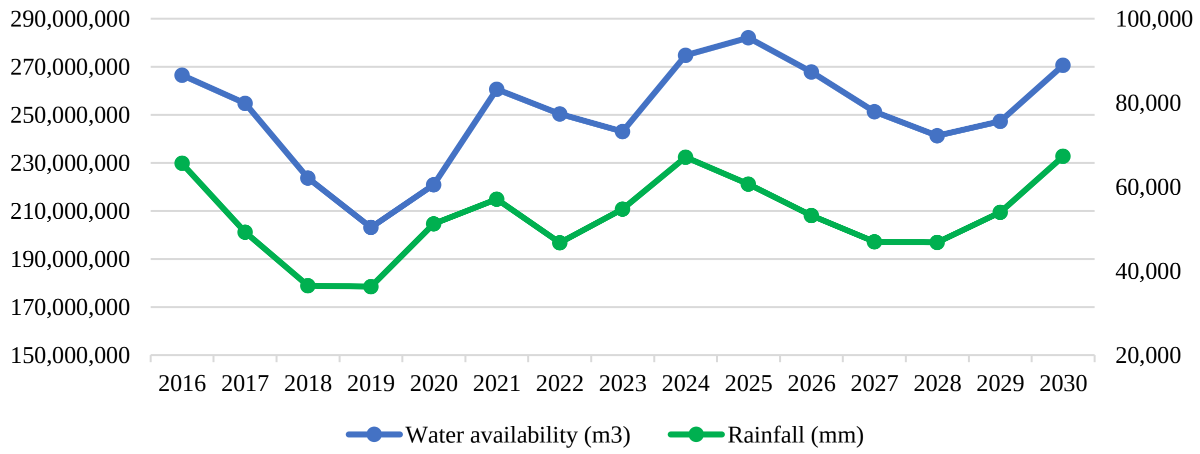


Figure 8. Graph of simulation results of the development of water availability and rainfall in Magetan Regency (2016-2030).

Regional economic development (agriculture, livestock, fisheries, industry, and tourism) also influences water demand in Magetan Regency (Gossling *et al.*, 2012; Burkhardt *et al.*, 2022; Halli *et al.*, 2022; Kwon *et al.*, 2022; Maswanganye *et al.*, 2022). The development of the agricultural sector in Magetan Regency comes from the growth in the number of livestock, with the growth of large livestock an average of 2.55% each year. Meanwhile, the area of agricultural land and fishery area did not show significant growth. Industrial growth in Magetan Regency is shown in terms of labor absorption, where there is a growth in labor absorption of 7.83% annually. While the growth of the tourism sector is shown in the growth of tourists (Sarangan Lake) of 2.38% each year.

Water is one of the most important elements in supporting life. In addition, water is a primary need in every household, agricultural area, economy, and industry. Water resources have always been a major issue in environmental management. Thus, it is necessary to have a management of water resources that starts from the government's model of water resources management policy (Ahmadov, 2020; Luo *et al.*, 2020; Thoma *et al.*, 2020; Huang, Yuan and Liu, 2021; Lv *et al.*, 2021).

Next, a simulation of regional development-based water management models with policy scenarios to avoid critical water conditions in Magetan Regency in the future will be discussed.

3. Simulation of Water Management Model Based on Regional Development with Policy Scenario

The design of water management policies is carried out through *ex-ante* simulations for 2016 to 2030 in a dynamic system model by carrying out scenarios of changes in the control variables. These changes form the basis for determining policy scenarios which include: (1) reforestation, planting 500,000 tree seedlings each year, (2) maintenance of rivers and lakes twice a year, (3) construction of reservoirs with a capacity of 5,000 m^3 each year. Model simulation results with policy scenarios are shown in Table 11.

Based on the model simulation results, in general the condition of the water balance in Magetan Regency during the period 2016 to 2030 is still in close to critical condition, but critical water conditions only occur during the 2018-2020 period. The model simulation results show that water availability is still fluctuating, but can be increased; while the need for water continues to grow over time. Comparison of the amount of water availability in Magetan Regency based on the model simulation results without policy scenarios and with the application of policy scenarios is shown in Table 12.

