JURNAL ILMU LINGKUNGAN
Volume 23 Issue 5 (2025) : 1308-1315 ISSN 1829-8907

System Dynamics Modeling for Clean Water Management in the Sleman Regency

Widodo Brontowiyono[1,6], M. M. Lanny W. Pandjaitan[2], Lukas[3], Lukman Hidayat[4], Ribut Lupyanto[5], and Kasam[6]

[1]Engineering Profession Study Program (*PSPPI*), Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia; email: widodo.12024006152@student.atmajaya.ac.id
[2]Master Program of Electrical Engineering, Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia
[3]Cognitive Engineering Research Group (CERG), Universitas Katolik Indonesia Atma Jaya, Jakarta, Indonesia
[4]Environmental and Forestry Agency of the Special Region of Yogyakarta, Indonesia
[5]Karunia Sejahtera Konsultan, Yogyakarta, Indonesia
[6]Department of Environmental Engineering, Universitas Islam Indonesia, Yogyakarta, Indonesia

ABSTRAK

Sebagai organisasi regional yang bertanggung jawab dalam memenuhi kebutuhan air masyarakat, Perusahaan Daerah Air Minum (PDAM) di Indonesia diharapkan dapat menjamin distribusi air bersih yang konsisten dan merata. Namun, kebocoran air dan berbagai permasalahan lain di PDAM sering kali mengurangi jumlah air yang dapat didistribusikan kepada masyarakat. Sebuah inisiatif untuk memenuhi kebutuhan air di tingkat provinsi telah diterapkan, dengan penekanan khusus pada distribusi air curah antar kabupaten dan kota. Inisiatif ini diklasifikasikan sebagai layanan dasar dalam Standar Pelayanan Minimal (SPM), yang bertujuan untuk meningkatkan ketersediaan sumber daya air. Penelitian ini menggunakan perangkat lunak STELLA 9.1.3 untuk menjalankan simulasi model kebijakan dan menentukan skenario kebijakan terbaik dalam pengelolaan air bersih di Kabupaten Sleman. Berdasarkan pemodelan neraca air dengan skenario Business as Usual (BaU), Kabupaten Sleman diperkirakan akan mengalami defisit air sebesar 144 liter per detik pada tahun 2035. Hasil simulasi skenario kebijakan menunjukkan dengan mengurangi kebocoran air hingga 20% dan menerapkan strategi pemanfaatan air curah secara maksimal (100 %) antar kabupaten/kota dapat meningkatkan ketersediaan air sebesar 283,72 liter per detik.

Kata Kunci: Air bersih, Sistem dinamis, Neraca air

ABSTRACT

As the regional organization responsible for fulfilling the community's water demands, the Municipal Waterworks in Indonesia, *Perusahaan Daerah Air Minum* (PDAM), is expected to ensure consistent and equitable distribution of clean water. However, water leaks and other issues in PDAMs tend to reduce the amount of water distributed to the community. An initiative to address water demands at the provincial level has been implemented, placing specific emphasis on the distribution of bulk water across regencies and cities. This initiative is classified as a fundamental service under the Minimum Service Standards (MSS), which aim to improve the availability of water resources. STELLA 9.1.3 software is used in this study to run a policy model simulation and determine the best possible policy scenario for clean water management in Sleman Regency. Sleman Regency is expected to have a water deficit of 144 liters per second in 2035, according to water balance modeling conducted under Business as Usual (BaU) conditions. According to the policy scenario simulation results, show that reducing air leakage by up to 20% and implementing a strategy for maximizing air flow utilization (100%) between districts/cities can increase water availability by 283.72 liters per second.

***Keywords*:** Clean water, System dynamics, Water balance

Citation: Brontowiyono, W., Pandjaitan, M. M. L. W., Lukas, Hidayat, L., Lupiyanto, R dan Kasam. (2025). System Dynamics Modeling for Clean Water Management in the Sleman Regency. Jurnal Ilmu Lingkungan, 23(5), 1308-1315, doi:10.14710/jil.23.5.1308-1315

1. INTRODUCTION

The main challenge in managing water resources in Indonesia is the increasing demand for water but with a relatively constant supply, and even in some cases it tends to decrease. This means that the competition for water is getting higher, while the need for water is absolute and cannot be delayed.

Indonesia has abundant water, but water management issues have an impact on unequal distribution of water between regions, water wastage, weak law enforcement and water pollution (Quincieu, 2015). The main challenge in managing water resources in Indonesia is the increasing demand for water but with a relatively constant supply, and even in some cases it tends to decrease (Pambudi, 2021). According to Berhanu et al. (2017), the factors causing this problem are an ever-increasing human population, dwindling areas suitable for water recharge, and water source exploitation. Aside from that, the impact of climate change on rainfall, land conversion, and other factors is shifting the nature of water flows toward extremes, posing a threat to water resource infrastructure (Sabar and Plamonia, 2012).

