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THE ANALYSIS OF CROSS-REGIONAL WATER RESOURCES MANAGEMENT IN INDONESIA: A SYSTEM DYNAMIC APPROACH

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Abstract

Water resources management is necessary to ensure the adequacy of water resources in a country or a region. In this study, sustainable water management strategies were analyzed using System Dynamics (SD) model to evaluate cross-regional water management sustainability in two regions in Indonesia. The interactions of four factors in the management of water resources in this study, including land, water supply, water demand, and payment for environment service (PES), were examined using a causal loop design model to predict the sustainability of future water resources. This model simulated data input from 2019 and forecasted the sustainability of water resources management until 2038. The sustainability of water resources management is measured by environmental (PVC> 0.8), economic (WUI <0.25) and social (LoS> 81.71) indicators. The results indicated that a single policy scenario intervention increased the leverage factor, but also has not been able to bring the management of water resources from all indicators to the sustainability stage. After the intervention of policy scenario combination was carried out, the environmental (PVC 0.86) and social (LoS 18.71) indicators were at sustainable stage, but not the economic indicators (WUI 1.17). Unsustainable management of water resources from an economic aspect implies the need for control of the demand sector to be below the supply value. Reducing the level of leakage and efficient use of water are the main tasks that are most realistically carried out by all stakeholders in controlling demand.

Keywords: Cross-regions, Sustainable strategies, System dynamics, Water resources management.

1. Introduction

Water is an essential factor in socio-economic and environmental systems [1]. It is a unique substance in the types of goods and services provided to mankind [2], and thus, proper management of water resources is indispensable for securing food production, reducing poverty, and eradicating water-related diseases [3]. It has a major role in the international relations [4] and the relations between border areas [5-9]. Water resources management provides economic benefits as a catalyst for mutually beneficial cross-regional (administrative) cooperation. Therefore, mutually beneficial cross-regional cooperation is needed to ensure availability and good management and thus its distribution can run in a sustainable manner without conflict.

In Indonesia, water resources are still managed by the central government as a form of control by the state. The government has a main role as a regulator of policies aimed at providing protection and ensuring the fulfillment of people's rights to water. With Indonesia's vast territory, water resources management is an issue that needs attention. The application of the principles of sustainability is very necessary so that the availability of water resources can be accounted for not only by the current generation but also by future generations [10].

The water resources management model in Indonesia is developed through integrated water resources management (IWRM), one of the frameworks for sustainable water management [11], which includes integration between administrative areas both horizontally and vertically. Currently, the issue of decentralization and regional autonomy policies launched by the government has led to an integrated management of water resources across these regions into the form of cooperation. In this collaboration, the party that acts as a water service provider is obliged to conserve water sources, while those who use the water services are obliged to pay compensation for environmental services that have been obtained as Payment for Environmental Service (PES).

In this paper, cooperation in cross-border water resources management in Indonesia involves two administrative regions: Kuningan District and Cirebon City. This cross-administrative cooperation in these two regions was studied in connection with the degradation of the catchment area of water resources and a decrease in water supply amid the increasing demand and the lack of realization of PES absorption for reforestation activities. If this problem continues, the continuation of cooperation in the area of water resources across this region will face uncertainty. This uncertainty is expected to increase in the future due to changes in climate, environment, population and other socio-economic developments [12]. Therefore, this study identifies the extent of sustainable management of water resources across regions (if left without action) as well as the best policies needed to support its sustainability.

Management of water resources across border areas is a complex issue as it involves various related factors. Some models of water resources management have been used in previous studies, such as the WEAP Model [13], Bayesian Network [14], and Multi-Agency [15]. As the concept of water resources management can be implemented either internally or externally (across borders) based on physical boundaries (watersheds) or administration, the two cross-border concepts are thought to have different forms of handling, especially regarding the cultural and political dimensions. In the present study, system dynamics modeling was used to identify the relationship and behavior of the influencing factors in water management [16]. Dynamic simulation allows us to observe the behavior of the system being modeled and its response to interventions over time [17].

Kotir et al. [18] used system dynamics as a learning tool to increase understanding of the long-term dynamics of the Volta basin, in Ghana and as a basis for exploring alternative policy scenarios for sustainable water resources management. A cross-border study conducted by Xi and Poh [19] who describes the use of system dynamics as a decision support tool to help achieve sustainable water management in Singapore involving Malaysia as a water supplier. Meanwhile, Ahmadov [20] analyzed cooperation across administrative boundaries in regional contexts such as the partnership of Azerbaijan, Russia, Georgia, Armenia, Iran, Azerbaijan-EU and Azerbaijan-UN in the water sector. However, limited studies apply system dynamics as a decision support tool to analyze cross-domestic administrative water resources systems that are equipped with a special synthesis of how compensation for payment for environmental services (PES) is intervened in the model. By integrating various policy scenarios in the system dynamics model, this study proposed policy formulations that need to be carried out by the related parties to strive for sustainable water resources management in both regions.

An important issue raised in this study is the uncertainty of future cooperation due to the declining condition of water resources carrying capacity (WRCC). A corporate plan issued by the Municipal Water Utility Company or PDAM in Cirebon City reports a drinking water deficit in 2021 if the quota of raw water supply from Kuningan Regency is not increased.

Figure 1 shows four interconnected variables consisting of forest land, water supply, water demand, and payment for environment service (PES) forming a strategic model in water resources management. Forest degradation in the catchment area is indicated as the cause of the decline in WRCC. Meanwhile, the absorption of PES funds is not optimal for forest restoration and is also suspected as the obstacle to restoration of critical forest land which causes the hydrological function in the water catchment area works improperly. This reinforces the previous study that only 16.2% of PES from the local government of Cirebon City are implemented for the conservation of water resources management by the local government of Kuningan Regency [21].