Water availability can be increased by an average of 5.75% by implementing policy scenarios. Furthermore, a comparison of the amount of water availability based on model simulation results without the application of policy scenarios and with the application of policy scenarios is also shown in graphical form; shown in Figure 9.

Critical water conditions in the future can be avoided by implementing policy scenarios. Water availability is still fluctuating because the main factor for water availability is rainfall. Rainfall is a macro variable that cannot be controlled in the (exogenous) model (Naderi, 2021; Juma *et al.*, 2022; Jayanti *et al.*, 2023). Nonetheless, the policy scenario is proven to be able to increase the availability of water in Magetan Regency.

Table 11. The results of the simulation of the water balance model in Magetan Regency with policy scenario (2016-2030)

Year	Water availability (m^3)	Water demand (m^3)	Water balance (m^3)	Water critical index(%)	Water critical condition
2016*	266,479,094	179,512,570.09	86,966,523.91	67.36	Close to critical
2017	255,207,211	181,322,902.83	73,884,308.06	71.05	Close to critical
2018	229,279,389	182,069,382.23	47,210,006.44	79.41	Critical
2019	212,609,387	182,823,842.09	29,785,545.22	85.99	Critical
2020	233,090,150	183,588,980.36	49,501,170.11	78.76	Critical
2021	276,448,011	184,364,979.73	92,083,031.45	66.69	Close to critical
2022	266,577,699	185,152,026.02	81,425,672.92	69.46	Close to critical
2023	259,434,880	185,950,308.24	73,484,571.39	71.68	Close to critical
2024	294,189,409	186,760,018.61	107,429,390.59	63.48	Close to critical
2025	302,726,346	187,581,352.65	115,144,993.00	61.96	Close to critical
2026	287,956,359	188,414,509.24	99,541,849.83	65.43	Close to critical
2027	270,508,090	189,259,690.63	81,248,399.06	69.96	Close to critical
2028	260,195,768	190,117,102.55	70,078,665.07	73.07	Close to critical
2029	267,002,619	190,986,954.26	76,015,664.58	71.53	Close to critical
2030	292,791,229	191,869,458.58	100,921,770.12	65.53	Close to critical

Note: *initial value

Table 6. Comparison of water availability without policy scenario and with the implementation of policy scenarios (2016-2030)

Year	Water availability (m^3)		Difference (%)
	Without policy scenario	With policy scenario	
2016*	266,479,094	266,479,094	0.00
2017	254,756,053	255,207,211	0.18
2018	223,746,879	229,279,389	2.47
2019	203,099,903	212,609,387	4.68
2020	220,957,998	233,090,150	5.49
2021	260,642,266	276,448,011	6.06
2022	250,418,774	266,577,699	6.45
2023	243,000,757	259,434,880	6.76
2024	274,744,003	294,189,409	7.08
2025	282,075,331	302,726,346	7.32
2026	267,848,484	287,956,359	7.51
2027	251,248,142	270,508,090	7.67
2028	241,329,638	260,195,768	7.82
2029	247,252,876	267,002,619	7.99
2030	270,652,574	292,791,229	8.18

