The Environment's Carrying Capacity Status Due To the Use of Groundwater by the Community

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Abstract

The enhancement of the shift in settlement areas in the suburbs of Jakarta is getting out of control. This phenomenon of urban sprawl development has changed the function of open land into built-up land for the construction of new housing infrastructure. This urban sprawl phenomenon will continue along with the escalating number of inhabitants. In addition, the development of residential areas in the outskirts of Jakarta, as happened in the research location in South Jakarta, has social and environmental impacts caused by the high use of groundwater by the community and makes residential areas unsustainable. This paper aims to assess the status of the environment's carrying capacity related to the occurrence of unsustainable settlements and to offer efforts to implement groundwater conservation in residential areas. This study develops a dynamic system model using a feedback approach to obtain the surroundings' carrying capacity status. The feedback approach uses three environmental subsystem models to address sustainable ecological problems: the social-environmental subsystem, the built environment subsystem, and the natural environment subsystem. The variables affecting the simulation system are the community's water needs, land conversion, and groundwater availability. The study's findings indicate that when it begins in 2070, the status of the environmental carrying capacity at the research location will be experiencing a severe water deficit, resulting in groundwater scarcity. Based on the scenario results, several policies can have a positive influence on increasing the status of environmental carrying capacity so that they can assist decision-makers in implementing groundwater conservation policies.

Keywords: *Environment carrying capacity; Groundwater balance; Community water needs; Groundwater availability; Dynamic system models; Groundwater conservation.*

1. INTRODUCTION

The increased potential of settlement areas continues to extend to the suburbs of Jakarta. This settlement expansion has received support from various infrastructure development plans from the government. The expansion of urban sprawl on the fringes of Jakarta is in line with the rapid growth of the urban population. As the population grows, the area of settlements gets bigger. The expansion of residential land influences smaller rainwater catchment areas and eventually reduces groundwater availability [1]. Decreasing groundwater availability can cause environmental degradation, making the area unsustainable [2]. Various impacts of environmental degradation have emerged, such as groundwater pollution, land subsidence, and groundwater depletion [3]–[6]. Moreover, this phenomenon causes a decrease in the region's environmental quality, especially in

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groundwater use [7]–[9]. Overuse of groundwater exacerbates groundwater imbalances around settlements [3]–[6].

Underground water is one of the natural resources that people need for viability [1], [10]. In theory, groundwater is a renewable natural resource [11], but its formation takes a long time, even decades [12]. In addition, groundwater has regenerative power, which is always in circulation from a hydrological cycle: rainfall accommodated in recharge areas, re-evaporation as evapotranspiration, water flowing to the surface as direct surface runoff, and groundwater infiltration. If people continue to exploit groundwater excessively without thinking about its management, then in the future, the groundwater supply on this earth will run out. Therefore, groundwater users must pay attention to the quality, quantity, and continuity of the groundwater so that the balance and sustainability of the groundwater can be maintained.

A high population increase will trigger enhanced community water needs. If the need for water and the potential for available water sources is not balanced, there will be a groundwater imbalance. Groundwater imbalance is one of the factors that cause socio-environmental impacts and makes residential areas unsustainable [1]. Due to the problem of this groundwater imbalance, people must understand their attitudes and behaviors toward groundwater use. Therefore, to maintain the balance of groundwater, it is necessary to conserve groundwater to avoid groundwater scarcity [13]. Groundwater conservation is an effort to protect, recover, maintain, and enhance the function of groundwater according to its ability to support sustainable development and life. One of the objectives of this groundwater conservation activity is to increase groundwater recharge in recharging areas while reducing environmental problems. In practice, groundwater conservation activities still require more detailed guidelines so that these conservation activities can run optimally.

In discussing the assessment of the status of the carrying capacity of the environment in residential areas, particularly repercussions from overuse of groundwater, and what makes residential areas unsustainable, there are several research questions: (1) How to assess the environment's carrying capacity status based on the groundwater balance (2) What are the efforts to implement groundwater conservation in residential areas? Therefore, this study aims to assess the status of the environment's carrying capacity related to unsustainable settlements and offer efforts to implement groundwater conservation in residential areas. This research conducted observations for approximately one year, from August 2020 to August 2021.

2. METHODOLOGY

2.1   Study area

The research location to analyze the status of environmental carrying capacity based on groundwater balance, mainly due to the community's excessive use of groundwater, is in the south district of Jakarta, precisely in Jagakarsa District. This area is the most southerly in the South Jakarta region. This area is a water catchment area in Jakarta that maintains the balance of the hydrological cycle. However, this area is experiencing rapid population growth due to a shift in residential areas from the city center that extends to this area. This phenomenon has caused much land to change its function from open land to built-up land for the construction of new housing infrastructure. According to data from the Jakarta Regional Development Planning Agency for 2018, the average housing and settlement construction in this area increased by 2.1% annually, while the population growth rate reached 2.3%. With such developments in this area, the space for rainwater infiltration is decreasing, which can result in reduced groundwater reserves. The groundwater quality in this area has a groundwater content that meets the characteristics

needed to be worthy of drinking. From an astronomical perspective, this area lies at 6° 15' 40.8" S latitude and 106° 45' 0" E longitude.

2.2   Approach to groundwater balance assessment

In assessing the status of the carrying capacity of the environment related to groundwater balance, use the concept of the carrying capacity of groundwater sources as the carrying capacity of the environment [1], [10], [14]–[16]. The carrying capacity of groundwater resources is their ability, as an environmental resource, to support the livelihoods of humans and other living things. In this concept, the management of groundwater resources uses the concept of fulfilling quality, quantity, and continuity without causing negative impacts on the environment. Therefore, the carrying capacity of groundwater sources is an essential index for sustainable development [17]. In theory, underground water balance is the gap between groundwater availability and water needs by the community, which informs the environmental carrying capacity of an area in conditions of water surplus or deficit status [1], [18], [19]. A surplus situation indicates that the availability of groundwater is sufficient, and an area is said to be in deficit if the availability of groundwater is insufficient. Therefore, this groundwater balance can be said to be a determinant of the status of the carrying capacity of the environment [1], [10], [14]–[16].

In this study, determining the status of environmental carrying capacity in residential areas is based on groundwater balance (GB), groundwater availability index (GAI), and groundwater use index (GUI). The parameter of groundwater balance (GB) is the difference between groundwater availability (SA) and community water needs (DA). Meanwhile, the groundwater availability index (GAI) parameter is a comparison between groundwater availability (SA) and community water needs (DA). The groundwater use index (GUI) parameter is the ratio of community water needs (DA) and groundwater availability (SA). The environmental carrying capacity of an area is declared surplus if it has an SA value more significant than the DA value and a groundwater availability index (GAI) value greater than 1. Meanwhile, an area is declared in deficit if the SA value is less than the DA value and the groundwater availability index (GAI) value is less than 1. In this study, to determine the classification of the groundwater use index (GUI) parameter results, following the guidelines of the Minister of Environment Regulation Number 17 (2009), (1) it is not critical if the GUI is below 25%. (2) It is mildly critical when the GUI is between 25% and 50%. (3) Medium-critical if the GUI concentration is between 50% and 100%. (4) GUI is severely critical if it exceeds 100%. The three parameters to evaluate the status of the bearing capacity of the environment are:

$$GB = (SA - DA) \tag{1}$$

$$GAI = \left(\frac{SA}{DA}\right) > 1 \tag{2}$$

$$GUI = \left(\frac{DA}{SA}\right) \tag{3}$$

Where: GB is groundwater balance; GAI is an index of groundwater availability; GUI is the groundwater use index; SA is groundwater availability; DA is community water needs.