Perusahaan Daerah Air Minum (PDAM) is expected to ensure equitable and efficient clean water distribution as a regional water supply company serving the community. Dewi et al. (2015) discovered that the quantity and quality of clean water provided by the PDAM-managed system varies across cities and regencies. Water loss and leakage during the distribution of clean water is one of the obstacles encountered by PDAM. The average water loss rate in Indonesia is 37%; in certain PDAMs, it can reach as high as 70% (Novalinda, 2012; Salam et al., 2013; Diasa et al., 2019). This indicates that water loss in Indonesia remains considerably high. This shows the considerable prospective financial setbacks that PDAM may face due to the non-revenue-generating nature of the water that has left the production facility (El-Ahmady and Sembiring, 2014).

According to (DPUESDM DIY, 2021) data on the Sleman Regency's clean water availability, 34.82% of the populace had access to drinking water in 2019. In comparison to earlier 2018 data, which showed 31.79%, it has increased. Actually, this data only includes residents who are served by PDAM's piped drinking water network. Sleman Regency provides clean water through a variety of strategies, including PDAM services, the Rural Fresh Water Supply System, and the use of dug wells and springs. However, the majority of Sleman Regency residents get their clean water primarily from well-extracted groundwater. According to Hendrayana et al. (2020), the domestic sector was the largest consumer of groundwater in Sleman Regency in 2018, consuming 61,988,198 m^3/year. Meanwhile, the fisheries industry consumed the least amount of groundwater, totaling 2,869 m^3/year.

Rising demand for clean water combined with insufficient supply will result in a negative water balance or a deficit in clean water availability. The goal of this research in Sleman Regency is twofold, i.e., first, to examine the water balance in Sleman Regency between 2020 and 2035, and second, to identify the most effective policy scenarios for resolving the water deficit in Sleman Regency. In this research, a dynamic system approach utilizing the STELLA 9.1.3 software is used.

2. METHODS

This study applies system dynamics methods to predict the management and demand for clean water in Sleman Regency. The purpose of this model is to provide policymakers with a learning tool to enhance their understanding of the dynamic long-term behavior of water availability in Sleman Regency. Additionally, it is intended to provide recommendations that can reinforce policies that focus on achieving sustainable water resources. According to Sterman (2000), a conventional system dynamics (SD) modelling framework typically encompasses four key phases: problem scoping and structuring, model conceptualisation, model implementation and testing, and scenario analysis. Figure 1 shows the steps involved in developing a dynamic system model.