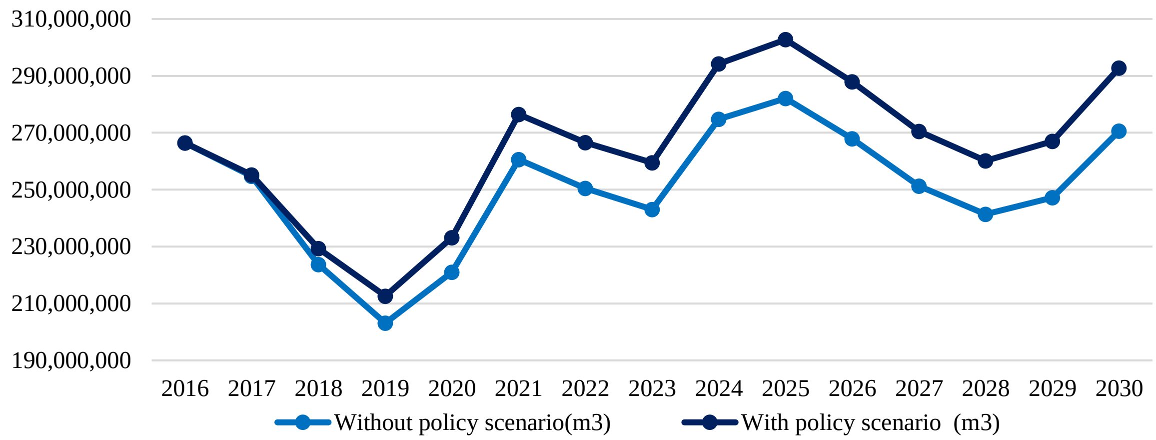


Figure 9. Graph of water availability without policy scenario and with the implementation of policy scenarios (2016-2030)

Reforestation has a direct positive impact on the availability of water in springs and wells; and indirectly has a positive impact on the availability of river water and lake water. However, reforestation cannot directly impact the hydrological cycle in Magetan Regency; It is assumed that there is a delay of two years. This delay occurs because newly planted plants take up to two years to grow and develop; grow roots that can bind and improve soil conditions. So that after two years, the plants can increase the infiltration of water into the soil and reduce the level of water runoff. Thus, further increasing the availability of spring water and wells (Ellison *et al.*, 2017).

Reforestation also improves surface water conditions, by preventing erosion. Reforestation indirectly increases surface water availability, by preventing erosion and deterioration of river cross-sectional conditions, and reducing sedimentation rates; thus, increasing the amount of water availability in the lake. Reforestation also improves surface water quality, by binding soil as a natural filter for water entering rivers and lakes. Even though reforestation can improve the condition of rivers and lakes, river maintenance is still necessary (Ellison *et al.*, 2017; Restrepo A, Kettner and Brakenridge, 2020; Rosas, Viveen and Vanacker, 2023).

River maintenance scenarios need to be encouraged to be carried out more frequently than before; with the maintenance of rivers and lakes/ponds, reservoirs, reservoirs for each watershed carried out twice a year. River maintenance is carried out by flushing the river with the aim of cleaning river sediments. River maintenance is also carried out by dredging river sediments; so, the river becomes deeper. This aims to prevent flooding and erosion along the watershed (Boldt *et al.*, 1999; Rosas, Viveen and Vanacker, 2023).

Maintenance of lakes/ponds, reservoirs, ponds is carried out by surface cleaning and dredging of sediments under the lakes/ponds, reservoirs, ponds. Cleaning the surface of the lake/pond aims to clean up dirt and debris that is on the surface of the lake/pond and that is carried by the currents into the lake/pond. Dredging of sediment under lakes/ponds, reservoirs, ponds aim to increase the volume of water that can be accommodated; thereby increasing the availability of water in lakes/ponds, reservoirs, ponds (Maswanganye *et al.*, 2022; Jayanti *et al.*, 2023; Rosas, Viveen and Vanacker, 2023). Nevertheless, increasing the availability of water reserves in lakes/ponds, reservoirs, ponds is not enough just to reforest and maintain lakes/ponds, reservoirs, ponds; the construction of reservoirs/reservoirs is necessary to increase the availability of water reserves in Magetan Regency.

The reservoir development scenario is carried out with a target of building an additional volume capacity of 5,000 m^3 each year. The construction of reservoirs/reservoirs is necessary for the purpose of increasing the capacity of surface water reserves for agriculture, livestock and fisheries in Magetan Regency (Zavalloni, Raggi and Viaggi, 2020; Jayanti *et al.*, 2023; Kim *et al.*, 2023).