2.3   method

This study estimates the status of environmental carrying capacity related to groundwater balance by developing a dynamic system model through a feedback approach. The purpose of developing this dynamic system modeling is to help policymakers and decision-makers better understand the impact of actions, plans, and the implementation of groundwater conservation policies. Meanwhile, the feedback approach aims to investigate the simulated movement patterns in the dynamic system model over time. The feedback approach is at the core of the dynamic system model, which describes a closed string of

causality. The feedback diagram in the dynamic-system model is known as the Causal Loop Diagram (CLD), which shows the interaction of all variables. Then, to conceptualize complex system structures and communicate model-based insights, simulate using stock and flow diagrams [20]–[22]. In general, feedback is information received as a form of response whose results or consequences turn into a stimulation to follow up as an element of policy improvement for the future [23]–[25]. This dynamic system model has several limitations [26] and has many uncertainties due to the complex dynamics of urban water systems [27], [28]. Environmental disturbances and anthropogenic factors are very influential in this dynamic system model [1], [18], [19]. Several strategies from scenario results with dynamic system modeling can become the basis for implementing a policy.

2.4 Validation model of research method

Because the dynamic system model uses a feedback approach, the system must verify the model [25]. The purpose of validating this model is to ensure the exactness of the outcomes of the modeled system simulation process. The verification carried out in this study was the validation of growth patterns and statistical validation. Statistical validation is model validation using statistical methods. This validation aims to check the validity of the results between the simulation value and the actual value in the model [29]. This statistical validation calculates the value of the average absolute error (AAE). AAE is the ratio between the simulation result and the actual value [30]. It is said to be valid if the statistical validity of the AAE value is less than 30% [30]. The variables used to evaluate these validations are the population variable and the total water demand variable. The statistical validation formula used is as follows:

$$AAE = \frac{(Si-Ai)}{Ai} x100\% \qquad (4)$$

$$Si = \sum \frac{Si}{n} \quad and \quad Ai = \sum \frac{Ai}{n} \qquad (5)$$

Where: A is the actual value; S is the simulation value; N is the observation time interval.

Validation of growth patterns aims to see the behavior curve pattern that occurs in the model. The feedback diagram shows four behavior curves in the modeled process [20], [23], [24], [26], [31], as presented in Figure 1. Constructive growth-pattern behavior curves are those that reinforce exponential growth and collapsed curves. Meanwhile, the negative growth pattern consists of a balancing decay behavior curve and a goal-seeking behavior curve. The validated simulation result encompasses both the mimicked growth pattern process and future trends. Consequently, the results of this validation become the basis on which policymakers formulate future policies for implementing groundwater conservation.
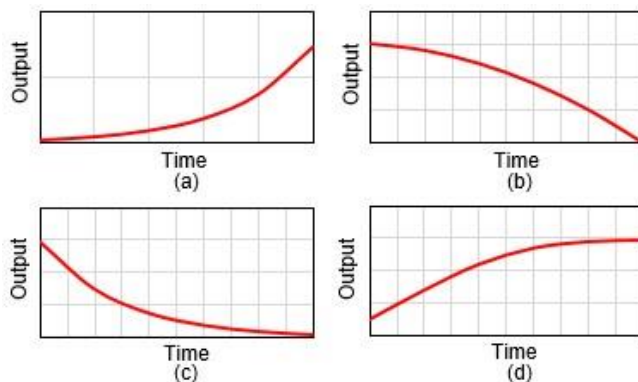

Figure 1. Behavior Curve

(a) Reinforcing Exponential-Growth Curve.

(b) Reinforcing Collapse Curve

(c) Balancing Decay Curve. (d) Balancing Goal-Seeking Curve

2.4 Descriptive analysis of subsystems

In assessing the status of environmental carrying capacity related to groundwater balance, the feedback system uses secondary data to predict the next few years, as presented in Table 1. This modeling uses secondary data from the South Jakarta Center for Statistics Yearbook, 2013–2019. Meanwhile, this paper performs model simulations to predict subsystem relationships in 2020–2080. The simulation uses three environmental subsystem models in building a dynamic system model with Powersim Constructor Studio 10 software: the social-environmental subsystem, the built environment subsystem, and the natural environment subsystem. The variables affecting the simulation system are the community's water needs, land conversion, and groundwater availability. The variables from the three subsystems that affect the model are presented in a CLD to see the interrelationship between variables in the system (Figure 2). In the meantime, do see the simulation process in SFD (Figure 3).

In this study, the simulation of the community's water needs subsystem as a social environment model includes domestic and non-household water needs variables. Domestic water needs variables include population, population water needs standards, and community behavior towards groundwater. Non-household water needs are estimated to be 30% of household water needs. The land conversion subsystem as a model of the built environment includes built land area, open land area, and total study area variables. In this case, what is meant by "built-up land area" is residential land, office land, public service land, and social facility land. What is meant by "open-up land" are environmental parks, interactive parks, river banks, green lines, and cemeteries. The underground water availability subsystem as a natural environment model consists of variables that increase and decrease the potential for groundwater availability. In this study, the assumption of initial groundwater availability is the volume of water from the estimated rainfall that seeps into the groundwater. This study assumes the initial groundwater availability at the study site using the Thornthwaite-Mather formula (1957) and the Ffolliot method [32] is 3,071,959 m3/year.

Table 1. Secondary data for the research method

Variable name	Data name	Data
1. The community water needs subsystem as a social-surroundings model	Total Population in 2013	285,767 people
	Total Population in 2014	288,731 people
	Total Population in 2015	297,737 people
	Total Population in 2016	298,608 people
	Total Population in 2017	318,578 people
	Total Population in 2018	378,865 people
	Total Population in 2019	401,730 people
	Birthrate	1.34%
	Death Rate	0.31%
	Immigration Rate	2.82%
	Emigration Rate	1.41%
	Population growth rate	3.17%
	Water demands standard	150 liters/person/day