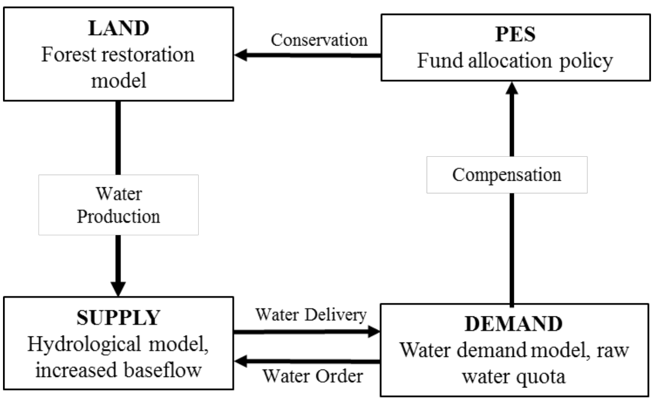


Fig. 1. Sub-system of water resources management in Kuningan Regency-Cirebon City.

If the compensation fund for environmental services can be maximally used for conservation activities, it can help restore critical forest land. The larger the compensation fund for environmental services, the faster the recovery process. A good reflection of forest restoration is very important to increase water production in the ground as water supply and increase the water demand of Cirebon City as well. The amount of water utilized by Cirebon City makes the funds of PES for Kuningan Regency in the context of conservation activities will increase. Therefore, this complex problem SD modeling will show how forest land, water supply, water demand and compensation for environmental services (PES) funds determine the sustainable behavior of water resources management across regions and formulate policies to solve problems.

2. Dynamic Simulation in Water Resources Management

SD is an approach aiming to understand the behavior of complex systems with simulation models [22], using simple mathematical concepts [23] and computer-based feedback control theory and modern theory of non-linear dynamics [24], and abstracting a phenomenon in the real world to a more explicit model [25]. It is a professional discipline first developed in 1956 at the Massachusetts Institute of Technology [26]. The selection of the SD model is based on the ability of this system to recognize the elements and relationships between elements in a system and to show the effect of the relationship on the overall system behavior in a model. SD provides model simulations to formulate the necessary policies by intervening in various scenarios. By intervening policies on the system behavior in the simulation of the SD model, the desired system behavior can be obtained, and the undesired system behavior can be avoided [27]. This present study aims to demonstrate the usefulness of SD as a decision support tool related to policy steps that must be taken in the context of sustainable cross-regional water resources management in Indonesia.

3. Method and Model Development Procedure

Water resources management involves a variety of complex, mutually influencing, and dynamic factors. By considering the complexity of the problem and the changing dynamics of these factors, this study is designed to be able to investigate various aspects in an integral manner, to explain structurally a phenomenon of water resources management using SD, and to examine the causal relationship and provide feedback. System analysis based on causal relationships and feedback loops can evaluate the dynamic behavior of an efficient system from various socio-economic aspects, system structures and strategies using software [4]. The relationships between variables were simulated using Vensim PLEx32 software. The simulation generates equations, causal loop diagrams, flow charts, time charts, and timetables. The simulation results were analyzed qualitatively.

The SD modeling stage begins with the steps of identifying and defining the dynamic problems of cross-regional water resources management. After identifying the problem, the system conceptualization is then formulated and thus the system behavior patterns can be seen over time. The system is described by a causal loop. Furthermore, the compiled concepts of the system or model structure are converted into the forms of equations or computer language. When the dynamic model of water resources management has been formulated, testing the model is conducted to enforce confidence in the validity of the model and to develop the model to be similar as the real system. After that, various alternative interventions that can be applied in the system are tested by looking at the possible impact of these interventions.

3.1. System conceptualization

After the problem identification was modelled, the interacting feedback structure was formed. This feedback structure is the building block of the model expressed through the causal loop. The feedback loop does not show the relationship between statistical correlations but describes the causal relationship of the variables forming loops. The model must contain at least one feedback loop, and in this study, a basic model with one feedback loop was used where arrows represent the influencing variables and the affected variables (see Fig. 2). Meanwhile, the positive and negative signs in the picture indicate the nature of the relationship between variables. Positive feedback loops accelerate changes in the system which can result in rapid growth or decline [28]. This type of growth pattern is often called exponential growth. In contrast, negative feedback loops oppose change and aim to look for behavioral displays.

Figure 2 shows four causal loop diagrams representing the links and feedbacks of the variables consisting of positive and negative loops. This indicates that the model in general has a balanced character in the process of achieving goals. Turnaround B1 indicates that the reduction of degraded forest land will strengthen the extent of vegetation forest land. This will happen when the maximum absorption of compensation for environmental services will transform critical land into reforested land. B2 reverse rotation will also amplify the decrease in evapotranspiration when the land with green vegetation is able to increase the amount of water that soaks into the soil (infiltration). The B3 loop illustrates a situation that can reinforce the increase in the value of compensation for environmental services (PES) funds when the supply of raw water received by Cirebon City increases. Meanwhile, the reverse rotation of R1 shows a comprehensive picture where the balance occurs when the expectation of increasing demand and PES can reduce degraded (critical) forest land thereby increasing the amount of supply.

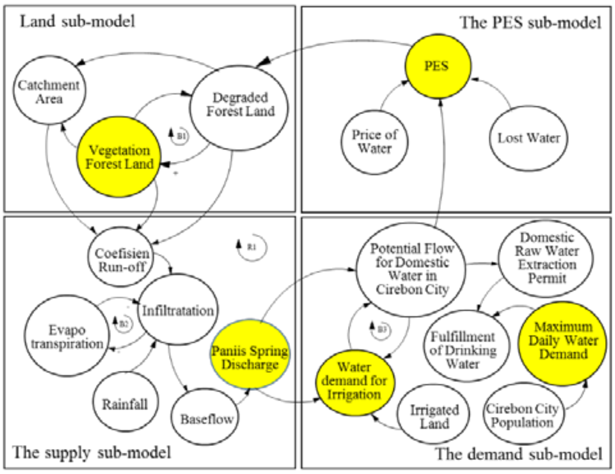


Fig. 2. Causal diagram loops of water resources management in Kuningan regency-Cirebon city.

