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MORALITY BEFORE KNOWLEDGE

Environmental carrying capacity modeling using system dynamics in the context of smart sustainable city: Jakarta case study

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ABSTRACT

Introduction: In Jakarta, rapid urbanization and population increase have led to serious environmental problems such air pollution, water scarcity, and land degradation. Excessive economic activity and population growth are placing pressure on the city's environmental carrying capacity, which is leading to a decline in living standards and an increase in demand on natural resources. Green open space in Jakarta has decreased significantly, currently at 9.8%, below the minimum requirement of 30%. **Methods:** This study uses a system dynamics approach to assess Jakarta's environmental carrying capacity in the context of a sustainable city. **Finding:** The study shows that Jakarta's land carrying capacity has decreased since 2018, with indications that water carrying capacity will decrease by 2032 if Jakarta do business as usual. Future scenario suggest that reducing the rate of land turnover and improving water flow will significantly improve the city's environmental sustainability. For example, reducing land change by 20-40% can restore land carrying capacity by 2040. **Conclusion:** By implementing policies that focus on reducing land change and improving water infrastructure, Jakarta can improve the quality of life and quality of life for its residents. The novelty of this study is that it integrates the concept of smart sustainable cities with system dynamics modelling to assess environmental sustainability and provides a comprehensive framework that can be adapted by other cities facing similar challenges. The report highlights gaps in current practices, such as the need to better integrate water and green space infrastructure, advanced technologies for water management, and overall land restoration strategies.

KEYWORDS: environmental carrying capacity, smart sustainable city, Jakarta, urbanization, system dynamics methods, sustainable development.

1. Introduction

The rate of population growth and metropolitan area expansion has significantly increased over time, putting pressure on the environment. Many cities have not been able to grow economically because they protect the environment and sometimes disregard the environmental carrying capacity. This has led to problems such as contaminated air, deficient water supplies, and infested soils (Su et al., 2019)(Zhang et al., 2023).

Southeast Asia as a region has been able to grasp most of the similar issues. As for instance strain, this is the case in the Indonesian metropolitan region of Mamminasata which is likely to suffer declines in environmental carrying capacity in the coming years due to the uncontrolled growth of the population and the economic activity(Pourebrahim et al.,

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2023). Further in East Javas' Lumajang Regency, the availability of the environmental carrying capacity in the region has also been compromised by the presence of three development sites for potential tourist locations(Bibri et al., 2018).

The centre of socio-political movements and the biggest city in the country is no exemption to the environmental strain. Factors such as rapid population influx, technology advancement alongside economic assessments over time have surpassed the environmental carrying capacity of Jakarta. As a result of all these, flooding, Air pollution and water shortages have become the order of the day(Amira Sofa, 2023).

The capacity of Jakarta's environment is significantly impacted by the city's growing population. The following are a few of the primary effects found: 1. Conversion of Land Due to the city of Jakarta's rapid population development, more land is required for public facilities, infrastructure, and housing. This frequently results in the conversion of agricultural and green land into development sites, reducing the amount of green open space (RTH) and upsetting nearby ecosystems. RTH in Jakarta is currently only about 9.8% of the entire area, a significant decrease from the legally mandated minimum aim of 30% (Wisnu Pudji Pawestri, 2022). 2. Lower Water Quality Water contamination is a result of population growth. The quantity of waste generated by industrial and domestic processes raises the water pollution level, which affects the purity of clean water sources. This worsens the already severe environmental circumstances by lowering the quality of the water in rivers and lakes (Hidayati et al., 2020). 3. An increase in the amount of air pollution The amount of cars and industrial activities in Jakarta are increasing air pollution. This could lead to a number of health problems, including respiratory and cardiovascular diseases. Research shows that air pollution in Jakarta is responsible for more than 90 million occurrences of respiratory symptoms (Ginanjar Syuhada, 2022). 4. Flooding and Damage to the Environment The loss of water catchment areas and land conversion increase Jakarta's susceptibility to flooding. The absence of catchment areas causes severe waterlogging in residential areas during heavy rainstorms (Wisnu Pudji Pawestri, 2022)(Hidayati et al., 2020). Additionally, biodiversity is decreased, and the natural balance is upset by ecosystem harm brought on by unplanned growth (Dinas Lingkungan Hidup, 2020). 5. Stress on Natural Resources Food and clean water supplies are among the natural resources under increased strain due to population growth. There is an imbalance between supply and demand for resources because of the growing need for food and water, which could exacerbate environmental conditions (Akhirul & Yelfida Witra, Iswandi Umar, 2020)(Tantular, 2003). 6. A Lower Standard of Living The effects of each of the aforementioned variables add to Jakarta's' declining standard of living. Residents live in an uneasy and unhealthy atmosphere because to issues including traffic, pollution, and limited access to green places (Dinas Lingkungan Hidup, 2020)(Ginanjar Syuhada, 2022). All things considered, the growing population of Jakarta presents significant obstacles to the environment's carrying capacity, necessitating deliberate thought and effort to manage growth and its effects responsibly.