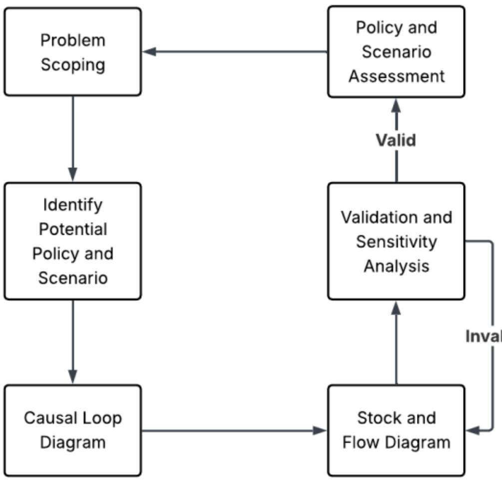


Figure 1. Flow Diagram for Creating a Dynamic System Model

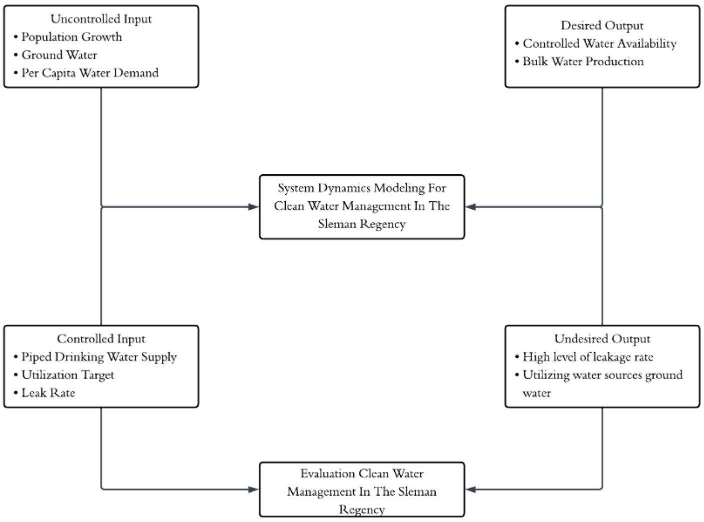


Figure 2. Causal Loop Diagram of a Clean Water Management System

Table 1. Variable and Data Source

No	Variable	Value	Unit	Source
1	Population	1,125,804	Jiwa	Sleman dalam angka 2021
2	Birth Rate	0.011	%/year	Sleman dalam angka 2022
3	Death Rate	0.007	%/year	Sleman dalam angka 2023
4	In Migration	0.02	%/year	Sleman dalam angka 2024
5	Out Migration	0.017	%/year	Sleman dalam angka 2025
6	Per Capita Water Demands	150	L/day	Direktorat Jenderal Cipta Karya, Dinas Pekerjaan Umum Tahun 1996
7	Ground Water	65,989,522	L/year	Hendrayana dkk, 2020
8	Bulk Water	363.05	L/second	DPUPESDM, 2021
9	Leak Rate	0.31	-	Habibi, Ahmad Fu'ad and Dr. Ir. Sindu Nuranto, M.S, 2017
10	Piped Drinking Water Supply	589.2	L/second	DPUPESDM, 2021

The initial phase of dynamic system modeling involves the construction of a Causal Loop Diagram (CLD), which shows the relationships among variables within the created system. Furthermore, the relationship between variables will be shown as either positive (+) or negative (-), i.e., it is observed that a positive relationship (+) has the effect of increasing the value of the dependent variable, whereas a negative relationship (-) has the effect of decreasing the value of the dependent variable. The Causal Loop Diagram (CLD) in this study is shown in Figure 2, as presented by Kotir et al. (2016). The Stock and Flow Diagram (SFD) will then be generated from the Causal Loop Diagram (CLD), which represents the system's model structure in detail, as well as entering mathematical equations for each variable before running the model.

Validation of the model has been carried out in order to assess the model's suitability in practical scenarios. The Mean Average Percent Error (MAPE) method is used for model validation. The MAPE method is used to identify differences between empirical calculation results, simulation results, and field-based observation data. The acceptable deviation limit is 10% (Asrib, 2012; Asmorowati & Sarasanty, 2021; Amalia Mardhatillah Arief et al, 2024). Calculations of MAPE are performed using the following equation:

$$MAPE = \left| \frac{Simulation - Actual}{Actual} \right| \times 100\%$$

Where:

MAPE : Mean Average Percent Error (%)
Simulation : average of simulation data on the system model
Actual : average historical data

Prior to policy scenario testing, sensitivity analysis is performed on every variable within the model. The purpose of this is to determine which variables have the most significant impact on the model.

3. RESULTS AND DISCUSSION

3.1. Model Simulation Results

The structure of the clean water management system model in Sleman Regency can be seen in Figure 3. Population size, groundwater utilization, water balance, water demands, and water availability in Sleman Regency will be analyzed in order to implement the generated model.

The simulation results for the model applying eksisting condition from 2014 to 2020 are presented in Figure 4 and Table 2. While Business as Usual (BaU) conditions—without any modifications to the variables in the model—from 2020 to 2035 are presented in Figure 5 and Table 3. It was discovered that the water balance in Sleman Regency will be negative in 2028, with a deficiency of 23,371,667.00 liters/year or 0.74 liters/second. This is due to a rise in water demand, which is escalating annually as a result of population growth. The total water consumption in the Sleman Regency is predicted to be 83,355,860,386.30 liters per year till the year 2035. The water supply from groundwater consumption is 65,989,522,000 liters/year, and no recharge to groundwater is projected until the modeling year. As a result, there is only enough water to supply that demand until 2027. The piped drinking water delivery system has a 31% leakage rate, resulting in a water supply of 589.2 liters/second provided. In the Business as Usual (BaU) scenario, the bulk water utilization number remains 0, indicating that no new bulk water has been added to the water availability.

The Business as Usual (BaU) graph for the clean water management system shown in Figure 4 demonstrates that population and water consumption continue to rise until the last year of simulation, when the amount of water consumed is highly dependent on population. The graph of water usage continues to rise, resulting in a constant decline in water availability.