3.2. Diagram flow structure

A system or model behavior is highly dependent on its structure, including the existing components and the interrelationships between these components. The parameters attached to each component will also play an important role. In a simple term, building a model structure is making a causal loop diagram that can reflect the actual system. Based on the structure of the model, the behaviors of each variable are developed and observed. The behavior of each variable is studied and then mathematically formulated so that it can be simulated to determine the behavior of the observed variables in relation to changes in time. Based on the feedback on the main model, the model structure is developed into a flow chart for further analysis using computer applications.

Figure 3 represents stock flow diagrams (SFD) of land sub-models involving the variables of forest vegetation land, degraded forest land, and land restoration from PES. Vegetation forest land is a target for improvement so that its hydrological function works well. If this land function works well, it will greatly affect the increase in water recharge. The area of vegetation forest land can be increased through restoration of degraded forest land supported by costs originating from compensation for environmental services (PES). Mathematically, the equation in the land sub-model can be stated as follows:

Vegetation land = INTEG (Recovery PES for reforestation + Recovery of natural forest land - degraded forest land, historical land degradation) (1)

Accumulation of forest recovery from PES = INTEG (Accumulation of forest recovery from PES,0) (2)

Degraded forest land = INTEG (Degraded forest land - Recovery of actual forest from PES - Recovery of natural forest land, historical land degradation) (3)

Forest recovery from PES = INTEG (actual forest recovery from PES - PES recovery for reforestation, 1) (4)

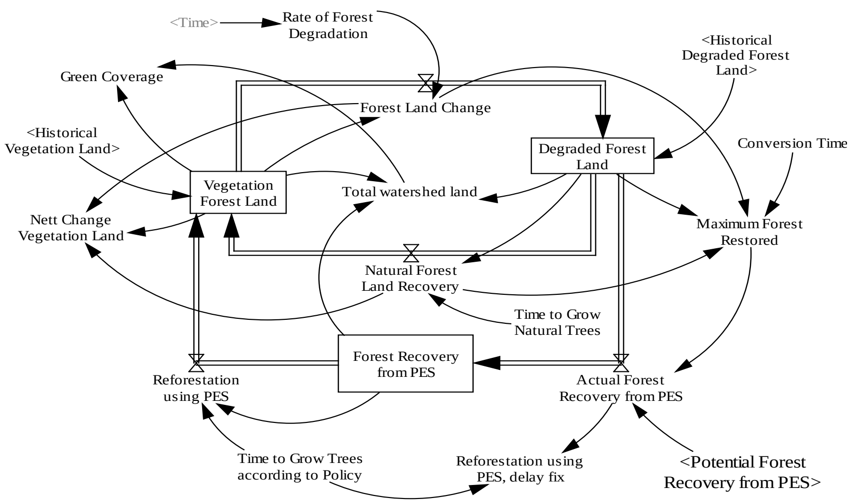


Fig. 3. SFD of land sub-model.

Figure 4 depicts the SFD Sub model of water availability which explains the hydrological ability of surface land in the catchment area to produce groundwater through the infiltration process. The sub-model of water availability comprises of the variables including rainfall and surface water runoff coefficient. Water availability is assessed by taking into account the amount of water flowing in the ground (base flow). Mathematically, the equation in the water availability sub-model can be stated as follows:

Baseflow from Non-Paniis watershed = rainfall infiltration of Non-Paniis watershed x Baseflow fraction of Non-Paniis watershed (5)

Baseflow from Paniis watershed = Baseflow fraction x rainfall infiltration (6)

Normal rainfall = INTEG (Rainfall changes, "average rainfall") (7)

Spring discharge of Paniis = (Baseflow from Non-Paniis watershed + Baseflow Paniis watershed) (8)

Rainfall infiltration = ((watershed rainfall - evapotranspiration)/converter mm to m) x total of watershed land x converter ha to m2 x (1 - "watershed run-off coefficient") (9)

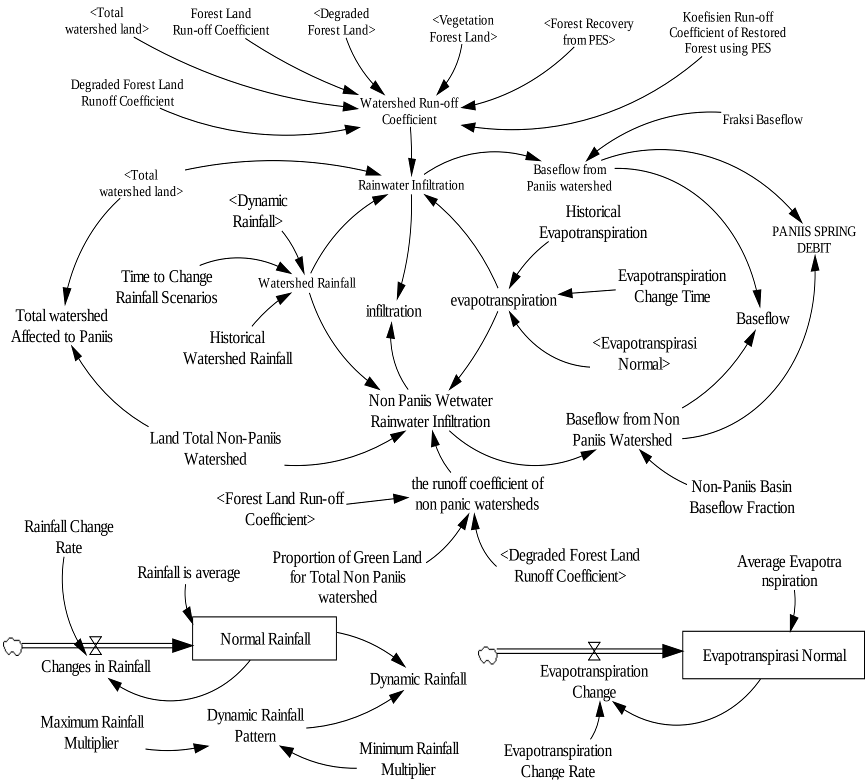


Fig. 4. SFD of water availability sub-model.