In addressing these issues, the Smart Sustainable City concept presents significant potential. Resources and environment are usually enhanced since ICT (Information Communication Technology) is applied in the cities to town operations. However, it should be noted that most of the previous research work in the area of studies has attempted independent assessment of the environmental carrying capacity neglecting the factor of interdependence of the other factors(Pourebrahim et al., 2023)(Bibri et al., 2018).

This study focuses on applying a systematic assessment of environmental carrying capacity in a Smart Sustainable City using Jakarta city as a case study. Considering the System Dynamics perspective, such a model will include population, economy and environment interaction, and examine the effects of the deployment of smart technologies. The uniqueness of this paper is on how the concept of Smart sustainable cities has been combined together with modelling of environmental carrying capacity in use of System Dynamics unlike the previous studies(3)(4).

In addition, the outcomes of the research will enhance understanding on the environmental carrying capacity of the capital city of Indonesia as well as provide technology oriented strategies for sustainable development. This model can also be modified by other cities which have the same complications.

2. Methods

Research on environmental carrying capacity in the context of smart sustainable cities, particularly focusing on Jakarta, covers several crucial areas. First, the concept of environmental carrying capacity must be understood in relation to urban environments, where methods like Ecological Footprint Analysis and Ecosystem Service Models can help estimate Jakarta's capacity (Firmansyah & Umilia, 2020). Urbanization plays a significant role, as rapid population growth affects infrastructure demand and public services, with land-use changes also impacting local ecosystems (Wei et al., 2015). Simulation and modeling, such as the System Dynamics Model, are essential for understanding the interaction of social, economic, and environmental variables that influence carrying capacity (Jin et al., 2016; Zulkarnain & Rodrigo, 2020). Additionally, in smart cities, information and communication technologies (ICT) are valuable for monitoring and improving resource management, making a data-driven approach critical to efficiently managing resources within a smart city framework (Gao et al., 2021).

A balanced consideration of ecological and social factors is vital, as economic growth, environmental quality, and social welfare are intertwined. Community participation in resource management often determines the success of sustainability initiatives (Long, 2022). Spatial planning and policy also play key roles, as reviewing and improving sustainable urban policies can enhance Jakarta's environmental carrying capacity. This involves assessing the effectiveness of existing policies and recommending improvements (Gao et al., 2021). Furthermore, case studies comparing Jakarta to other cities with sustainable smart city models offer valuable insights, and regional variables, including policy frameworks and geographic conditions, must be examined to understand their influence on environmental capacity (Harmain et al., 2021). Together, these research areas form a comprehensive approach to assessing and improving Jakarta's environmental sustainability in the context of a smart city.

It is expected, through the investigation of these research domains, that improved understanding regarding environmental carrying capacity will be achieved, as well as information related to the potential transition of this city towards a sustainable smart city.

2.1 System Dynamics Method

The System Dynamics method offers a structured approach to modeling environmental carrying capacity in the context of a smart sustainable city, with Jakarta as the case study. The first step is system identification and scope, where the focus is determined, such as examining the population tolerance level in Jakarta. This involves outlining major components related to subsystems, including natural resource management, environmental factors, socio-economic elements, and infrastructure (Dehghan et al., 2024; C. Bao et al., 2022). Next, data and information collection is essential, gathering both historical and projected data on key variables like population growth, land use, resource consumption, and emissions. The relationships between these variables are identified through existing research and theories (Dehghan et al., 2024; K. Bao et al., 2023).

Following this, a causal loop diagram is developed to visually depict the causal relationships between the variables, identifying both positive and negative feedback loops that influence environmental carrying capacity (Dehghan et al., 2024; C. Bao et al., 2022; K. Bao et al., 2023). Based on this, a stock and flow diagram is created to model the accumulation and flow between variables, incorporating mathematical equations to represent these relationships (Dehghan et al., 2024; C. Bao et al., 2022; K. Bao et al., 2023).

Model calibration and validation follow, where parameters are adjusted to ensure the model's output aligns with historical data, and validation is done through sensitivity testing or comparison with independent data (Dehghan et al., 2024; K. Bao et al., 2023). Once validated, scenarios and simulations are generated to explore the impacts of various policies or interventions, such as emission reduction, resource efficiency improvement, and population control. Model simulations are conducted for each scenario, and the outcomes are compared (Dehghan et al., 2024; K. Bao et al., 2023).

The final step involves analyzing and interpreting the results, focusing on environmental carrying capacity indicators such as air quality, water availability, and green space per capita. In the context of Jakarta as a smart sustainable city, the findings are used to provide policy recommendations aimed at improving the city's environmental carrying capacity (Dehghan et al., 2024; C. Bao et al., 2022). By following these steps, a comprehensive System Dynamics model can be created, offering valuable insights for decision-making in the pursuit of a sustainable future for Jakarta.

3. Results and Discussion

3.1 Business As Usual Scenario

The purpose of the modeling is to see whether the population growth rate of Jakarta City in the next 20 years will find problems with environmental carrying capacity, especially water carrying capacity (quantity) and land carrying capacity (quantity) as well as environmental carrying capacity as a whole. If there are problems, how to overcome them.