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	Hotel water demands standard	150 liters/person/day
	Total hotel bed	-
	Hotel Growth Rate	-
2. The land conversion subsystem as a built-environment model	Built-up land area	20,910,000 m^2
	Open-up land area	4,100,000 m^2
	Total land area	25,010,000 m^2
	Development rate	3%
	Use of Built-up land area	0.6
	Use of Open-up land area	0.3
3. The groundwater availability subsystem is a natural-environment model	Rainfall	2,463 mm/year
	Evaporation rate	1,700 mm/year
	Average temperature	27.87 ^{0}C
	Groundwater Pollution	10%
	Pollution category	light polluted
	Prediction of initial availability of groundwater	3,071,959 m^3/year
Source: the South Jakarta Center for Statistics Yearbook		
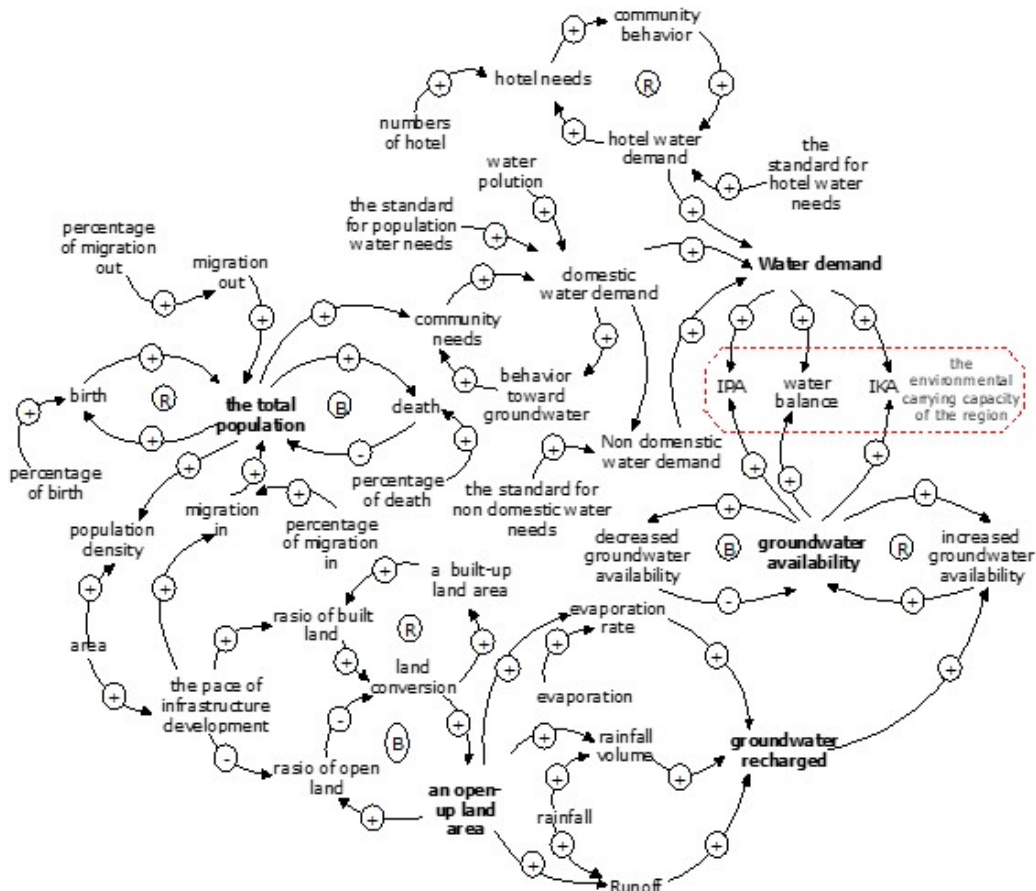
Figure 2 Causal Loop Diagram of the three subsystems

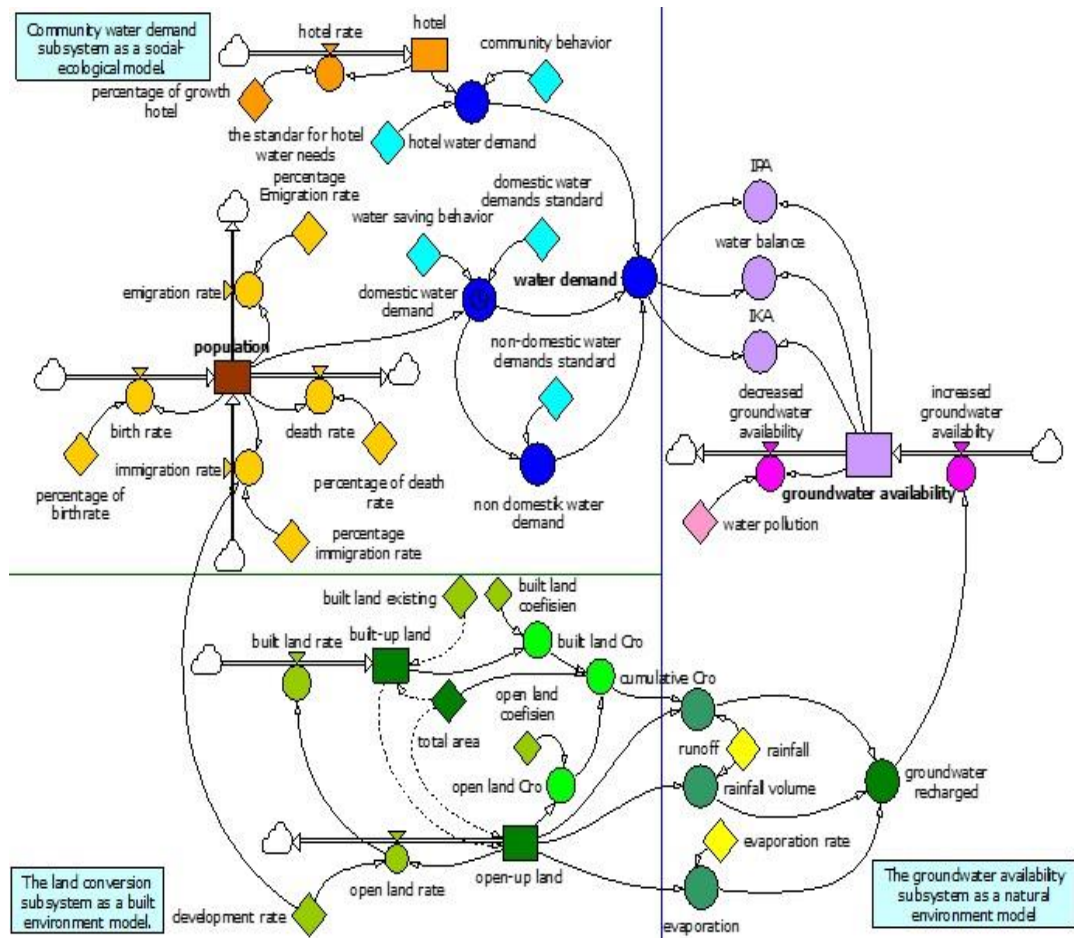Source: the results of developing a dynamic system model

Figure 3. Stock Flow Diagrams of the three subsystems

Source: the results of developing a dynamic system model

3. RESULTS

This research, to assess the status of the environment's carrying capacity related to the occurrence of unsustainable settlements, uses the concept of the carrying capacity of groundwater sources as the carrying capacity of the environment. In this study, the simulation produces three parameters to determine the status of environmental carrying capacity in residential areas: the groundwater balance (GB), the groundwater availability index (GAI), and the groundwater use index (GUI). Meanwhile, to estimate the value of the three indicators, utilize equality (1), (2), and (3). These three parameters become the basis for knowing the status of the environmental carrying capacity in residential areas in a surplus or deficit state. The outcome of the process modeled in this study concludes that in 2020–2065, this study area will be a groundwater surplus area with a mild critical condition category with a GB value greater than 1, a groundwater availability index (GAI) value greater than 1, and a GUI value between 25% and 50% (Table 2). However, when it starts in 2070, groundwater availability begins to decline. The study area will experience a groundwater deficit with a severe critical condition category, resulting in groundwater scarcity (Fig. 4). Based on the simulation results, in 2080, the environment's carrying capacity at the study site will be unsustainable. Therefore, it is appropriate that this condition deserves special attention from the central and regional governments before environmental degradation occurs, mainly due to the overuse of groundwater.