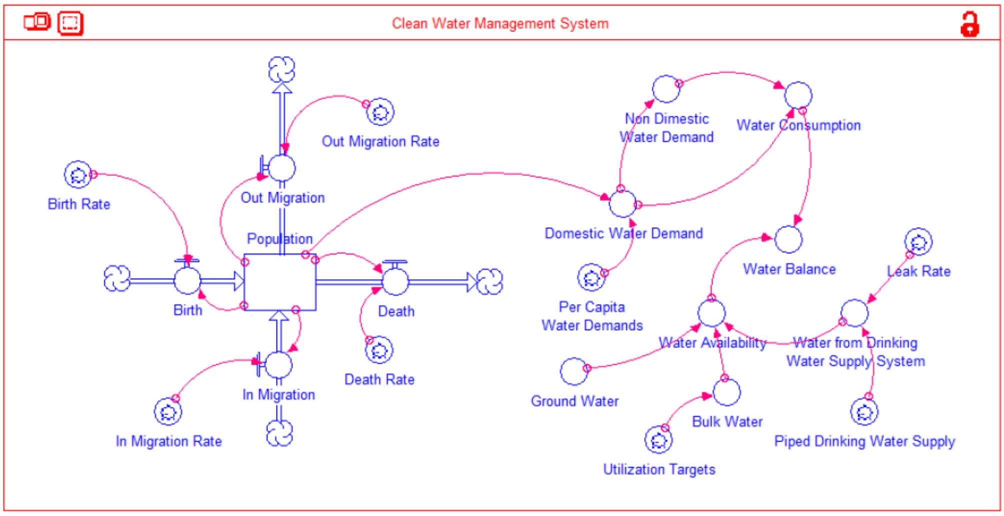


Figure 3. Stock And Flow Diagram of The Clean Water Management System

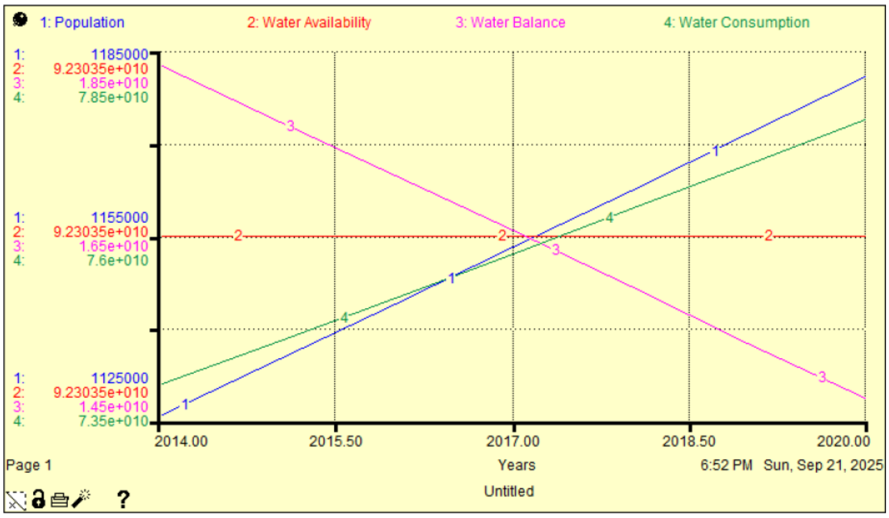


Figure 4. Eksisting Condition Clean Water Management System Diagram

Table 2. Eksisting Condition Clean Water Management System Data

No.	Year	Number of Population (Person)	Water Availability (liters/year)	Water Consumption (liters/year)	Water Balance (liters/year)
1	2014	1,125,804.00	92,303,475,760.00	18,338,152,960.00	73,965,322,800.00
2	2015	1,134,810.43	92,303,475,760.00	17,746,430,377.60	74,557,045,382.40
3	2016	1,143,888.92	92,303,475,760.00	17,149,974,014.54	75,153,501,745.46
4	2017	1,153,040.03	92,303,475,760.00	16,548,746,000.58	75,754,729,759.42
5	2018	1,162,264.35	92,303,475,760.00	15,942,708,162.50	76,360,767,597.50
6	2019	1,171,562.46	92,303,475,760.00	15,331,822,021.72	76,971,653,738.28
7	2020	1,180,934.96	92,303,475,760.00	14,716,048,791.82	77,587,426,968.18