Figure 5 represents the SFD of water demand sub-model by variables of water demand for irrigation and domestic or drinking water. Water needs for irrigation are determined by the area of irrigated land, usage standards and the length of the planting period. Meanwhile, the need for drinking water is determined by population, water usage standards, and leakage factors. The demand for water for irrigation purposes increases in line with the increase in the area of agricultural land. Meanwhile, the need for drinking water increases along with the increase in population and water consumption. The demand for drinking water is assessed by taking into account the maximum daily requirement. Mathematically, the equations in the water demand sub-model are as follows:

Paniis agricultural land = INTEG (Agricultural land change, historical agricultural land) (10)

Population of Cirebon City = INTEG (Population growth in Cirebon City, historical population of Cirebon City (11)

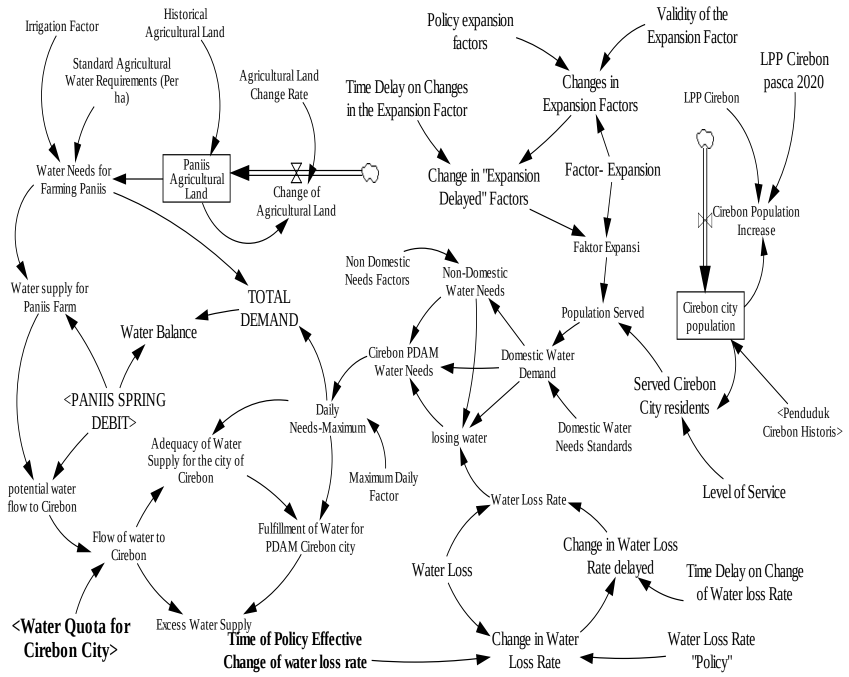


Fig. 5. SFD of water demand sub-model.

Figure 6 depicts the PES sub-model composed of water price variables, raw water volume, and leakage that will affect the PES value. The volume of raw water for drinking water is calculated after experiencing a reduction by irrigation-the prioritized service. The value of PES as compensation for the use of raw drinking water will increase if the price of water and the volume of raw water used increases, while water leakage decreases. The PES value is obtained by using a calculation formula that has been agreed upon by the two cooperating parties. Mathematically, the equation in the PES sub-model can be written as follows:

PES allocation for Paniis watershed = percentage allocation of Paniis watershed x PES (12)

PES allocation for others = PES - PES allocation for Paniis watershed (13)

PES allocation for rehabilitating degraded land of Paniis watershed = percentage allocation for PES rehabilitation x PES allocation for Paniis watershed (14)

PES = Water price x correction factor of PES x water flow to Cirebon (15)

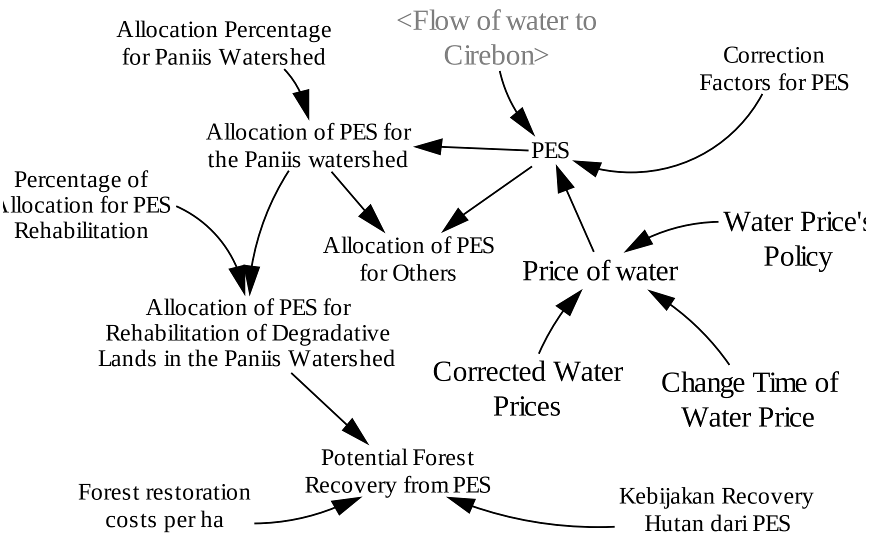


Fig. 6. SFD of PES sub-model.