Jakarta's population growth is increasing in line with its average population growth rate (including births, deaths, urbanization, and transmigration) according to statistical data from the Badan Pusat Statistik (BPS)/Central Bureau of Statistics of Daerah Khusus Ibukota (DKI)/Special Capital Region Jakarta Province of 1.19%, thus increasing the population each year, and forming a positive feedback or reinforcing loop, R1. However, the increase in Jakarta's population that increases the actual Jakarta Population Ratio is the population density itself against its carrying capacity, forming a negative feedback or balancing loop, B2 against the increase in Jakarta's population itself. With the increase in Jakarta's population, it causes an increase in the conversion of built-up land in particular and the need for green open land for the balance of Jakarta's population for clean air and recreation areas, while increasing the supply of land and the carrying capacity of land quantity, forming a positive feedback on population growth or reinforcing loop, R3. Likewise, the increase in open land will increase the supply of water and the carrying capacity (quantity) of water by forming a positive feedback or reinforcing, R4. All of these cause and effect processes are depicted in the Causal Loop Diagram as in Fig. 1.

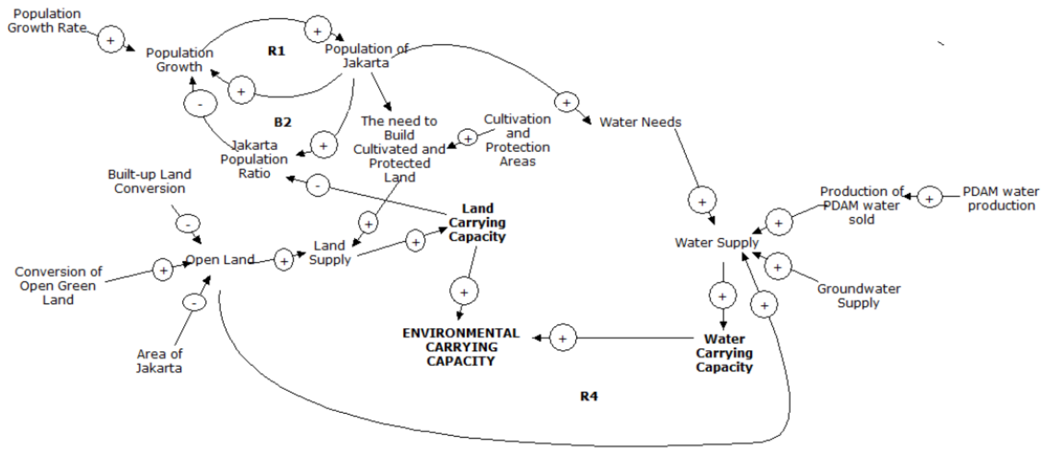

Fig. 1 Causal Loop Diagram
(Reseacher Processed with Powersim Studio 10 Academic, 2024)

3.1.1 Model Assumptions

The data used here is generally secondary data taken from BPS DKI Jakarta Data from 2015-2019, DKI Jakarta Province Green Open Space Data, and from published journals to accelerate the results of the model simulation. From the secondary data above, the author obtained the initial figure for the population of Jakarta of 10,177,924 people, and the population growth rate of Jakarta of 1.19%. The area of DKI Jakarta Province is 662.33 km2, with the current green open land conversion rate of 9.8% and the current built-up land conversion rate reaching 60% including buildings and road infrastructure. The protected forest and cultivation areas in 2015 were 17.6 km2 and are assumed to continue to be added with the land printing capacity figure being 50% and requiring 5 years. This land carrying capacity model will be simulated with the assumption that the classification figure for the population density area (population density) is between medium and high, namely 30,000 people per km2. For the water carrying capacity model simulation data, the following figures were obtained; the average normal water requirement per person per day is 150 liters, Perusahaan Daerah Air Minum (PDAM)/Water Service Local Government Company water production in 2015 was 560,382,856 m3, and the leakage rate according to PDAM Jaya data was 46%, and currently with all the existing problems, both the number of installations that have not increased with the utilization of existing rivers, the maximum PDAM production figure is 558,450,000 m3 so that many have taken the initiative to take groundwater to cover water needs that are not met by PDAM Jaya. The author also assumes that there is a limit on groundwater extraction according to Government Regulation of the Republic of Indonesia Number 43 of 2008 concerning Groundwater, which is 100 m3 per month per head of family as the maximum limit for groundwater use and in DKI Jakarta Province there are 3,126,634 heads of families (KK) and it is assumed that 10% of these KK take groundwater, so that the maximum limit for groundwater extraction per year is 375,196,080 m3. All of the calculations above are included in the simulation variables in the Stock Flow Diagram as in Figure 2.