Reservoirs and ponds are infrastructure facilities that are very crucial in the development of the agricultural sector. The need for irrigation water is the need for water with the largest amount in Magetan Regency. Reservoirs and reservoirs are a source of water for irrigation in various agricultural areas. This is because the river water discharge tends to be unstable. When the river water discharge decreases, reservoirs and ponds can provide water reserves for irrigation purposes. On the other hand, when river water discharge overflows, reservoirs and ponds prevent overflows in irrigation channels and prevent paddy fields from being flooded. Thus, reservoirs and ponds are solutions in managing the supply of water needs for irrigation (Zavalloni, Raggi and Viaggi, 2020; Maswanganye *et al.*, 2022; Jain *et al.*, 2023; Jayanti *et al.*, 2023; Kim *et al.*, 2023).

CONCLUSION

The annual water balance of Magetan Regency shows that the water balance and water critical index of Magetan Regency are in near critical condition. In detail, the clean water balance of Magetan Regency shows that the condition is not critical; with the water balance from Municipal Waterworks sources (springs) in critical water conditions, and the water balance from well water sources in Magetan Regency is not critical. The surface water balance in Magetan Regency is in a critical water condition.

Integrated water management is needed to avoid critical water conditions in Magetan Regency in the future. The design of the model uses the dynamic system method. The model formed is valid and is a legitimate representative of the reality being studied; to produce reliable simulation results.

The model simulation results show that water availability fluctuates from year to year, and water demand continues to grow over time. In general, the condition of the water balance in Magetan Regency during the period 2016 to 2030 is close to critical; however, critical water conditions also occurred during the 2018-2020, 2023, and 2027-2029 periods.

The condition of the water balance indicates that management of water resources is needed starting from the government policy model for managing water resources. Based on the results of model simulations with the application of policy simulations, the water balance in Magetan Regency during the period 2016 to 2030 is still in a near critical condition, but critical water conditions only occur during the 2018-2020 period.

It is concluded that critical water conditions in the future can be avoided by implementing policy scenarios. The policy scenarios include: (1) reforestation, planting 500,000 tree seedlings each year, (2) maintenance of rivers and lakes twice a year, (3) construction of a reservoir with a capacity of 5,000 m^3 each year. Water availability is still fluctuating because the main factor for water availability is rainfall. Rainfall is a macro variable that cannot be controlled in the model (exogenous). Nonetheless, the policy scenario is proven to be able to increase the availability of water in Magetan Regency.

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Supplement 1.
Equation Formula of Water Resources Management Model Based on Regional Development

AGRICULTURE_NEEDS(t) = AGRICULTURE_NEEDS(t - dt) + (growth_rate__of_agriculture_needs) * dt INIT

AGRICULTURE_NEEDS = 50757565

INFLOWS:

growth_rate__of_agriculture_needs = (AGRICULTURAL__LAND_AREA-(delay(AGRICULTURAL__LAND_AREA,1)))*1869

FARM_NEEDS(t) = FARM_NEEDS(t - dt) + (growth_rate_of_farm_needs) * dt

INIT FARM_NEEDS = 4493880

INFLOWS:

growth_rate_of_farm_needs = (TOTAL_OF_CATTLE_LIVESTOCK-(delay(TOTAL_OF_CATTLE_LIVESTOCK,1)))*14.63

FISHERY_NEEDS(t) = FISHERY_NEEDS(t - dt) + (growth_rate_of_fishery_needs) * dt

INIT FISHERY_NEEDS = 2772014 INFLOWS:

growth_rate_of_fishery_needs = (TOTAL_FISHERIES_AREAS(delay(TOTAL_FISHERIES_AREAS,1)))*25494

INDUSTRIAL_NEEDS(t) = INDUSTRIAL_NEEDS(t - dt) + (growth_rate_of__industrial_needs) * dt

INIT INDUSTRIAL_NEEDS = 15546176 INFLOWS:

growth_rate_of__industrial_needs = (INDUSTRIAL_SECTOR_LABOR_ABSOPTION-(delay(INDUSTRIAL_SECTOR_LABOR_ABSOPTION,1)))*(0.015*260)

LAKES_RESERVOIRS__AND_PONDS(t) = LAKES_RESERVOIRS__AND_PONDS(t - dt) + (growth_rate_of_lakes_reservoirs_and_ponds) * dt