4. Results and Discussion

After the model is formulated, the dynamic behavior of the variables is studied through computer simulation using Vensim PLEx32 software. Testing of model reproduction by comparing the behavior of the model with historical data is carried out to ensure that the computer program and its application works correctly. The extent to which the accuracy of the model behavior approaches existing historical data indicates the validity of the model. The historical data compared with the model behavior in this study is data on forest vegetation land, degraded forest land, Paniis spring discharge, population, agricultural land and PES in a certain time period which has historical data.

Figure 7 shows the validation testing to related variables in the model. The tested variables were found to be valid and thus can be used to analyze the policies of sustainable cross-regional water resources management in Kuningan regency and Cirebon city. The sustainability is assessed based on environmental, economic, and social indicators. From the environmental indicators, the sustainability of water resources management was obtained from the percentage of vegetation coverage (PVC) above 80. Water use index (WUI) below 0.25 is used as the economic indicator of sustainability while level of services (LoS) of clean water above 81.77% is the social indicator of sustainability.

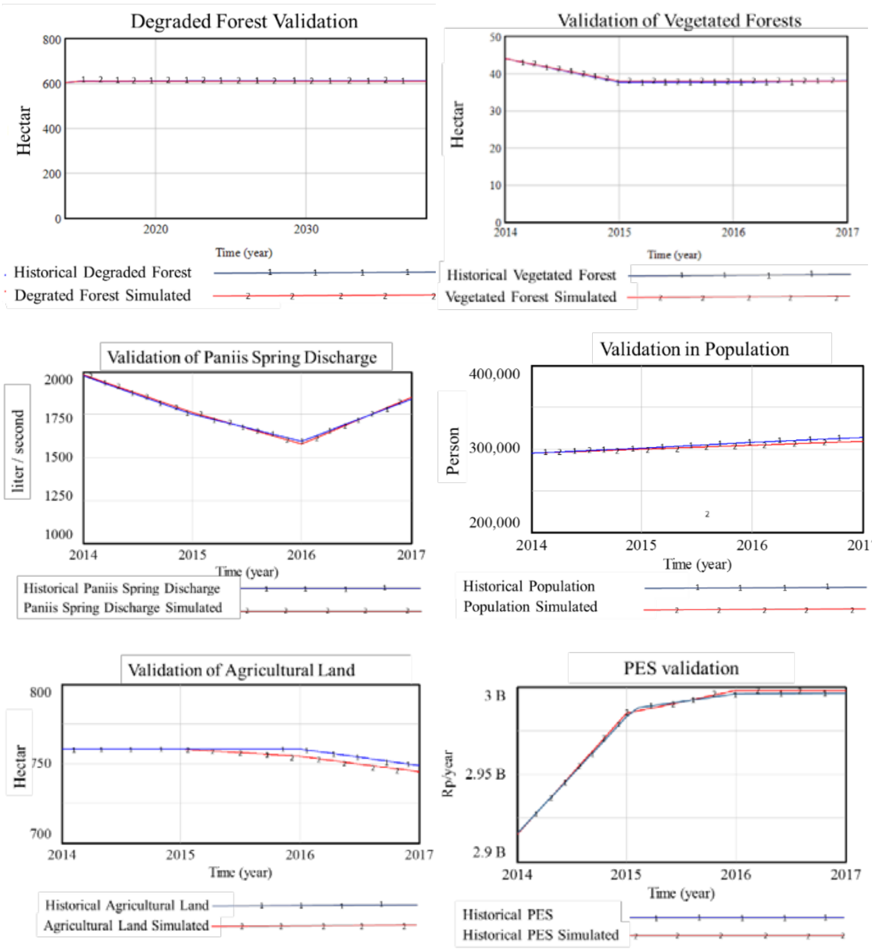
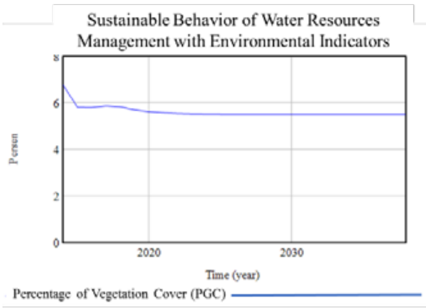


Fig. 7. Model validation testing to variables.

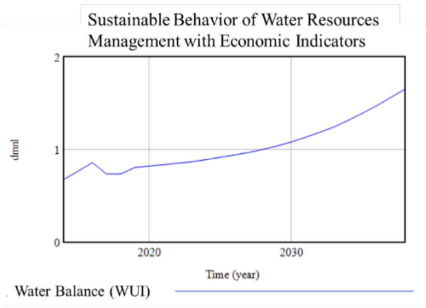
To examine the significance of the future possibilities, the variables this model are simulated to see the sustainable behavior of water resources management in the long term (20 years) starting in 2019, without any policy intervention (business as usual scenario).