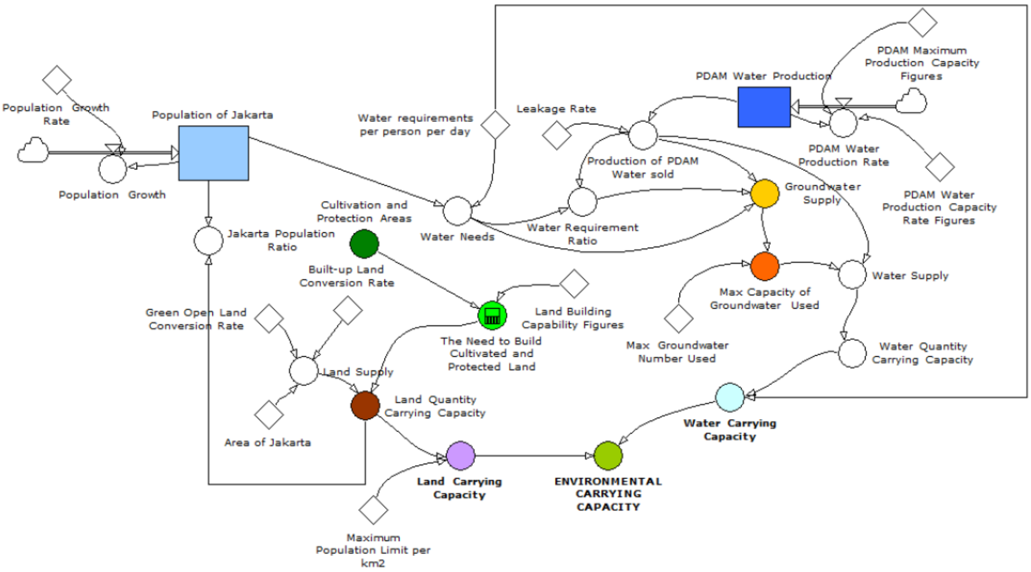

Fig. 2 Stock Flow Diagram – Business As Usual (BAU) Scenario
(Reseacher Processed with Powersim Studio 10 Academic, 2024)

From the assumptions above, the following model simulation results are obtained: 1. From Table 1, it can be seen that the land carrying capacity in the City of Jakarta Province has exceeded its maximum capacity since 2018, which is 10,468,853 people with a population of 10,547,560 people. 2. From Table 2, it can be seen that the water carrying capacity in the City of Jakarta Province in 2032 will be exceeded, namely the water carrying capacity is only for 12,360,896 people with the population of DKI Jakarta Province at that time in 2032 of 12,458,097 people. 3. So overall, the environmental carrying capacity in DKI Jakarta Province has been exceeded since 2018.

Table 1. Land Carrying Capacity – Business As Usual Scenario

Year	Population of Jakarta	Land Carrying Capacity
2015	10177924	10423210
2016	10299674	10423535
2017	10422880	10433945
2018	10547560	10468853
2019	10673731	10521121
2020	10801412	10574035
2021	10930620	10616671
2022	11061373	10646270
2023	11193691	10664772
2024	11327591	10675473
2025	11463094	10681304
2026	11600217	10684332
2027	11738980	10685846
2028	11879404	10686578
2029	12021507	10686924
2030	12165310	10687082
2031	12310833	10687154
2032	12458097	10687186
2033	12607122	10687200
2034	12757930	10687206
2035	12910542	10687208

2036	13064980	10687209
2037	13221265	10687210
2038	13379420	10687210
2039	13539466	10687210
2040	13701427	10687210

(Reseacher Processed with Powersim Studio 10 Academic, 2024)

Table 2. Water Carrying Capacity – Business As Usual Scenario

Year	Population of Jakarta	Water Carrying Capacity
2015	10177924	12379960
2016	10299674	12379960
2017	10422880	12379960
2018	10547560	12379960
2019	10673731	12379960
2020	10801412	12379960
2021	10930620	12379960
2022	11061373	12379960
2023	11193691	12379960
2024	11327591	12379960
2025	11463094	12379960
2026	11600217	12379960
2027	11738980	12379960
2028	11879404	12379960
2029	12021507	12379960
2030	12165310	12379960
2031	12310833	12379960
2032	12458097	12379960
2033	12607122	12379960
2034	12757930	12379960
2035	12910542	12379960
2036	13064980	12379960
2037	13221265	12379960
2038	13379420	12379960
2039	13539466	12379960
2040	13701427	12379960

(Reseacher Processed with Powersim Studio 10 Academic, 2024)

Table 3. Environmental Carrying Capacity – Business As Usual Scenario

Year	Population of Jakarta	Environment Carrying Capacity
2015	10177924	10423210
2016	10299674	10423535
2017	10422880	10433945
2018	10547560	10468853
2019	10673731	10521121
2020	10801412	10574035
2021	10930620	10616671
2022	11061373	10646270
2023	11193691	10664772
2024	11327591	10675473
2025	11463094	10681304
2026	11600217	10684332

2027	11738980	10685846
2028	11879404	10686578
2029	12021507	10686924
2030	12165310	10687082
2031	12310833	10687154
2032	12458097	10687186
2033	12607122	10687200
2034	12757930	10687206
2035	12910542	10687208
2036	13064980	10687209
2037	13221265	10687210
2038	13379420	10687210
2039	13539466	10687210
2040	13701427	10687210