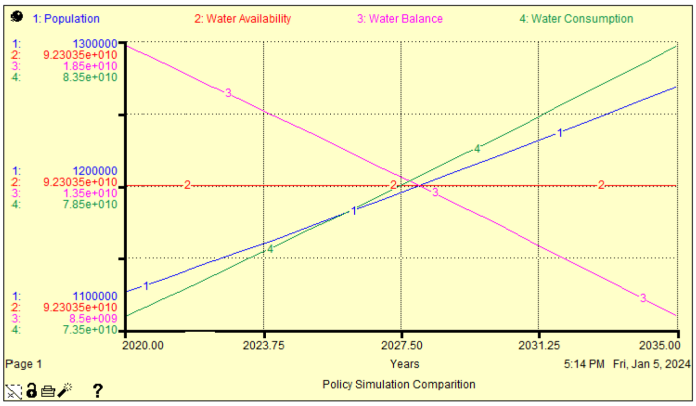


Figure 5. Business as Usual (BaU) Clean Water Management System Diagram

Table 3. Business as Usual (BaU) Clean Water Management System Data

No.	Year	Number of Population (Person)	Water Availability (liters/year)	Water Consumption (liters/year)	Water Balance (liters/year)
1	2020	1,125,804.00	78,810,419,728.00	73,965,322,800.00	4,845,096,928.00
2	2021	1,142,691.06	78,810,419,728.00	74,557,045,382.40	4,253,374,345.60
3	2022	1,159,831.43	78,810,419,728.00	75,153,501,745.46	3,656,917,982.54
4	2023	1,177,228.90	78,810,419,728.00	75,754,729,759.42	3,055,689,968.58
5	2024	1,194,887.33	78,810,419,728.00	76,360,767,597.50	2,449,652,130.50
6	2025	1,212,810.64	78,810,419,728.00	76,971,653,738.28	1,838,765,989.72
7	2026	1,231,002.80	78,810,419,728.00	77,587,426,968.18	1,222,992,759.82
8	2027	1,249,467.84	78,810,419,728.00	78,208,126,383.93	602,293,344.07
9	2028	1,268,209.86	78,810,419,728.00	78,833,791,395.00	-23,371,667.00
10	2029	1,287,233.01	78,810,419,728.00	79,464,461,726.16	-654,041,998.16
11	2030	1,306,541.50	78,810,419,728.00	80,100,177,419.97	-1,289,757,691.97
12	2031	1,326,139.63	78,810,419,728.00	80,740,978,839.33	-1,930,559,111.33
13	2032	1,346,031.72	78,810,419,728.00	81,386,906,670.05	-2,576,486,942.05
14	2033	1,366,222.20	78,810,419,728.00	82,038,001,923.41	-3,227,582,195.41
15	2034	1,386,715.53	78,810,419,728.00	82,694,305,938.79	-3,883,886,210.79
16	2035	1,407,516.26	78,810,419,728.00	83,355,860,386.30	-4,545,440,658.30

Table 4. Mean Average Percent Error (MAPE) Model Validation Method

No.	Year	Number of Population (People)	
		Historical Data	Simulation Data
1	2014	1,180,479	1,180,479
2	2015	1,180,479	1,189,922
3	2016	1,103,534	1,199,442
4	2017	1,193,512	1,209,037
5	2018	1,206,714	1,218,710
6	2019	1,075,575	1,228,459
7	2020	1,125,804	1,238,287
Average		1,152,300	1,209,191
MAPE		0.049 or 4.93%	

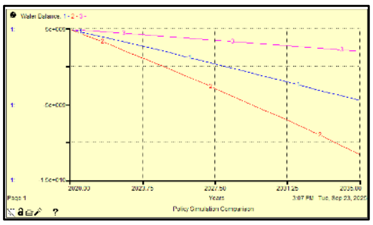
3.2. Model Validation

Since this modeling is forecast-based, structural validation is the most probable type of validation to be applied. Prior to being applied in the scenario analysis, the model was tested through three tests: model debugging, model verification, and model validation (Daniel et al, 2021). The variable exerting the greatest influence on water balance values is regarded as the most sensitive.

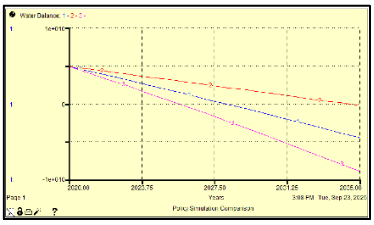
Model debugging was first undertaken to identify and correct errors that could hinder proper functioning, such as inaccurate equations. Subsequently, model verification was performed to evaluate consistency. The SFD model successfully passed both debugging and verification, indicating the absence of equation errors and unit inconsistencies. Model validation was then conducted to assess the level of confidence in the model's predictive capability. In addition, a behaviour test was applied to examine whether the model outputs are consistent with observed real-world dynamics and theoretical expectations. This model is valid for various reasons based on structural validation, i.e.:

1. Water consumption will continue to rise exponentially as the population grows;
2. Water availability is the sum of the piped drinking water supply system and groundwater that form a linear line; and
3. The water balance will continue to decline as water consumption increases, forming an exponential (dynamic) line in this case

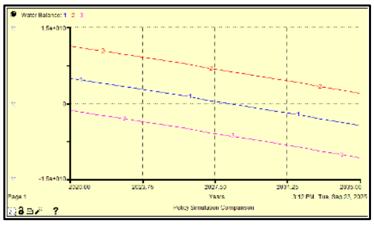
Table 4 shows the results of model validation calculations using the Mean Average Percent Error (MAPE) approach.