Figure 8 shows the simulation results of a business-as-usual scenario (reference) which illustrates the unsustainable behavior of water resources management according to environmental, economic and social indicators. Figure 8 (a) shows that the value of PVC has decreased from 5.69 to 5.50 from 2019 to 2038, which means that it has not reached the PVC target of ≥ 80%. With such conditions, it can be perceived that the management of water resources according to environmental indicators is not yet sustainable. Figure 8 (b) shows the value of WUI which continues to increase from 0.91 in 2019 to 0.97 in 2038, but it has not reached the WUI target of ≤ 0.25. With this condition, the management of water resources from an economic aspect is not yet sustainable. Figure 8 (c) shows the LoS value of 1.0 (or 100%), stagnating from 2014 to 2021, then decreasing to 0.51 (or 51%) until

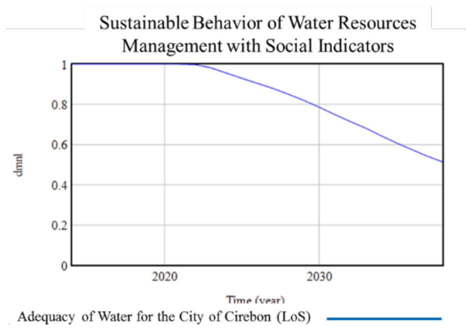
2038. This means that resource management water according to socially sustainable indicators is only until 2021.



(a)



(b)

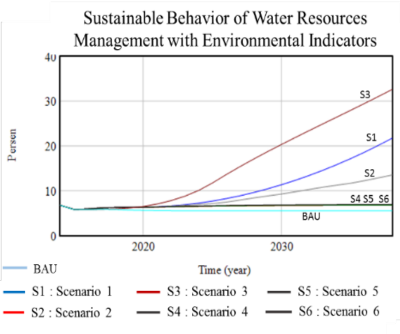


(c)

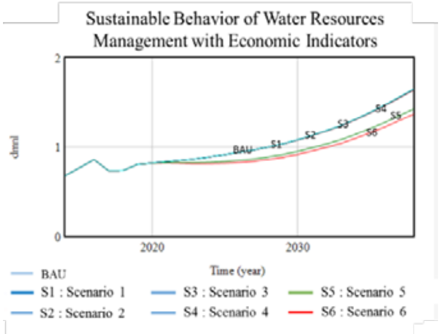
Fig. 8. Sustainable behavior of water resources management with environmental indicators (a), economic indicators (b) and social indicators (c) on the basis of a business-as-usual scenario.

Furthermore, from the analysis results of the behavior in the reference scenario, various policy alternatives interventions (six scenarios) were tried into the model. Scenario 1 was the simulation of the policy to increase the allocation of the use of PES compensation funds which is fully utilized for the management of water resources in the recharge area of the Paniis spring. The following policy alternative interventions include an increase in water prices (Scenario 2), controlling the rate of forest degradation (Scenario 3), an increase in the raw water quota for Cirebon City (Scenario 4), a decrease in the level of water loss (Scenario 5) and limiting the expansion of the sales of processed water outside the area by water utility company (PDAM) in Cirebon City (Scenario 6). Figure 9 shows the sustainable behavior of water resources across regions after being intervened with a single scenario.

Based on Fig. 9, the simulation results of a single policy scenario have not shown the expected results. The achievement of PVC, WUI and LoS values has not yet reached the values required to bring environmental, economic and social indicators towards sustainable water resources management. The continuity of cross-regional water resources management has only shown progress after a combination of various policy scenarios was intervened. Table 1 illustrates the achievement of sustainable water resources management according to the policy scenario applied.



(a)



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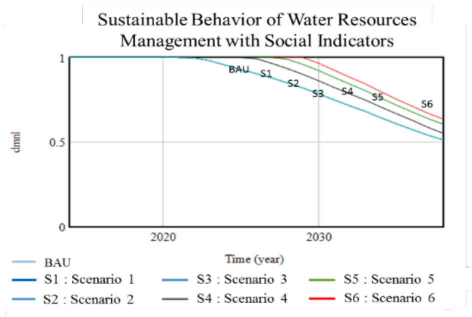


(c)

Fig. 9. Sustainable behavior of cross-regional water resources management due to the intervention of a single policy scenario.

Table 1. Results of combination policy scenarios in with the indicators in cross-regional water resources management.

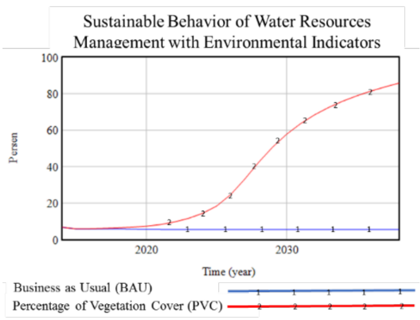
Scenario	**Sustainability**		
	Environment Indicator PVC ≥ 80%	**Economic Indicator WUI ≤ 0.25**	**Social Indicator LoS ≥ 81.77%**
Scenario 1	22	1.64	51.35
Scenario 2	14	1.65	51.35
Scenario 3	33	1.64	51.35
Scenario 4	7	1.65	55.24
Scenario 5	7	1.43	60.68
Scenario 6	6	1.85	45.16
Scenario 1+2+3	86*	1.62	51.35
Scenario 1+2+3+4+5	86*	1.40	66.63
Scenario 1+2+3+4+5+6	86*	1.16	82.61*

*The policy scenario succeeded in bringing about the sustainable management of water resources.

The results of the simulations show that two combined policy scenarios have succeeded in delivering a sustainable status of water resources management across Kuningan District-Cirebon City, i.e., a combination of 1+2+3 scenarios and a combination of all scenarios. The combination of policy scenarios 1+2+3 has succeeded in delivering the management of water resources across Kuningan

District-Cirebon City to a sustainable status from environmental indicators (PVC > 80%). Meanwhile, to bring social indicators to the status of sustainability (TP > 81.77%), a combined implementation of all policy scenarios is required. Meanwhile, economic indicators have not succeeded in bringing about sustainable water resources management (IPA < 0.25) even though all policy scenarios are combined. Figure 10 shows the simulation results of various policy scenarios to illustrate the behavior of water resources management after interventions by a combination of policy scenarios.