(Reseacher Processed with Powersim Studio 10 Academic, 2024)

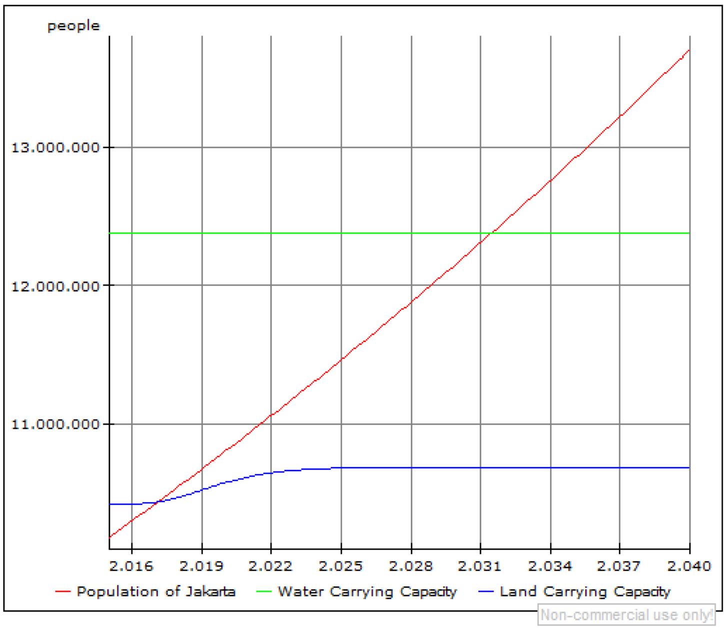

Fig. 3 Simulation Graphic - Busine As Usual Scenario
(Reseacher Processed with Powersim Studio 10 Academic, 2024)

3.2 Future scenario

To address the issues of land and water carrying capacity in Jakarta, simulations were conducted using several scenarios. In the first scenario, for land carrying capacity, the rate of built-up land conversion was reduced by 20% to 40%. The simulation results, as shown in Table 3, reveal a surprisingly sufficient carrying capacity for the period from 2015 to 2040, assuming a population density of 30,000 people per km^2, the same as in the BAU (Business-As-Usual) scenario. This reduction can be implemented incrementally, with a 5% decrease every four years over 25 years, making the first year's reduction easier to manage. Policies to close horizontal housing expansion and focus on vertical housing development, such as apartments, are recommended to reduce open land conversion, while increasing green open spaces to 30% gradually. The addition of protected forests or cultivation areas has little impact on improving land carrying capacity.

For the water carrying capacity simulation, efforts to repair leaks—both technically and legally—reduced the current 46% leak rate to 27%, and potentially to 19%. Handling leaks could be carried out incrementally, starting with a 3% reduction in the first year, making water capacity sustainable from 2015 to 2023. Afterward, an annual reduction of approximately 1.4% over 17 years could bring the remaining leak rate down by 24%. This approach to managing PDAM water leaks is feasible and can be executed effectively.

In the second scenario, the approach to land carrying capacity remains the same as in the first scenario. However, for water carrying capacity, technological interventions or new water sources are introduced, such as the creation of new PDAM installations along rivers passing through Jakarta. Additionally, the construction of water reservoirs and cascades is proposed, which would serve both as water storage facilities and as recreational areas, enhancing green open spaces in the process. Together, these scenarios offer comprehensive strategies for improving both land and water carrying capacity in Jakarta.

From the simulation, the installation of new PDAM water production capacity of 400 million m3 can be carried out in stages every 2 years, and carried out for 8 years of work, and leakage suppression can also be carried out in stages up to 30% for 25 years from 2015. This can reduce groundwater usage by 60% from the BAU scenario from 375 million m3 to 150 million m3 per year.