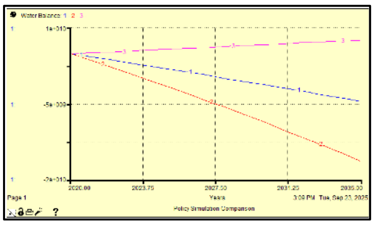
a) Birth rate



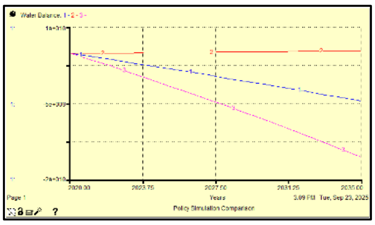
b) Death rate



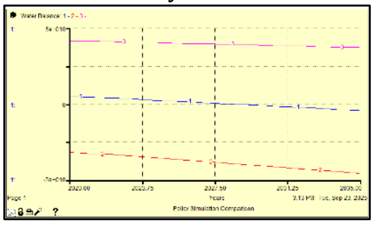
c) Piped drinking water supply system



d) In-migration rate

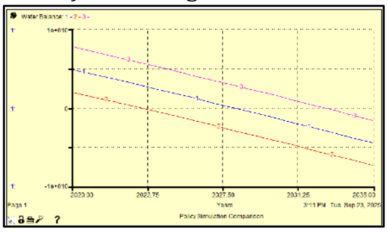


e) Out-migration rate



f) Per capita water demand

g) Utilization targets



h) Leakage rate

Figure 5. Sensitivity Analysis Results

3.3. Sensitivity Analysis

Death rate, birth rate, in-migration rate, out-migration rate, per capita water demand, piped drinking water supply system, leakage rate, and utilization targets are the eight variables whose sensitivity to the model will be evaluated. The policy scenario analysis will involve the intervention of one or more variables (Guemouria, Ayoub., et al, 2023).

To conduct a sensitivity analysis, the values of the tested variables were altered by +50% and -50% relative to the Business as Usual (BaU) conditions, with no adjustments made to the values of the other variables. The variable that has the greatest influence on changes in water balance values is the most sensitive. According to the results of the water balance variable sensitivity test (Figure 5), the utilization targets, leakage rate, per capita water demand, and piped drinking water supply system variables are sensitive to changes in the water balance throughout the modeling year.

3.4. Policy Scenario Simulation

Until the final year of modeling, several policy scenarios will be implemented to meet water demands in Sleman Regency and ensure that there is no water shortage. Scenario 1 represents current conditions or Business as Usual (BaU). Scenario 2 shows a scenario that reduces the leak rate to 20%. Scenario 3 shows a scenario that maximizes bulk water services to 100%. Scenario 4 shows a scenario that maximizes bulk water services at 100% while reducing leakage to 20%.

The simulation results for the four policy scenarios are shown in Figure 6. The lines labeled 1, 2, 3, and 4 correspond to the simulation results for scenarios 1, 2, 3, and 4, respectively. According to the simulation results, water availability in scenario 2 is expected to be adequate until 2031. This implies that there is a limited increase in water adequacy compared to scenario 1, with four-year duration. As a result, the water balance is expected to be negative in 2032, resulting in a deficit of 2,501,529,426.30 liters per year or 79.32 liters per second until 2035. In scenario 3, bulk water across regencies/cities increases the source of water availability, resulting in positive water balance results until 2035 of 6,903,704,141.70 liters per year, or 218.92 liters per second. According to the simulation results for scenario 4, water availability is sufficient for water demands until 2035, with a surplus water balance of 8,947,615,373.70 liters/year or 283.72 liters/second. To meet water demands until the modeling year, simply increasing water sources originating from bulk water across regencies/cities is sufficient. However, it would be more optimal to have a policy in terms of overcoming leaks in the water distribution of the piped water supply system, where with a policy to overcome a leakage rate of up to 20%, the water surplus could be increased to 64.8 liters/second.