Figure 10 (a) shows the sustainable behavior of water resources management after a combination of 1+2+3 scenarios was intervened. In this simulation, it can be seen that since 2019 the PVC parameter graph has begun to move away from the BAU graph and is slowly increasing to reach a PVC value of 86% in 2038. With a PVC value of 86%, it means that it has exceeded the desired target, indicating the status of sustainable water resources management.



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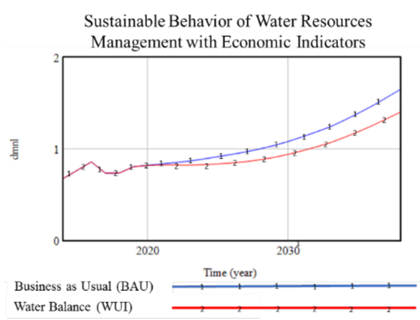

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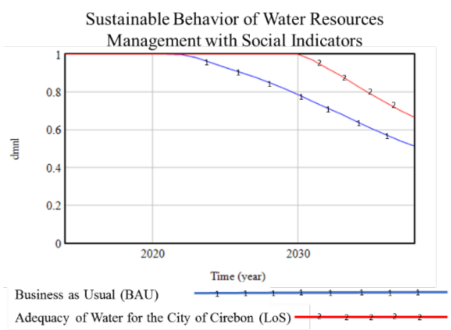

(c)

Fig. 10. Sustainable behavior of water resources management with environmental indicators (a), economic indicators (b) and social indicators (c) on the basis of combined policy scenarios.

This sustainability is due to the policy of increasing the water price (scenario 2) which has succeeded in increasing PES. With 100% allocated for water resources management (Scenario 1) and 75% of the allocation used for reforestation activities, the burden of land restoration decreases from 341 ha in 2028 to 94 ha in

2038. The use of PES for conservation activities results in significant forest land cover. The application of PES on private land has succeeded in accelerating the abandonment of agricultural land and, through this process, forest growth and the recovery of services are obtained [29]. Then, with efforts to control the rate of degradation (Scenario 3) through forest protection mechanisms by the authorities, the natural tree growth process becomes uninterrupted so that it has succeeded in reducing 100% of the degraded land, from 614 ha to 0 ha. Likewise, the tree load that must be recovered decreased 100% from 18 ha / year to 0 ha / year. With the performance of such land systems, the forest vegetation continues to increase as described in Table 1 (environmental indicators).

Table 2 shows the implementation of combined scenarios (Scenarios 1, 2, and 3) has resulted in forest vegetation of covering an area of 556 ha in 2038, showing 15 times increase from the existing condition of 38 ha. With this scenario, the achievement of 556 ha land area vegetation coverage successfully covers 86% of the area in the catchment area of the Paniis spring area. These results indicate that PES contributes significantly to the sharing of funding for reforestation activities. In line with previous research, ecological protection financing in the form of basin eco-compensation - a system that requires environmental compensation primarily for cross-regional water supply - is very helpful in overcoming China's ecological problems [30]. The compensation program also ensures the success of water conservation programs and the sustainability of water cooperation between regions [31].

Figure 10 (b) shows the behavior of unsustainable water resources management even after a combination of all policy scenarios was intervened. In the simulation, it can be seen that since 2019 the WUI value cannot reach the value below 0.25. After taking a value below 1 (one) until 2035, this WUI value will increase again until it reaches the WUI value of 1.17 in 2038. With this condition, it indicates that the status of water resources management according to economic indicators is not sustainable. This is due to the implementation of a combined scenario (Scenarios 1,2,3) which can only increase 2% of water supply and cannot fulfil the total demand in which its capacity has been controlled through the decrease in the drinking water demand by the combined policy of scenarios 4,5, and 6. The combined policy scenarios has successfully reduced the water demand up to 28% from the reference scenario of 74.165.304 m^3/year to 53.482.336 m^3/year. The balance supply and demand as an impact from the combined policy scenarios is described in Table 1 (economic indicator).

Based on Table 2, the supply-demand difference has been negative since 2036, meaning that the balance of water resources is disrupted, and the supply cannot keep up with demand. In this condition, the ratio of demand to supply stated in the water use index (WUI) is > 1, indicating that the management of water resources from economic indicators is unsustainable.

To increase supply, the physical condition of the degraded watershed needs to be restored, but this recovery takes a very long time. Therefore, it is necessary to reduce demand as a reasonable anticipatory step. As is done in China, to ensure sustainable management of water resources, making water conservation a top priority and controlling water demand needs to be done [32]. Noiva et al explained that efficient water use, demand management, reuse, and recycling are needed for sustainability [33]. The main components that trigger increased demand are population, water loss, and water consumption. Reducing the rate of population growth is a long-term solution that needs to be considered. Therefore, reducing the level of water loss will be an option for activities in the short term. The annual routine activities in water utility company management are very supportive of this effort. The reduction in water consumption is also very significant to reduce this demand. A water-saving lifestyle is needed to minimize the level of water consumption. In case of shortage of water resources, saving water is an effective approach to increase the carrying capacity of water resources [34]. Furthermore, reusing used water will indirectly help reduce the load on the supply. With the aim of increasing water efficiency and finding a balance between water supply and demand, water control is carried out by accelerating the technological transformation of urban water supply networks, reducing leaks in water transmission and distribution, and increasing urban sewage treatment and recycling efforts [35].