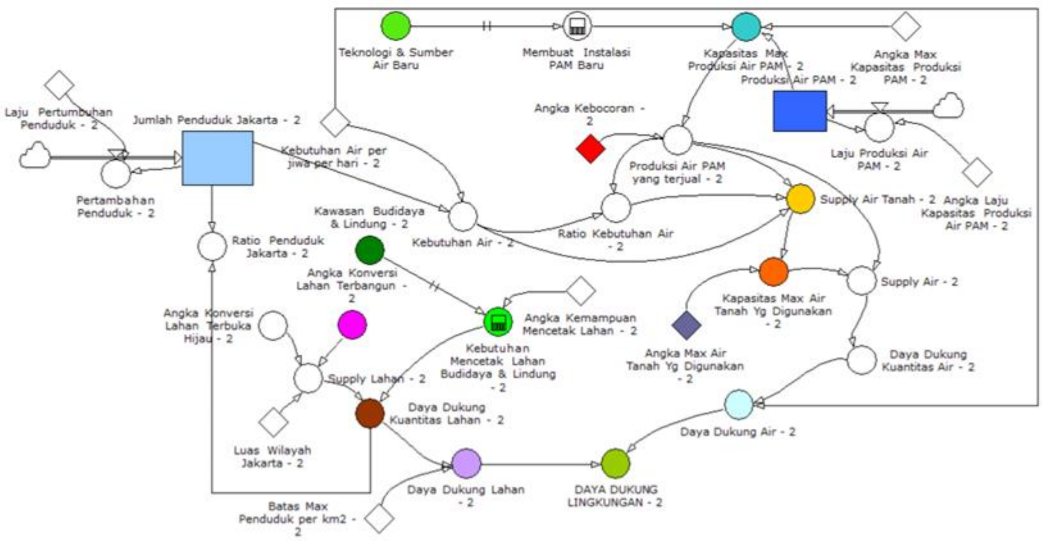

Fig. 4 Stock Flow Diagram – Second Scenario
(Reseacher Processed with Powersim Studio 10 Academic, 2024)

Table 4. Land Carrying Capacity – Second Scenario

Year	Population of Jakarta	Land Carrying Capacity
2015	10177924	13869190
2016	10299674	14181107
2017	10422880	14288284
2018	10547560	14325112
2019	10673731	14337766
2020	10801412	14342114
2021	10930620	14343608
2022	11061373	14344121
2023	11193691	14344298
2024	11327591	14344358
2025	11463094	14344379
2026	11600217	14344386
2027	11738980	14344389
2028	11879404	14344390
2029	12021507	14344390
2030	12165310	14344390

2031	12310833	14344390
2032	12458097	14344390
2033	12607122	14344390
2034	12757930	14344390
2035	12910542	14344390
2036	13064980	14344390
2037	13221265	14344390
2038	13379420	14344390
2039	13539466	14344390
2040	13701427	14344390

(Reseacher Processed with Powersim Studio 10 Academic, 2024)

Table 5. Water Carrying Capacity – Second Scenario

Year	Population of Jakarta	Water Carrying Capacity
2015	10177924	14529373
2016	10299674	14529373
2017	10422880	14529373
2018	10547560	14529373
2019	10673731	14529373
2020	10801412	14529373
2021	10930620	14529373
2022	11061373	14529373
2023	11193691	14529373
2024	11327591	14529373
2025	11463094	14529373
2026	11600217	14529373
2027	11738980	14529373
2028	11879404	14529373
2029	12021507	14529373
2030	12165310	14529373
2031	12310833	14529373
2032	12458097	14529373
2033	12607122	14529373
2034	12757930	14529373
2035	12910542	14529373
2036	13064980	14529373
2037	13221265	14529373
2038	13379420	14529373
2039	13539466	14529373
2040	13701427	14529373

(Reseacher Processed with Powersim Studio 10 Academic, 2024)

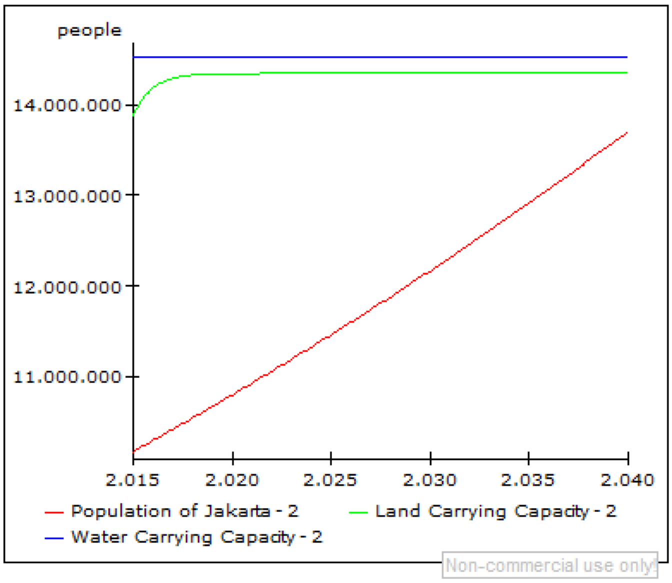

Fig. 5 Second Scenario Simulation Graphic
(Reseacher Processed with Powersim Studio 10 Academic, 2024)

3.3 Methods Comparisson Used in the Assessment of Environmental Carrying Capacity

The paper employs several methods to assess the future environmental carrying capacity in the Mamminasata area of Indonesia, providing valuable insights for sustainable development planning. One of the key methods used is statistical calculations, which predict the region's environmental carrying capacity up to 2031. This involves analyzing demographic data and land cover predictions to determine the region's ability to support its population and activities. Census data from local government agencies is also incorporated to understand current population dynamics and project future growth, a critical factor in carrying capacity assessments. Additionally, the study relies on land cover prediction data from previous studies, focusing on residential, agricultural, and protected land functions. This helps assess the impact of land use changes over time on the ecosystem's capacity.