Table 2. Prediction on the status of environmental carrying capacity

| Year	The community water needs m³/year	The groundwater availability m³/year	Groundwater balance (GB) m³/year	Groundwater availability index (GAI)	Groundwater use index (GUI) %	The status of environmental carrying capacity
2020	5,893,962	108,610,379	102,716,417	18.427	5	not critical surplus
2024	7,284,989	130,369,036	123,084,046	17.896	6	not critical surplus
2028	9,004,311	137,248,313	128,244,002	15.243	7	not critical surplus
2032	11,129,409	135,346,942	124,217,533	12.161	8	not critical surplus
2036	13,756,048	128,524,868	114,768,819	9.343	11	not critical surplus
2040	17,002,597	119,195,627	102,193,029	7.010	14	not critical surplus
2044	21,015,361	108,842,299	87,826,938	5.179	19	not critical surplus
2048	25,975,173	98,352,840	72,377,667	3.786	26	mild critical surplus
2052	32,105,545	88,237,507	56,131,962	2.748	36	mild critical surplus
2056	39,682,738	78,769,395	39,086,657	1.985	50	mild critical surplus
2060	49,048,216	70,074,920	21,026,704	1.429	70	medium critical surplus
2064	60,624,031	62,191,755	1,567,725	1.026	97	medium critical surplus
2068	74,931,840	55,105,676	-19,826,164	0.735	136	severe critical deficit
2072	92,616,419	48,773,759	-43,842,660	0.527	190	severe critical deficit
2076	114,474,716	43,138,806	-71,335,910	0.377	265	severe critical deficit
2080	141,491,765	38,138,121	-103,353,643	0.270	371	severe critical deficit
Source: Simulation outcomes of the dynamic system model						
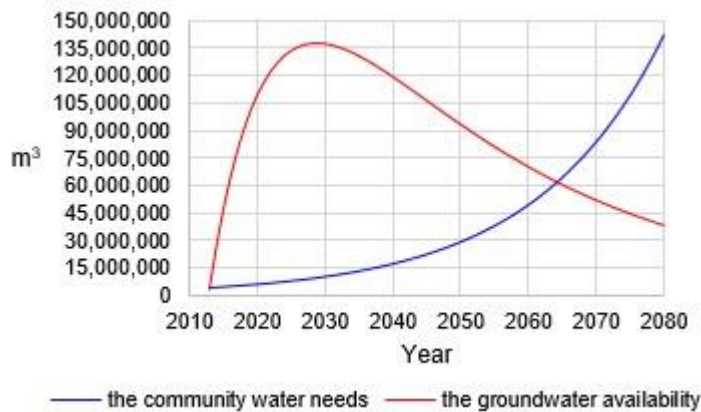
Figure 4. Simulation on the status of environmental carrying capacity

In this discussion, the effort to improve the environmental carrying capacity status in residential areas is to carry out several scenarios. Several strategies developed from scenario results with dynamic system modeling can become the basis for stakeholders to implement groundwater conservation policies. In this study, the simulation performs several design scenarios using three environmental subsystem models in building a dynamic system model: the social-environmental subsystem, the built environment subsystem, and the natural environment subsystem. The variables affecting the simulation system are the community's water needs, land conversion, and groundwater availability. Based on the results of this study, several scenarios for implementing groundwater conservation policies in the future yield some positive results. The positive results with the scenario of reducing the rate of development are a decrease in the population, which results in a cutback in the community's need for groundwater, an increase in the area of open land as a groundwater catchment area, and an increase in the amount of groundwater absorption, which can reduce water runoff. In addition, the other positive results from the screenplay design in this study are: (1) reducing the percentage of people's behavior towards groundwater, which has an impact on reducing community water needs; and (2) reducing groundwater pollution, which has a take effect on increasing underground water availability.

In this study, planning and managing groundwater resources in an area requires predicting community water needs. Therefore, the simulation of the community's water needs subsystem as a social environment model includes population variables and community water needs. The simulation results conclude that population growth and community water needs are positively correlated [33]–[37]. In addition, the simulation shows that reducing the rate of development in residential areas results in a decrease in population, which results in reduced community water needs. Based on the simulation results, with a scenario of reducing the percentage rate of infrastructure development by 1.5% from 3%, in 2080, the community's water demand in the study area will decrease by 36.8%. Another positive result of scenario planning in this subsystem is reducing the percentage of community behavior toward groundwater by 10% from 20%. The results of the scenario design indicate that in 2080, the need for water will decrease by 33.23%. In the land conversion subsystem as a model of the built environment, the simulation includes the effect of the variable area of built-up land and open land on changes in groundwater availability. In this simulation, positive results with a scenario of decreasing the rate of development in residential areas by 1.5% from 3% in 2080 can increase open land as water catchment areas by 37.5%. Thus, the space for rainwater infiltration is increasing, and in the end, groundwater reserves are also increasing.

With the increased number of residents, the residential area is getting bigger, so it has an impact on reducing rainwater catchment areas and ultimately has an influence on reducing the availability of groundwater [1]. The subsystem of groundwater availability

in a natural environment model calculates the amount of groundwater availability using data on temperature, rainfall, cumulative rainwater that flows on the ground surface, evaporation rate, and the size of the study area. In this subsystem, the variable that can increase groundwater availability is groundwater recharge, while the variable that can decrease groundwater availability is groundwater pollution. In this simulation, under the scenario of reducing the rate of development in residential areas by 1.5% from 3%, groundwater recharge will increase by 48.6% in 2080. Another positive result of the scenario planning in this study is to reduce groundwater pollution by 8% from 10%. The simulation outcomes in this study conclude that in 2080, groundwater availability will increase by 15.6%.