Figure 10 (c) shows the sustainability of water resources management after the combined intervention of six scenarios. Based on the simulation, the LoS graph moves away from the reference scenario. The achievement of LoS runs up to 2034 and declines to 82.61% in 2038. Despite the declining trend, the value of LoS still meets the requirement for sustainability (LoS > 81.77%). This achievement indicates the water resources management from social indicator has a sustainable level. This occurs as a result of the implementation of the policy scenarios 4,5, and 6 towards efforts to control drinking water demand. The scenario implementation has succeeded in bringing the capacity of drinking water demand to equal that of raw water supply. If the policy of the leakage rate (scenario 5) is reduced to 10% and the sale of drinking water outside the service area (scenario 6) is eliminated to 0%, the demand for drinking water can be reduced by 32% from 65,156,460 m^3/year to 44,473,488 m^3/year at the end of the simulation year. On the one hand, increasing the supply of raw water with the Water Retrieval and Utilization Permit (scenario 4) to 1,165 or 36,739,440 m3/year also makes the maximum daily requirement acceptable, as explained in Table 1 (social indicators).

Table 2 shows the comparison of domestic raw water supply for Cirebon City with drinking water demand, resulting in LoS of 83% in the city. This achievement means that the management of water resources according to social indicators is towards sustainability.

Table 2. Summary of cross-regional water resources management sustainability according to environmental, economic and social indicators.

	Environment Indicator					Economic Indicator				Social Indicator			
Year	**Degraded Forest Land [ha]**	**Forest Recovery from PES [ha]**	**Natural Forest Land Recovery [ha/year]**	**Vegetation Forest Land [ha]**	**PVC [%]**	**Paniis Spring Discharge [m^3/year]**	**Total Demand [m^3/year]**	**Water Balance**	**WUI**	**Potential Flow to Cirebon [m^3/year]**	**Flow to Cirebon [m^3/year]**	**“Daily Maximum Demand” [m^3/year]**	**LoS**
2014	606	0	17	44	7	62,455,804	42,302,260	20,153,544	0.68	50,378,600	28,697,760	30,225,052	0.95
2015	607	5	17	38	6	55,487,732	42,575,360	12,912,372	0.77	43,410,524	28,697,760	30,498,152	0.94
2016	603	8	17	39	6	49,841,200	42,781,344	7,059,856	0.86	37,833,572	33,459,696	30,773,718	1.09
2017	598	12	17	40	6	58,410,720	42,901,812	15,508,908	0.73	46,560,680	33,459,696	31,051,774	1.08

2018	594	14	17	42	6	58,414,144	43,038,140	15,376,004	0.74	46,708,348	33,459,696	31,332,342	1.07
2019	590	16	17	44	7	53,905,128	43,440,444	10,464,684	0.81	42,333,056	36,739,440	31,868,370	1.15
2020	581	21	17	47	7	53,431,936	43,639,484	9,792,452	0.82	42,004,656	36,739,440	32,212,202	1.14
2021	565	32	16	53	8	52,963,924	42,952,464	10,011,460	0.81	41,686,616	36,739,440	31,675,156	1.16
2022	542	46	15	62	10	52,501,980	41,609,848	10,892,132	0.79	41,372,672	36,739,440	30,480,544	1.21
2023	513	63	15	74	11	52,047,248	40,116,548	11,930,700	0.77	41,064,004	36,739,440	29,133,304	1.26
2024	475	83	14	92	14	51,601,636	39,087,036	12,514,600	0.76	40,762,536	36,739,440	28,247,934	1.30
2025	400	134	11	116	18	51,170,148	38,367,876	12,802,272	0.75	40,473,300	36,739,440	27,671,030	1.33
2026	271	225	8	154	24	50,764,344	37,952,876	12,811,468	0.75	40,207,884	36,739,440	27,396,416	1.34
2027	127	318	4	205	32	50,382,280	37,835,384	12,546,896	0.75	39,964,360	36,739,440	27,417,466	1.34
2028	44	341	1	265	41	50,009,124	38,101,208	11,907,916	0.76	39,727,932	36,739,440	27,820,012	1.32
2029	15	314	0	321	49	49,625,624	38,639,928	10,985,696	0.78	39,479,364	36,739,440	28,493,666	1.29
2030	5	277	0	368	57	49,227,884	39,481,908	9,745,976	0.80	39,214,780	36,739,440	29,468,804	1.25
2031	2	241	0	408	63	48,817,448	40,609,504	8,207,944	0.83	38,935,756	36,739,440	30,727,814	1.20
2032	1	209	0	440	68	48,397,028	41,852,128	6,544,900	0.86	38,645,024	36,739,440	32,100,124	1.14
2033	0	182	0	467	72	47,969,200	43,205,560	4,763,640	0.90	38,345,180	36,739,440	33,581,544	1.09
2034	0	160	0	490	75	47,536,116	45,000,968	2,535,148	0.95	38,038,404	36,739,440	35,503,256	1.03
2035	0	140	0	510	78	47,099,484	46,945,764	153,720	1.00	37,726,420	36,739,440	37,572,700	0.98
2036	0	123	0	527	81	46,660,648	48,985,816	(2,325,168)	1.05	37,410,596	36,739,440	39,735,764	0.92
2037	0	108	0	542	83	46,220,648	51,257,604	(5,036,956)	1.11	37,091,996	36,739,440	42,128,952	0.87
2038	0	94	0	556	86	45,780,304	53,482,336	(7,702,032)	1.17	36,771,456	36,739,440	44,473,488	0.83

5. Conclusion

One of the important things in water resources management is the balance of supply and demand which is influenced by the interconnected complex factors. To understand the dynamics and interactions of these factors, the System Dynamics modeling method can be used to understand this problem more deeply and predict the future. System Dynamics demonstrates how to integrate these factors to identify problems that occur, how policies are implemented, and finally how to formulate sustainable water resources management. Based on model simulations, it is found that implementing one policy alone is not sufficient to assist cross-regional water resources management to achieve sustainability, especially if no single policy is implemented (busines as usual). Sustainability is starting to be achieved by applying a combination of policy scenarios, although only from the perspective of environmental and social indicators. This result encourages all stakeholders to reduce demand growth to realize sustainable water resources management in the future.

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