The research outlines specific metrics to evaluate various types of carrying capacity, including agricultural, protected functions, population, and housing, to give a comprehensive view of the region's sustainability prospects. These metrics are computed to provide a thorough analysis. Future projections are also included, based on current trends and data. For example, the study predicts that by 2031, approximately 45% of the agricultural land currently used for food crops will be preserved, reflecting a commitment to sustainable land use practices. Together, these methods create a detailed understanding of the environmental carrying capacity in Mamminasata, guiding future planning efforts (Hakim et al., 2023). The paper employs several methods to assess the future environmental carrying capacity in the Mamminasata area of Indonesia, providing valuable insights for sustainable development planning. One of the key methods used is statistical calculations, which predict the region's environmental carrying capacity up to 2031. This involves analyzing demographic data and land cover predictions to determine the region's ability to support its population and activities. Census data from local government agencies is also incorporated to understand current population dynamics and project future growth, a critical factor in carrying capacity assessments. Additionally, the study relies on land cover prediction data from previous studies, focusing on residential, agricultural, and protected land functions. This helps assess the impact of land use changes over time on the ecosystem's capacity.

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3.4 Limitations of the Study on Environmental Carrying Capacity

The paper assessing the future environmental carrying capacity in the Mamminasata area has several limitations that should be considered. One key limitation is data dependency, as the study relies heavily on census data from local government agencies and land cover prediction data from previous studies. If the data is outdated or inaccurate, the reliability of the carrying capacity predictions could be compromised. Additionally, there are uncertainties in the projections made for 2031, as they are based on current trends and statistical methods. Unforeseen changes in population growth, land use policies, or environmental conditions could result in discrepancies between the predicted and actual carrying capacities. The study also focuses on specific metrics—demographic, residential, agricultural, and protected functions—which may overlook other important factors such as economic conditions, social dynamics, and technological advancements that influence sustainability.

Moreover, the scope of analysis is limited to the Mamminasata area, making it difficult to generalize the findings to other regions in Indonesia with different environmental, social, or economic conditions. Finally, while the report emphasizes the need for sustainable development, it does not address the importance of ongoing monitoring or adaptive management. Without continuous evaluation, the effectiveness of the suggested measures for preserving carrying capacity could be compromised. Given these limitations, caution is needed when interpreting the findings or applying them to policy decisions in Mamminasata. Future studies could enhance the reliability and relevance of the results by addressing these constraints. (Hakim, A. M. Y., Baja, S., Rampisela, D. A., Arif, S., Matsuoka, M., & Ridwansyah, 2023).

The study on the Environmental Carrying Capacity (DDTL) of tourism areas in Lumajang Regency has several limitations that should be considered: The research on tourism potential and environmental carrying capacity in Lumajang Regency has several limitations that should be noted. First, the scope of the study is restricted to three tourist destinations—Ranu Pane, Wotgalih Beach, and Tumpak Sewu Waterfall. This limited focus may not provide a comprehensive understanding of the overall tourism potential or environmental carrying capacity of the entire region, leading to generalized conclusions that may not apply to other areas within Lumajang Regency. Methodologically, the study utilizes the DDTL calculation approach by Cifuentes (1992), which considers Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC), and Effective Carrying Capacity (ECC). While this method is well-established, it may overlook certain factors that influence tourism sustainability, such as seasonal variations, socio-economic conditions, and changes in tourist behavior.

The data collection process, which includes literature research, interviews with key stakeholders, and observations, introduces potential biases as stakeholders' perspectives may not reflect the views of all residents or tourists. Additionally, relying on secondary data could limit the precision of the study's findings. The study also does not specify the time frame of the data collection, which is critical for understanding tourism trends and environmental impacts over time. Without this, the results might not account for increasing tourist numbers or evolving environmental conditions. Moreover, the study lacks long-term projections or suggestions for future tourism growth, which is essential for the sustainable management of tourism resources in Lumajang Regency. Finally, the generalizability of the findings is limited, as the results may not apply to regions with different environmental, cultural, or economic contexts. Each tourist destination has unique characteristics that may influence its carrying capacity, underscoring the need for similar studies in various locations for broader applicability.These limitations highlight the need for further research and a more comprehensive approach to understanding the environmental carrying capacity of tourism areas in Lumajang Regency and beyond (Wati et al., 2023).

3.5 Comparison with Mamminasata and Lumajang Areas

Research in the Mamminasata area shows significant land cover changes and a lack of environmental carrying capacity. The second scenario in Jakarta can be seen as an effort to overcome the lack of water carrying capacity with new technological interventions, which are not found in research in the Mamminasata area.

Research in Lumajang Regency emphasizes the importance of analyzing the environmental carrying capacity of tourist areas. The second scenario in Jakarta can be seen as an effort to increase water carrying capacity as one aspect of the environment, which is not found in research in Lumajang Regency.

Simulation with System Dynamic is used to analyze complex interactions between various factors in the environmental system. In the context of Jakarta, this simulation can help predict the impact of new technological interventions on water and land carrying capacity, as well as provide recommendations for directions in spatial planning based on the results of the environmental carrying capacity analysis.

In conclusion, this study shows that new technology interventions can be an effective solution in increasing water carrying capacity in Jakarta. The second scenario involving new PDAM installations, additional water reservoirs, and leakage suppression can reduce groundwater use by up to 60% from the BAU scenario.