INIT LAKES_RESERVOIRS__AND_PONDS = 26500000 INFLOWS:

growth_rate_of_lakes_reservoirs_and_ponds = CONSTRUCTION_OF_RESERVOIRS_AND_PONDS+(0.2*(LAKES_RESERVOIRS

__AND_PONDS*((RAINFALL-(delay(RAINFALL,1)))/(delay(RAINFALL,1)))))

RAINFALL(t) = RAINFALL(t - dt) + (growth_rate_of__rainfall) * dt

INIT RAINFALL = 65543

INFLOWS:

growth_rate_of__rainfall = RAINFALL*GROWTH_OF_RAINFALL

REFORESTATION(t) = REFORESTATION(t - dt) + (growth_rate_of__reforestation) * dt

INIT REFORESTATION = 500000 INFLOWS:

growth_rate_of__reforestation = REFORESTATION__TREE_PLANTING

RIVER(t) = RIVER(t - dt) + (growth_rate_of_river) * dt

INIT RIVER = 107090174

INFLOWS: growth_rate_of_river = (0.5*(RIVER*((RAINFALL(delay(RAINFALL,1)))/(delay(RAINFALL,1))))) - (0.2*(RIVER*((RIVER_AND_LAKE__SEDIMENTS-

(delay(RIVER_AND_LAKE__SEDIMENTS,1)))/(delay(RIVER_AND_LAKE__SEDIMENTS,1))))) - (0.01*(RIVER*(((delay(REFORESTATION,1))-(delay(REFORESTATION,2)))/(delay(REFORESTATION,2)))))

RIVER_AND_LAKE__SEDIMENTS(t) = RIVER_AND_LAKE__SEDIMENTS(t - dt) + (growth_rate_of_river_and_lake_sediments) * dt

INIT RIVER_AND_LAKE__SEDIMENTS = 12 INFLOWS:

growth_rate_of_river_and_lake_sediments = +SEDIMENTATION_OF__RIVERS_AND_LAKES - (10*(MAINTENANCE_OF__RIVERS_AND_LAKES*(RIVER_AND_LAKE__SEDIMENTS*((WATER_NEEDS_FOR_MAINTENANCE_OF_RIVERS_AND_LAKES(delay(WATER_NEEDS_FOR_MAINTENANCE_OF_RIVERS_AND_LAKES,1)))/(delay(WATER_NEEDS_FOR_MAINTENANCE_OF_RIVERS_AND_LAKES,1))))))

SPRINGS(t) = SPRINGS(t - dt) + (growth_rate_of_springs) * dt INIT SPRINGS = 1797552 INFLOWS:

growth_rate_of_springs = (0.5*(SPRINGS*((RAINFALL(delay(RAINFALL,1)))/(delay(RAINFALL,1))))) +(0.04*(SPRINGS*(((delay(REFORESTATION,1))-(delay(REFORESTATION,2)))/(delay(REFORESTATION,2)))))

TOTAL_POPULATION_OF_MAGETAN_REGENCY(t) = TOTAL_POPULATION_OF_MAGETAN_REGENCY(t - dt) + (growth_rate_of__population) * dt

INIT TOTAL_POPULATION_OF_MAGETAN_REGENCY = 627984 INFLOWS:

growth_rate_of__population = TOTAL_POPULATION_OF_MAGETAN_REGENCY*POPULATION_GROWTH_RATE_IN_MAGETAN_REGENCY

TOURISM_SECTOR_NEEDS(t) = TOURISM_SECTOR_NEEDS(t - dt) + (growth_rate_of_tourism_sector_needs) * dt INIT TOURISM_SECTOR_NEEDS = 3090528 INFLOWS:

growth_rate_of_tourism_sector_needs = (TOTAL_OF_TOURIST_SARANGAN_LAKE-(delay(TOTAL_OF_TOURIST_SARANGAN_LAKE,1)))*3.609