In this research, the only way to know the correctness of the analysis is to validate growth patterns and use statistical validation. Based on the simulation, the results of the validation of growth patterns indicate that population growth and the increasing need for water in the community follow the Reinforcing Exponential Growth curve (Figure 5 and 6), which indicates that the two variables escalate every year. Meanwhile, the results of behavior validation on the behavior pattern of built-up land show that the increase in the built-up area follows the balancing goal-seeking curve behavior theory, which concludes that along with time, the variable built-up land gets wider (Figure 7). For the results of behavior validation for open land, the decrease in the open land area follows the balancing decay curve, which shows that open land tends to decrease over time (Figure 8). Based on the validation results in this study, the model created shows performance in actual conditions and followed the modeled process. For statistical verification, the validation value uses equations (4) and (5) and uses time series data from population data and community water needs from 2013 to 2019. This validity value compares actual values with simulated data from dynamic systems. Based on the outcome of the statistical validation, the AAE was 3.88% (Figure 9). The validation results in the study area are valid because the statistical validity of the AAE value is less than 30% [30]. These results indicate that the deviation from the simulation results to the actual conditions is relatively small, and the model shows good performance.

In this discussion, the effort to improve the environmental carrying capacity status in residential areas is to carry out several scenarios. Several strategies developed from scenario results with dynamic system modeling can become the basis for stakeholders to implement groundwater conservation policies. In this study, the simulation performs several design scenarios using three environmental subsystem models in building a dynamic system model: the social-environmental subsystem, the built environment subsystem, and the natural environment subsystem. The variables affecting the simulation system are the community's water needs, land conversion, and groundwater availability. Based on the results of this study, several scenarios for implementing groundwater conservation policies in the future yield some positive results. The positive results with the scenario of reducing the rate of development are a decrease in the population, which results in a cutback in the community's need for groundwater, an increase in the area of open land as a groundwater catchment area, and an increase in the amount of groundwater absorption, which can reduce water runoff. In addition, the other positive results from the screenplay design in this study are: (1) reducing the percentage of people's behavior towards groundwater, which has an impact on reducing community water needs; and (2) reducing groundwater pollution, which has a take effect on increasing underground water availability.
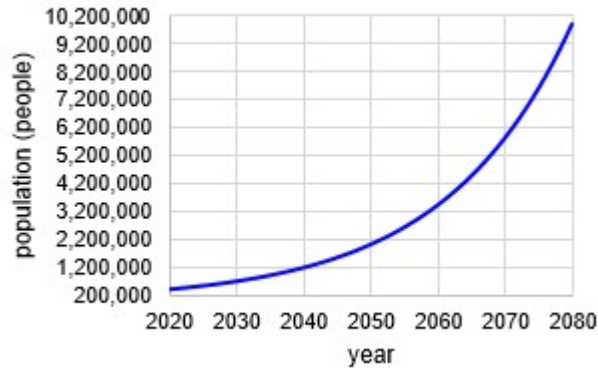
Figure 5. Validation of population growth behavior

Source: Calculation outcomes of the dynamic system model
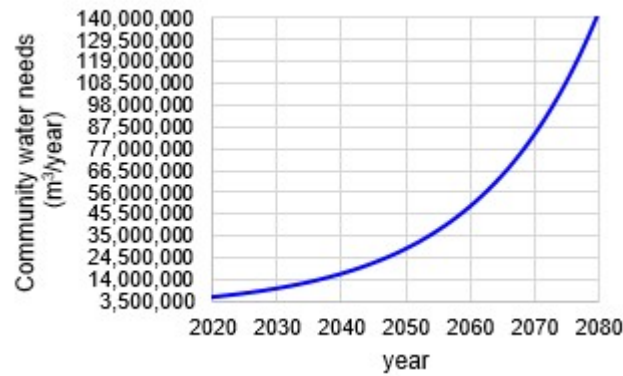

Figure 6 Validation of community water needs behavior

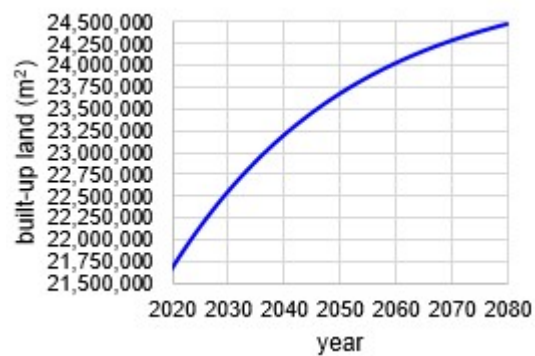Source: Calculation outcomes of the dynamic system model

Figure 7. Validation of built-up land behavior

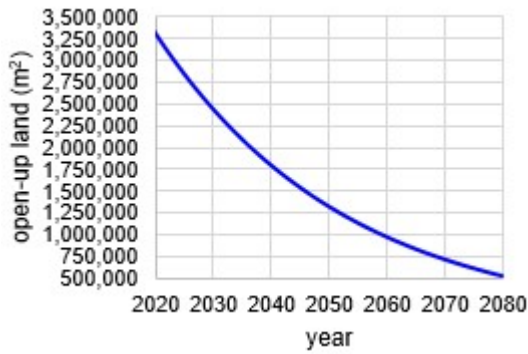Source: Calculation outcomes of the dynamic system model

Figure 8. Validation of open-up land behavior

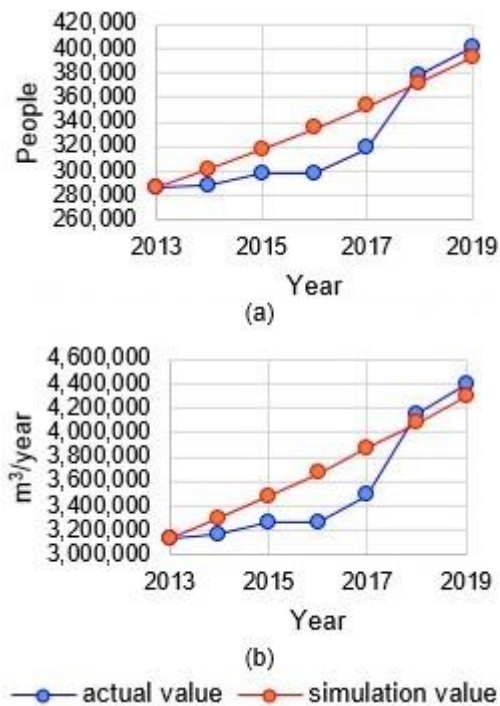Source: Calculation outcomes of the dynamic system model

Figure 9 Statistical validation

(a) Population. (b) Community water needs.

 Source: Calculation outcomes of the dynamic system model

4. DISCUSSION

In this discussion, the simulation designs several scenarios to improve the status of environmental carrying capacity in residential areas. This scenario design aims to obtain a policy strategy that can solve the problem of groundwater scarcity and assist decision-makers in implementing groundwater conservation policies in residential areas. In order to implement the groundwater conservation policy, the central and regional governments should periodically increase their efforts to carry out outreach activities that involve the community. As listed in the 2015 SDGs, community involvement is significant in managing groundwater resources [28], [38], [39]. Reducing people's behavior toward groundwater is one of the materials of socialization activities. In this study, what is meant by people's behavior toward groundwater is the habit of people using groundwater excessively in their daily lives [40], [41]. Therefore, one of the programs is a policy to

reduce people's dependence on groundwater by urging people to make groundwater infiltration media in the form of yards overgrown with grassy vegetation. This policy will be easy to implement because almost 90% of the houses in this residential area have yards.