Comparison with research in the Mamminasata area and Lumajang Regency shows that these efforts can be integrated with a more holistic environmental protection strategy. Simulation with System Dynamics can help predict the impact of new technology interventions and provide recommendations for spatial planning based on the results of environmental carrying capacity analysis.

This study has novelty and research contribution because it integrates the Smart Sustainable City concept with comprehensive environmental carrying capacity modeling using System Dynamics. This has not been done in previous studies.

The contribution of this study is to provide innovative solutions to increase water carrying capacity in Jakarta through new technology interventions, as well as providing recommendations for spatial planning based on the results of environmental carrying capacity analysis.Thus, this research can cover the gap in previous research and provide a significant contribution in increasing environmental carrying capacity in Jakarta.

4. Conclusions

Environmental Carrying Capacity Modeling in the Context of Smart Sustainable City: Jakarta Case Study highlights the importance of environmental capacity management in Jakarta through a dynamic system model approach. The results of the study indicate the need to reduce land conversion rates, reduce clean water leakage, and build new infrastructure to manage water resources more efficiently. To enrich this analysis, we will compare it with five similar articles from other relevant cities.

Comparative study in Tokyo, Japan, this article discusses the application of environmental capacity models to manage water and land in Tokyo. The study shows that reducing land conversion can be achieved through zoning policies and revitalizing unused land. The gap with Jakarta is the lack of an integrative approach in land revitalization that can increase green open spaces (Mizunoya et al., 2021)(Takano et al., 2023).

Comparative study in Amsterdam, Netherlands, in this study, Amsterdam adopted advanced technology to reduce water leakage in the distribution system. The sensor-based approach and real-time monitoring succeeded in reducing water loss. Jakarta can learn from the use of this technology to improve the efficiency of its existing piping system (Heskes & Tinga, 2023).

Comparative study in Cape Town, South Africa, this study shows how Cape Town manages water resources by building reservoirs and rainwater harvesting systems. This approach not only supplies water but also creates recreational spaces. The gap in Jakarta is the need for integration between water infrastructure and green open spaces to improve quality of life (Mogano et al., 2023).

Comparative study in Toronto, Canada, this article highlights the importance of new technology interventions in water management. Toronto has successfully implemented an innovative water treatment system to utilize alternative water sources. Jakarta has the potential to adopt a similar system, but still faces challenges in terms of investment and technology adaptation (Susan Ros, 2019).

Comparative study in Seoul, South Korea, this study emphasizes the importance of multi-functional management in water infrastructure, where reservoirs not only function as reservoirs but also as public spaces. This approach can be applied in Jakarta with a focus on reservoir design that provides recreational and environmental functions (Lee et al., 2023).

From this comparison, several key gaps in Jakarta's urban planning and sustainability efforts become apparent. First, Jakarta needs to improve the integration between water infrastructure and green open space, as is done in Cape Town and Seoul. In terms of technology for water management, The use of advanced technology to monitor and manage water leakage is still underdeveloped in Jakarta compared to Amsterdam. Additionally, the city needs to implement a more holistic and sustainable approach to land revitalization, like in Tokyo needs to be implemented to reduce land conversion.

Through this analysis, Jakarta has the opportunity to adopt various best practices from other cities in environmental capacity management. By focusing on reducing land conversion, reducing water leakage, and building new infrastructure, Jakarta can improve the quality of its environment and the lives of its citizens. The identified gaps provide direction for policies and strategies that need to be taken to realize the vision of a smart sustainable city.

There are number of areas that require further research to enhance the study of Environmental Carrying Capacity Modeling using the System Dynamics technique, particularly in the context of sustainable smart cities like Jakarta. First, deeper exploration of the interaction between social and environmental variables is essential. This involves understanding how factors like education, income, and environmental awareness interact with elements such as air and water quality, which can aid in more effective policy formulation. Additionally, research into the effects of various policies, such as those concerning waste management, renewable energy, and emission reductions, could provide valuable insights into long-term impacts on environmental carrying capacity. Engaging stakeholders in participatory models will also improve the relevance and acceptance of the models, ensuring that community needs are reflected in decision-making. Another crucial area for research is enhancing Jakarta's resilience to climate change. By using the System Dynamics approach, city planners can assess risks and develop adaptation strategies to mitigate the effects of climate change. Furthermore, evaluating system performance through sustainability indicators will allow for more accurate measurement of how adopted policies impact social, economic, and environmental conditions. Urbanization also poses significant pressure on Jakarta's resources and infrastructure, making it vital to study how rapid growth affects environmental carrying capacity. Finally, innovations in technology, such as the use of big data and the Internet of Things (IoT), could improve resource management and energy efficiency, and research on their impacts could further enhance Jakarta's ability to achieve sustainability.

It is intended that by concentrating on these research areas, more profound understandings and potent remedies to enhance Jakarta's environmental carrying capacity within the framework of a sustainable smart city will be generated.

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