WELLS(t) = WELLS(t - dt) + (growth_rate_of_wells) * dt INIT WELLS = 131091368 INFLOWS:

growth_rate_of_wells = (0.5*(WELLS*((RAINFALL(delay(RAINFALL,1)))/(delay(RAINFALL,1)))))
+(0.04*(WELLS*(((delay(REFORESTATION,1))-(delay(REFORESTATION,2)))/(delay(REFORESTATION,2)))))
AGRICULTURAL_FARM__FISHERIES_NEEDS = AGRICULTURE_NEEDS+FARM_NEEDS+FISHERY_NEEDS
AGRICULTURAL__LAND_AREA = 27159+(27159*((time-2017)*GROWTH_OF__IRRIGATED_FIELDS))

CONSTRUCTION_OF_RESERVOIRS_AND_PONDS = 5000

DOMESTIC_NEEDS = TOTAL_POPULATION_OF_MAGETAN_REGENCY* 54.307

GROWTH_IN_THE_NUMBER_OF_CATTLE = 0.0255

GROWTH_OF_FISHERIES_AREA = 0.00

GROWTH_OF_THE_NUMBER_OF_TOURIST_SARANGAN_LAKE = 0.0238

GROWTH_OF__IRRIGATED_FIELDS = 0.00

INDUSTRIAL_GROWTH = 0.0783

INDUSTRIAL_SECTOR_LABOR_ABSOPTION = 54434+(54434*((time2017)*INDUSTRIAL_GROWTH))
+(0.0976*(TOTAL_POPULATION_OF_MAGETAN_REGENCY(delay(TOTAL_POPULATION_OF_MAGETAN_REGENCY,1))))

MAGETAN_REGENCY_WATER_AVAILABILITY = SUBSURFACE_WATER+SURFACE_WATER

MAGETAN_REGENCY_WATER_BALANCE = MAGETAN_REGENCY_WATER_AVAILABILITY-MAGETAN_REGENCY_WATER_DEMAND

MAGETAN_REGENCY_WATER_CRITICAL_INDEX = (MAGETAN_REGENCY_WATER_DEMAND/MAGETAN_REGENCY_WATER_AVAILABILITY)*100

MAGETAN_REGENCY_WATER_DEMAND = DOMESTIC_NEEDS+AGRICULTURAL_FARM__FISHERIES_NEEDS+INDUSTRIAL_NEEDS+TOURISM_SECTOR_NEEDS+WATER_NEEDS_FOR_MAINTENANCE_OF_RIVERS_AND_LAKES

MAINTENANCE_OF__RIVERS_AND_LAKES = 2

POPULATION_GROWTH_RATE_IN_MAGETAN_REGENCY = 0.017

REFORESTATION__TREE_PLANTING = 500000

SEDIMENTATION_OF__RIVERS_AND_LAKES = 0.5(0.5*(0.6*(((delay(REFORESTATION,1))-(delay(REFORESTATION,2)))/(delay(REFORESTATION,2)))))

SUBSURFACE_WATER = SPRINGS+WELLS

SURFACE_WATER = LAKES_RESERVOIRS__AND_PONDS+RIVER

TOTAL_FISHERIES_AREAS = 22+(22*((time2017)*GROWTH_OF_FISHERIES_AREA))

TOTAL_OF_CATTLE_LIVESTOCK = 107596+(107596*((time2017)*GROWTH_IN_THE_NUMBER_OF_CATTLE))

TOTAL_OF_TOURIST_SARANGAN_LAKE = 856234+(856234*((time-2017)*GROWTH_OF_THE_NUMBER_OF_TOURIST_SARANGAN_LAKE))

WATER_NEEDS_FOR_MAINTENANCE_OF_RIVERS_AND_LAKES = 68748480+(109.50*(TOTAL_POPULATION_OF_MAGETAN_REGENCY(delay(TOTAL_POPULATION_OF_MAGETAN_REGENCY,1))))

GROWTH_OF_RAINFALL = GRAPH(TIME) (2017, -0.242), (2018, -0.333), (2019, -0.214), (2020, 0.349), (2021, 0.378), (2022, -0.325), (2023, 0.0248), (2024, 0.393), (2025, -0.092), (2026, -0.112), (2027, -0.157), (2028, -0.065), (2029, 0.098), (2030, 0.226)