Rapid population growth as a result of rapid infrastructure development causes a shift in land use, affecting the availability of underground water in the area [42]–[46]. Each area has a different amount of groundwater availability depending on the influencing factors, including hydrological conditions, soil topography, climatology, and geology [47]–[50]. Expansion of residential land has an impact on reducing open-space land and ultimately has an impact on reducing rainwater catchment areas. This condition causes a cutback in water entry into the ground due to escalating rainwater flowing over the surface. With a cutback in water entry into the ground, groundwater availability will also decrease. In this research, increasing the area of open land in order to multiply water entry into the ground is one method for increasing groundwater availability. In this research, the strategy to increase the area of open land is to decrease the percentage rate of infrastructure development in residential areas. The outcomes of the process being modeled based on this strategy plan indicate that the area of open land has increased. With an increase in the area of open land in the residential area, groundwater availability will also increase [51]–[53].

In this research, another venture to increase groundwater availability is to decrease groundwater pollution in residential areas. The higher the level of groundwater pollution, the less potential groundwater availability there is [47], [54]–[57]. One way to reduce groundwater pollution is through outreach activities by the central and regional governments. This counseling aims to help people in residential areas understand ecologically sound land use and take positive action about groundwater. In addition, support from stakeholders is essential in formulating national policies that can lead to the management of groundwater resources. Good governance of groundwater resources and effective stakeholder engagement constitute a cycle of mutual support [58], [59].

5. CONCLUSION

Groundwater imbalance in residential areas is one of the factors that cause socio-environmental impacts. The groundwater imbalance in this study results from the community's high use of groundwater. Therefore, it is necessary to conserve groundwater to improve the environment's carrying capacity in residential areas. For that reason, before environmental degradation occurs, groundwater conservation in residential areas deserves special attention from the central and regional governments. The activity of implementing groundwater conservation is not only an effort to manage groundwater resources but also an effort to manage the people who use them. In practice, groundwater conservation activities still require more detailed guidelines to run optimally. Because currently, all existing regulations related to managing groundwater sources in residential areas, both at the central and regional levels, still necessitate improvements that lead to the problem of sustainability. Therefore, this paper offers several policy recommendations to central and local government stakeholders to improve the environment's carrying capacity in residential areas. The first recommendation is to bridge the link between residential areas and the environment's carrying capacity. Stakeholders must ensure that related policies are within the framework of government regulations at the central and regional levels. The second recommendation is to prioritize policies for groundwater conservation that can assist the government in facilitating urban sprawl development. In this study, to improve the status of environmental carrying capacity in residential areas, the scenario results offer several policies and programs for implementing groundwater conservation activities as recommendations. The proposed policies in this study are: (1) policies to reduce people's dependence on groundwater

through government regulations urging people to make groundwater infiltration media in the form of yards overgrown with grass. This policy will be easy to implement because almost 90% of the houses in this residential area have a yard; (2) a policy that ensures that the area of green open space is at least 30% of the total residential area, following regional regulations; and (3) national-scale regulations that have designed sustainable conceptions of settlements related to the implementation of groundwater conservation. After all, good governance of groundwater resources and effective stakeholder engagement constitute a mutually reinforcing cycle.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare there is no potential conflict of interest in the publication of this work.

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ABBREVIATIONS

AAE	: Average Absolute Error
CLD	: Causal Loop Diagram
DA	: Community Water Needs
GB	: Groundwater Balance
GAI	: Groundwater Availability Index
GUI	: Groundwater Use Index
SA	: Groundwater Availability
SFD	: Stock And Flow Diagrams

AUTHORS CONTRIBUTIONS

E. Savitri: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - Original Draft. D. M. Hartono: Conceptualization, Methodology, Resources, Writing - Review & Editing, Supervision, Funding acquisition. S.S. Moersidik: Validation, Formal analysis, Resources, Writing - Review & Editing, Funding acquisition. T.E.B. Soesilo: Interpreted the data and results, Methodology, Software, Formal analysis, Visualization, Project administration

References

[1] C. Meng, X. Wang, and Y. Li, "An optimization model for water management based on water resources and environmental carrying capacities: A case study of the Yinma River Basin, Northeast China," Water (Switzerland), vol. 10, no. 5, p. 565, 2018, doi: 10.3390/w10050565.

[2] S. J. McGrane, "Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: a review," Hydrological Sciences Journal, vol. 61, no. 13, pp. 2295–2311, 2016, doi: 10.1080/02626667.2015.1128084.

[3] F. J. Chang, C. W. Huang, S. T. Cheng, and L. C. Chang, "Conservation of groundwater from over-exploitation—Scientific analyses for groundwater resources management," Science of the Total Environment, vol. 598, no. 1, pp. 828–838, 2017, doi: 10.1016/j.scitotenv.2017.04.142.

[4] J. Liu, X. Xie, Z. Ma, G. Fang, H. He, and M. Du, "A multiple-iterated dual control model for groundwater exploitation and water level based on the optimal allocation model of water resources," Water (Switzerland), vol. 10, no. 4, p. 432, 2018, doi: 10.3390/w10040432.

[5] H. Zhang, J. Yu, C. Du, J. Xia, and X. Wang, "Assessing risks from groundwater exploitation and utilization: Case study of the Shanghai megacity, China," Water (Switzerland), vol. 11, no. 9, p. 1775, 2019, doi: 10.3390/w11091775.

[6] S. Halder, M. B. Roy, and P. K. Roy, "Analysis of groundwater level trend and groundwater drought using Standard Groundwater Level Index: a case study of an eastern river basin of West Bengal, India," SN Applied Sciences, vol. 2, no. 3, p. 507, 2020, doi: 10.1007/s42452-020-2302-6.

[7] P. Luo et al., "Water quality trend assessment in Jakarta: A rapidly growing Asian megacity," PLoS ONE, vol. 14, no. 7, pp. 1–17, 2019, doi: 10.1371/journal.pone.0219009.

[8] M. Kooy, C. T. Walter, and I. Prabaharyaka, "Inclusive development of urban water services in Jakarta: The role of groundwater," Habitat International, vol. 73, pp. 109–118, 2016, doi: 10.1016/j.habitatint.2016.10.006.

[9] R. F. Lubis, "Urban hydrogeology in Indonesia: A highlight from Jakarta," IOP Conference Series: Earth and Environmental Science, vol. 118, no. 1, 2018, doi: 10.1088/1755-1315/118/1/012022.

[10]   R. Jia, X. Jiang, X. Shang, and C. Wei, "Study on the water resource carrying capacity in the middle reaches of the heihe river based on water resource allocation," Water (Switzerland), vol. 10, no. 9, 2018, doi: 10.3390/w10091203.

[11]   F. Aksever, A. Davraz, and R. Karaguzel, "Groundwater balance estimation and sustainability in the sandıklı basin (Afyonkarahisar/Turkey)," Journal of Earth System Science, vol. 124, no. 4, pp. 783–798, 2015, doi: 10.1007/s12040-015-0569-6.