Figure 6. Comparison Diagram of Policy Scenario Simulation Results

Table 5. Comparison of Data from Policy Scenario Simulation Results

No.	Year	Water Balance (liters/year)			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	2020	4,845,096,928.00	6,889,008,160.00	16,294,241,728.00	18,338,152,960.00
2	2021	4,253,374,345.60	6,297,285,577.60	15,702,519,145.60	17,746,430,377.60
3	2022	3,656,917,982.54	5,700,829,214.54	15,106,062,782.54	17,149,974,014.54
4	2023	3,055,689,968.58	5,099,601,200.58	14,504,834,768.58	16,548,746,000.58
5	2024	2,449,652,130.50	4,493,563,362.50	13,898,796,930.50	15,942,708,162.50
6	2025	1,838,765,989.72	3,882,677,221.72	13,287,910,789.72	15,331,822,021.72
7	2026	1,222,992,759.82	3,266,903,991.82	12,672,137,559.82	14,716,048,791.82
8	2027	602,293,344.07	2,646,204,576.07	12,051,438,144.07	14,095,349,376.07
9	2028	-23,371,667.00	2,020,539,565.00	11,425,773,133.00	13,469,684,365.00
10	2029	-654,041,998.16	1,389,869,233.84	10,795,102,801.84	12,839,014,033.84
11	2030	-1,289,757,691.97	754,153,540.03	10,159,387,108.03	12,203,298,340.03
12	2031	-1,930,559,111.33	113,352,120.67	9,518,585,688.67	11,562,496,920.67
13	2032	-2,576,486,942.05	-532,575,710.05	8,872,657,857.95	10,916,569,089.95
14	2033	-3,227,582,195.41	-1,183,670,963.41	8,221,562,604.59	10,265,473,836.59
15	2034	-3,883,886,210.79	-1,839,974,978.79	7,565,258,589.21	9,609,169,821.21
16	2035	-4,545,440,658.30	-2,501,529,426.30	6,903,704,141.70	8,947,615,373.70

According to the policy simulation results (Table 5), increasing the availability of water from cross-regency/city bulk water services with 100% service and lowering the leakage rate from a piped water supply system by up to 20% can alleviate water shortages in Sleman Regency until 2035. Furthermore, meeting cross-regency/city bulk water services is one type of basic service from the Minimum Service Standards for Provincial Public Works based on Government Regulation No. 2 of 2018, where the implementation of Minimum Service Standards must include the type of basic service, the quality of basic service, and the recipients of basic service. Cross-regencies/cities bulk water services are implemented in the Special Region of Yogyakarta province to meet the community's water demands.

4. CONCLUSION

The results of dynamic system modeling show that under Business as Usual (BaU) conditions, the water balance in Sleman Regency is projected to be negative by 2025. Policy scenario simulations were run with the goal of achieving positive results in terms of balance until the modeling process's final year. The simulation results for Scenario 2 show a deficit in water balance by 2031. Throughout the modeling year, a consistent surplus of 218.92 liters per second is observed in Scenario 3. Scenario 4 results show a positive outcome in terms of water balance in 2035, with a surplus of 283.72 liters per second. It was determined that choosing Scenario 4 would be the best plan of action to deal with the problem of insufficient water availability in Sleman Regency.

REFERENCES

Arief, Amalia Mardhatillah, Hari Siswoyo, and Ussy Andawayanti. 2024. Improving Drinking Water Management Efficiency in Batu City Water Utility with System Dynamics Modelling Approach. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering Vol. 15 No.1 pp. 70-79, 2024*

Asmorowati, E.T. and D. Sarasanty, 2021. Water Availability Model Based on System Dynamic: Sadar Sub-Watershed Case Study. *IOP Conf. Series: Earth and Environmental Science 819 (2021) 012089*

Asrib, A. R., 2012. Model Pengendalian Sedimentasi Waduk Akibat Erosi Lahan dan Longsoran di Waduk Bili-Bili

Sulawesi Selatan (Model of Sedimentation Control of Reservoir due to Land Erosion and Landslide in Bili-Bili Dam South Sulawesi). *Dissertation.* IPB University. 166 pages.

Badan Pusat Statistik (BPS). 2021. Kabupaten Sleman Dalam Angka 2021

Badan Pusat Statistik (BPS). 2022. Kabupaten Sleman Dalam Angka 2022

Badan Pusat Statistik (BPS). 2023. Kabupaten Sleman Dalam Angka 2023

Badan Pusat Statistik (BPS). 2024. Kabupaten Sleman Dalam Angka 2024

Badan Pusat Statistik (BPS). 2025. Kabupaten Sleman Dalam Angka 2025

Berhanu, B. M., M. Blackhurst, M. J. Kirisits, P. Jamarillo, & D. Carlson, 2017. Feasibility of Water Efficiency and Reuse Technologies as Demand-Side Strategies for Urban Water Management. *Journal of Industrial Ecology*, 21(2), pp. 320–331.

Daniel, D., Julivius Prawira, Trimo Pamudji Al Djono, S. Subandriyo, Arya Rezagama, and Aries Purwanto. 2021. A System Dynamics Model of the Community-Based Rural Drinking Water Supply Program (PAMSIMAS) in Indonesia. Water 2021, 13, 507.