[12]   M. Velis, K. I. Conti, and F. Biermann, "Groundwater and human development: synergies and trade-offs within the context of the sustainable development goals," Sustainability Science, vol. 12, no. 6, pp. 1007–1017, 2017, doi: 10.1007/s11625-017-0490-9.

[13]   M. E. Varua, B. Maheshwari, J. Ward, and S. Dave, "Groundwater conservation attitudes, behaviour and water management: The case of farmers in rural India," WIT Transactions on Ecology and the Environment, vol. 220, pp. 141–150, 2017, doi: 10.2495/WRM170141.

[14]   M. Dou, J. X. Ma, G. Q. Li, and Q. T. Zuo, "Measurement and assessment of water resources carrying capacity in Henan Province, China," Water Science and Engineering, vol. 8, no. 2, pp. 102–113, 2015, doi: 10.1016/j.wse.2015.04.007.

[15]   M. Naimi Ait-Aoudia and E. Berezowska-Azzag, "Water resources carrying capacity assessment: The case of Algeria's capital city," Habitat International, vol. 58, pp. 51–58, 2016, doi: 10.1016/j.habitatint.2016.09.006.

[16]   B. Widodo et al., "Analysis of Environmental Carrying Capacity for the Development of Sustainable Settlement in Yogyakarta Urban Area," Procedia Environmental Sciences, vol. 28, no. SustaiN 2014, pp. 519–527, 2015, doi: 10.1016/j.proenv.2015.07.062.

[17]   G. Ruggiero, G. Verdiani, and S. Dal Sasso, "Evaluation of carrying capacity and territorial environmental sustainability," Journal of Agricultural Engineering, vol. 43, no. 2, p. 10, 2012, doi: 10.4081/jae.2012.e10.

[18]   G. M. Sanchez, A. Terando, J. W. Smith, A. M. Garcia, C. R. Wagner, and R. K. Meentemeyer, "Forecasting Water Demand Across a Rapidly Urbanizing Region," Science of the Total Environment, pp. 1–48, 2020, doi: 10.1016/j.scitotenv.2020.139050.

[19]   S. Li, X. Chen, V. P. Singh, X. Qi, and L. Zhang, "Tradeoff for water resources allocation based on updated probabilistic assessment of matching degree between water demand and water availability," Science of the Total Environment, vol. 716, p. 134923, 2020, doi: 10.1016/j.scitotenv.2019.134923.

[20]   A. Ghasemi, B. Saghafian, and S. Golian, "System dynamics approach for simulating water resources of an urban water system with emphasis on sustainability of groundwater," Environmental Earth Sciences, vol. 76, no. 18, pp. 1–15, 2017, doi: 10.1007/s12665-017-6887-z.

[21]   L. Tianhong, Y. Songnam, and T. Mingxin, "Simulation and optimization of water supply and demand balance in Shenzhen: A system dynamics approach," Journal of Cleaner Production, vol. 207, pp. 882–893, 2019, doi: 10.1016/j.jclepro.2018.10.052.

[22]   F. Qiang, L. Tianxiao, L. Dong, and D. He, "Simulation study of the sustainable utilization of urban water resources based on system dynamics: A case study of Jiamusi," Water Science and Technology: Water Supply, vol. 16, no. 4, pp. 980–991, 2016, doi: 10.2166/ws.2016.013.

[23]   Chen, S. Ahmad, A. Kalra, and Z. X. Xu, "A dynamic model for exploring water-resource management scenarios in an inland arid area: Shanshan County, Northwestern China," Journal of Mountain Science, vol. 14, no. 6, pp. 1039–1057, 2017, doi: 10.1007/s11629-016-4210-1.

[24]   T. Wei, I. Lou, Z. Yang, and Y. Li, "A system dynamics urban water management model for Macau, China," Journal of Environmental Sciences (China), vol. 50, pp. 117–126, 2016, doi: 10.1016/j.jes.2016.06.034.

[25]   H. Balali and D. Viaggi, "Applying a system dynamics approach for modeling groundwater dynamics to depletion under different economical and climate change scenarios," Water (Switzerland), vol. 7, no. 10, pp. 5258–5271, 2015, doi: 10.3390/w7105258.

[26]   M. Zomorodian, S. H. Lai, M. Homayounfar, S. Ibrahim, S. E. Fatemi, and A. El-Shafie, "The state-of-the-art system dynamics application in integrated water resources modeling," Journal of Environmental Management, vol. 227, no. November 2017, pp. 294–304, 2018, doi: 10.1016/j.jenvman.2018.08.097.

[27]   M. Garcia, K. Portney, and S. Islam, "A question driven socio-hydrological modeling process," Hydrology and Earth System Sciences, vol. 20, no. 1, pp. 73–92, 2016, doi: 10.5194/hess-20-73-2016.

[28]   A. Mashhadi Ali, M. E. Shafiee, and E. Z. Berglund, "Agent-based modeling to simulate the dynamics of urban water supply: Climate, population growth, and water shortages," Sustainable Cities and Society, vol. 28, pp. 420–434, 2017, doi: 10.1016/j.scs.2016.10.001.

[29]   M. H. Ahmadi and M. Zarghami, "Should water supply for megacities depend on outside resources? A Monte-Carlo system dynamics simulation for Shiraz, Iran," Sustainable Cities and Society, vol. 44, pp. 163–170, 2019, doi: 10.1016/j.scs.2018.10.007.

[30]   W. Rusiawan, P. Tjiptoherijanto, E. Suganda, and L. Darmajanti, "System Dynamics Modeling for Urban Economic Growth and CO2 Emission: A Case Study of Jakarta, Indonesia," Procedia Environmental Sciences, vol. 28, pp. 330–340, 2015, doi: 10.1016/j.proenv.2015.07.042.

[31]   Sun and Yang, "Simulation of water resources carrying capacity in Xiong'an New Area based on system dynamics model," Water (Switzerland), vol. 11, no. 5, 2019, doi: 10.3390/w11051085.

[32]   Nugroho, Tamagawa, Riandraswari, and Febrianti, "Thornthwaite-Mather water balance analysis in Tambakbayan watershed, Yogyakarta, Indonesia," MATEC Web of Conferences, vol. 280, p. 05007, 2019, doi: 10.1051/matecconf/201928005007.

[33]   M. Suárez-Varela, "Modeling residential water demand: An approach based on household demand systems," Journal of Environmental Management, vol. 261, no. June 2019, 2020, doi: 10.1016/j.jenvman.2019.109921.

[34] C. Okello, B. Tomasello, N. Greggio, N. Wambiji, and M. Antonellini, "Impact of population growth and climate change on the freshwater resources of Lamu Island, Kenya," Water (Switzerland), vol. 7, no. 3, pp. 1264–1290, 2015, doi: 10.3390/w7031264.