Dewi, K. H., Koosdaryani, & A. Y. Muttaqien, 2015. Analisis Kehilangan Air Pada Pipa Jaringan Distribusi Air Bersih PDAM Kecamatan Baki, Kabupaten Sukoharjo (Water Loss Analysis in PDAM's Clean Water Distribution Network Pipes in Baki District, Sukoharjo Regency). *e-Jurnal Matriks Teknik Sipil*, March, pp. 9-16.

Diasa, I Wayan., I Ketut Soriarta, and Ida Bagus Gede Suryawan, 2019. Analysis of Water Loss (Non-Revenued Water) in the Drinking Water Supply System Network (SPAM) Case Study: Mengwi District. *Fakultas Teknik UNR, Gradien Vol.11, No.2, Oktober 2019.*

Dinas Pekerjaan Umum, Perumahan dan Energi Sumber Daya Mineral. 2021. Laporan Akhir Pendataan SPM Bidang Ke-PU-an (Air Minum) DPUESDM DIY Tahun 2021

Direktorat Jenderal Cipta Karya. 1996. Buku Panduan Pengembangan Air Minum. Jakarta: Departemen Pekerjaan Umum

El-Ahmady, I. I., & E. Sembiring, 2014. Pemilihan Program Pengendalian Kehilangan Air serta Pengaruh Implementasinya Terhadap Peningkatan Pendapatan PDAM (The Selection of Water Loss Control Program and The Effect of The Implementation for PDAM's Income). *Jurnal Teknik Lingkungan*, 20(2), pp. 142- 151.

Guemouria, Ayoub., Abdelghani Chehbouni, Salwa Belaqziz, Terence Epule Epule, Yassine Ait Brahim, El Mahdi El Khalki, Driss Dhiba, and LhoussaineBouchaou. 2023. System Dynamics Approach for Water Resources Management: A Case Study from the Souss-Massa Basin. *Water 2023, 15, 1506*

Habibi, Ahmad Fu'ad dan Sindu Nuranto. 2017. Tinjauan Pemeliharaan Pipa Air Minum PDAM Tirtamarta Yogyakarta Untuk Menekan Tingkat Kebocoran Air. *Teknik Pengelolaan Dan Pemeliharaan Infrastruktur Sipil. Universitas Gadjah Mada*

Hendrayana, H., I. A. Riyanto, A. Nuha, 2020. Tingkat Pemanfaatan Air Tanah di Cekungan Air Tanah (CAT) Yogyakarta-Sleman (Groundwater Utilization Level in Groundwater Basins Yogyakarta-Sleman). *Geodika: Jurnal Kajian Ilmu dan Pendidikan Geografi, 4(2),* pp. 127-137.

Kotir, J. H., C. Smith, G. Brown, N. Marshall, & R. Johnstone, 2016. A System Dynamics Simulation Model for Sustainable Water Resources Management and Agricultural Development in The Volta River Basin, Ghana. *Science of the Total Environment*, 573, pp. 444–457.

Novalinda, 2012. Design of Clean Water Distribution to Residential Homes to Anticipate Leaks. *Jurnal Teknik Sipil dan Arsitektur, Vol. 1, No. 1. (2019)*

Pambudi, Andi Setyo, 2021. Overview and evaluation of the Indonesia's Water Resources Management Policies for Food Security. *InJAST Volume 2, Number 2, Pages:84-93*

DPUESDM DIY, 2021. *Final Report on SPM Data Collection in The Public Sector (Drinking Water) DPUESDM DIY 2021*. Yogyakarta

Quincieu, Eric, 2015. *Summary of Indonesia's Agriculture, Natural Resources, and Environment Sector Assessment*. Asian Development Bank.

Indonesia. *Minimum Service Standards for Provincial Public Works based on Government Regulation No. 2 of 2018*. Jakarta.

Sabar, A., & N. Plamonia, 2012. Tantangan Pembangunan Infrastruktur Sumber Daya Air Berkelanjutan Menghadapi Perubahan Iklim Ikhwal Urban Metropolitan Jakarta (The Challenges of Sustainable Water Resources Infrastructure Development in the Context of Climate Change in Urban Metropolitan Jakarta). *Seminar Nasional: Tantangan Pembangunan Berkelanjutan & Perubahan Iklim di Indonesia Medan: USU-BLH Sumut (June 2, 2012).*

Salam, A. Ejah Umraeni., Muh.Tola, Mary Selintung, and Farouk Maricar, 2013. Application of Artificial Intelligence in Prediction Large and Location of Leaks in Water Distribution Pipelines. *Jurnal Ristek Riset Teknik Elektro Vol. 2-No.2.*

Sterman, D.J., 2000. Business Dynamics: Systems Thinking and Modelling for a Complex World. United States of America: The McGraw-Hill Companies.