[35] J. A. Trasviña-Carrillo, J. Wurl, and M. A. Imaz-Lamadrid, "Groundwater flow model and statistical comparisons used in sustainability of aquifers in arid regions," Resources, vol. 8, no. 3, p. 134, 2019, doi: 10.3390/resources8030134.

[36] N. Ashoori, D. A. Dzombak, and M. J. Small, "Identifying water price and population criteria for meeting future urban water demand targets," Journal of Hydrology, vol. 555, pp. 547–556, 2017, doi: 10.1016/j.jhydrol.2017.10.047.

[37] X. Chen, F. Li, X. Li, Y. Hu, and P. Hu, "Evaluating and mapping water supply and demand for sustainable urban ecosystem management in Shenzhen, China," Journal of Cleaner Production, vol. 251, p. 119754, 2020, doi: 10.1016/j.jclepro.2019.119754.

[38] Y. Hu, C. Y. Liu, and T. Chen, "Ecological improvement and community participation: Lessons from xiaoping river ecological improvement project in Jinan, China," Community Development Journal, vol. 52, no. 1, pp. 21–37, 2017, doi: 10.1093/cdj/bsw049.

[39] M. Velis, K. I. Conti, and F. Biermann, "Groundwater and human development: synergies and trade-offs within the context of the sustainable development goals," Sustainability Science, vol. 12, no. 6, pp. 1007–1017, 2017, doi: 10.1007/s11625-017-0490-9.

[40] S. H. A. Koop, A. J. Van Dorssen, and S. Brouwer, "Enhancing domestic water conservation behaviour: A review of empirical studies on influencing tactics," Journal of Environmental Management, vol. 247, no. June, pp. 867–876, 2019, doi: 10.1016/j.jenvman.2019.06.126.

[41] T. Makino, K. Noda, K. Keokhamphui, H. Hamada, K. Oki, and T. Oki, "The effects of five forms of capital on thought processes underlying water consumption behavior in suburban vientiane," Sustainability (Switzerland), vol. 8, no. 6, p. 538, 2016, doi: 10.3390/su8060538.

[42] S. Kundu, D. Khare, and A. Mondal, "Past, present and future land use changes and their impact on water balance," Journal of Environmental Management, vol. 197, pp. 582–596, 2017, doi: 10.1016/j.jenvman.2017.04.018.

[43] M. Pulido-Velazquez et al., "Integrated assessment of the impact of climate and land use changes on groundwater quantity and quality in the Mancha Oriental system (Spain)," Hydrology and Earth System Sciences, vol. 19, no. 4, pp. 1677–1693, 2015, doi: 10.5194/hess-19-1677-2015.

[44] Z. Sun, F. Wu, C. Shi, and J. Zhan, "The impact of land use change on water balance in Zhangye city, China," Physics and Chemistry of the Earth, vol. 96, pp. 64–73, 2016, doi: 10.1016/j.pce.2016.06.004.

[45] A. Chemura, D. Rwasoka, O. Mutanga, T. Dube, and T. Mushore, "The impact of land-use/land cover changes on water balance of the heterogeneous Buzi sub-catchment, Zimbabwe," Remote Sensing Applications: Society and Environment, vol. 18, pp. 1–11, 2020, doi: 10.1016/j.rsase.2020.100292.

[46] M. Mirhosseini, P. Farshchi, A. A. Noroozi, M. Shariat, and A. A. Aalesheikh, "An investigation on the effect of land use land cover changes on surface water quantity," Water Science and Technology: Water Supply, vol. 18, no. 2, pp. 490–503, 2018, doi: 10.2166/ws.2017.107.

[47] A. I. Tukur, A. B. Nabegu, D. A. Umar, E. A. Olofin, and W. N. Azmin Sulaiman, "Groundwater condition and management in Kano region, Northwestern Nigeria," Hydrology, vol. 5, no. 1, pp. 1–21, 2018, doi: 10.3390/hydrology5010016.

[48] S. O. Grinevskii, "The effect of topography on the formation of groundwater recharge," Moscow University Geology Bulletin, vol. 69, no. 1, pp. 47–52, 2014, doi: 10.3103/S0145875214010025.

[49] L. E. Condon and R. M. Maxwell, "Evaluating the relationship between topography and groundwater using outputs from a continental-scale integrated hydrology model," Water Resources Research, vol. 51, no. 8, pp. 6602–6621, 2015, doi: 10.1002/2014WR016774.

[50]   E. Rukundo and A. Doğan, "Dominant influencing factors of groundwater recharge spatial patterns in Ergene river catchment, Turkey," Water (Switzerland), vol. 11, no. 4, p. 653, 2019, doi: 10.3390/w11040653.

[51]   C. Mohan, A. W. Western, Y. Wei, and M. Saft, "Predicting groundwater recharge for varying land cover and climate conditions-a global meta-study," Hydrology and Earth System Sciences, vol. 22, no. 5, pp. 2689–2703, 2018, doi: 10.5194/hess-22-2689-2018.

[52]   A. Singh, S. N. Panda, V. N. E. Uzokwe, and P. Krause, "An assessment of groundwater recharge estimation techniques for sustainable resource management," Groundwater for Sustainable Development, vol. 9, pp. 1002–1018, 2019, doi: 10.1016/j.gsd.2019.100218.

[53]   R. K. Adhikari, S. Mohanasundaram, and S. Shrestha, "Impacts of land-use changes on the groundwater recharge in Ho Chi Minh City, Vietnam," Environmental Research, vol. 185, pp. 1–10, 2020, doi: 10.1016/j.envres.2020.109440.

[54]   K. Howard and R. Gerber, "Impacts of urban areas and urban growth on groundwater in the Great Lakes Basin of North America," Journal of Great Lakes Research, vol. 44, no. 1, pp. 1–13, 2018, doi: 10.1016/j.jglr.2017.11.012.

[55]   P. Kumar et al., "Effect of land use changes on water quality in an ephemeral coastal plain: Khambhat City, Gujarat, India," Water (Switzerland), vol. 11, no. 4, p. 724, 2019, doi: 10.3390/w11040724.

[56]   C. P. Liyanage and K. Yamada, "Impact of population growth on the water quality of natural water bodies," Sustainability (Switzerland), vol. 9, no. 8, 2017, doi: 10.3390/su9081405.

[57]   S. Patra, S. Sahoo, P. Mishra, and S. C. Mahapatra, "Impacts of urbanization on land use /cover changes and its probable implications on local climate and groundwater level," Journal of Urban Management, vol. 7, no. 2, pp. 70–84, 2018, doi: 10.1016/j.jum.2018.04.006.

[58]   S. B. Megdal, S. Eden, and E. Shamir, "Water governance, stakeholder engagement, and sustainable water resources management," Water (Switzerland), vol. 9, no. 3, pp. 1–7, 2017, doi: 10.3390/w9030190.

[59]   A. Akhmouch and D. Clavreul, "Stakeholder Engagement for Inclusive Water Governance: 'Practicing What We Preach' with the OECD Water Governance Initiative," Water (Switzerland), vol. 8, no. 5, pp. 1–17, 2016, doi: 10.3390/w8050204.