Jurnal Presipitasi
Media Komunikasi dan Pengembangan Teknik Lingkungan
e-ISSN: 2550-0023

Vol 21, No 3, 2024, 879-893
Article available at homepage presipitasi

Regional Case Study

Developing Causal Loop Diagram for Urban Development and Land Carrying Capacity in Surakarta

Ari Arsianti[1*], Winny Astuti[2], Suryanto[3], Callista Fabiola Candraningtyas[4], Eko Primabudi[5]

[1] Postgraduate Program in Environmental Science, Universitas Sebelas Maret, Surakarta, Indonesia 57126
[2] Department of Regional and Urban Planning, Faculty of Engineering, Universitas Sebelas Maret, Surakarta, Indonesia 57126
[3] Department of Economics Development, Faculty of Economics and Business, Universitas Sebelas Maret, Surakarta, Indonesia 57126
[4] Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret, Surakarta, Indonesia 57126
[5] Ramboll Carbon Capture Competence Center, Copenhagen, Denmark, 2300
* Corresponding Author, email: ari.arsianti@gmail.com

Abstract

Surakarta has an area of 46.72 km² with a population of 583,961 people. The land use in Surakarta for housing is 62% and for open space is only 9.82% of the area. Meanwhile, economic growth in this city has always experienced an increasing trend, where in 2023 investment growth reached 55.82%. This study aims to determine the general picture through the causal relationship between the components of urban development and the carrying capacity of land in Surakarta. This study uses a quantitative descriptive approach. Data is obtained from identified variables which are then arranged dynamically using Causal Loop Diagram (CLD) analysis processed with Vensim software. The results show that there is a supply model (built-up area and green open space) and a demand model (population, investment, and Gross Domestic Product). The relationship between variables describes the causal relationship in Surakarta's Land Carrying Capacity divided into three rounds, namely Loop B1 (Land Carrying Capacity – Demand - Supply - Land Carrying Capacity), Loop B2 (Supply - Built-up Land - Land Conversion - Green Open Space – Supply), and Loop R1 (Population - Demand - Investment - GDP - GDP per capita – Population).

Keywords: Land carrying capacity; casual loop diagram; supply; demand; vensim

1. Introduction

Cities play a very important role in national economic development. However, due to the high population and resource consumption, urban environmental degradation has become a serious problem. It is generally believed that urban development and human activities will affect the ecological environment (Fang et al, 2017). Cities, as centers of human activity, can pose environmental challenges such as greenhouse gas emissions and environmental degradation. The relationship between the urban environment and human activities has become the focus of global research focusing on the structure of urban ecosystems (including the impacts of green open spaces, water bodies, and air quality on population health), human activity patterns (traffic flow, land use change, and its impact on environmental quality), the role of socio-economic and environmental factors, and the effectiveness of policies and management (Zhou et al, 2024). In some developing countries, the process of intense urbanization accompanied by climate change has made cities more vulnerable to disturbances such as natural disasters, resource crises, political instability, and financial crises (Li et al, 2020). Research conducted by Budiyanti et al. (2024), shows that in 2005-2010, urban population growth increased at a growth rate of 1.2%. While at the national level, urbanization is projected to reach 66.6% in 2035 (BPS, 2013). The 21st century world will be a world that is largely urbanized. This shows that developing countries must be able to increase their capacity in managing urban infrastructure, services, and housing to maintain urban capacity (Pertiwi, 2017).

Surakarta, also known as Solo, is a city located in Central Java, Indonesia. Surakarta has become the center of cultural and economic activities in the region. The city has experienced rapid urban development, which has led to population growth and increased demand for infrastructure and services. Mardiansjah (2018), stated that Surakarta City has rapid and complex growth dynamics because it experienced rapid urban population growth of up to three times in a period of thirty years between 1980 and 2010. It is further explained that the pattern of urbanization and population growth shows a pattern that widens towards the outskirts, with urban population growth in the outskirts occurring faster than stagnant growth in Surakarta. It is estimated that the stagnation in Surakarta is caused by limited potential land for urban development in its administrative area, which is also combined with the availability of potential land for extensive urban development in the outskirts supported by the availability of a regional road network connecting the outskirts with centers of activity in Surakarta (Astuti et al., 2024). In a study conducted by Ridwan (2022), it was found that the average annual temperature in Surakarta is 27°C, but in recent times it has reached 39°C - 44°C due to the lack of Green Open Space in Surakarta.

Based on Surakarta City Regional Regulation Number 6 of 2021 concerning the Regional Medium-Term Development Plan for 2021 - 2026, land use in the Surakarta City area is mostly for settlements with an area of 2,889.8 ha while the rest is for economic activities and public facilities. There was an increase in the use of residential land from 2,876.7 ha (2014) to 2,889.9 ha (2018). This increase was caused by the conversion of land in Surakarta City which was originally for productive agricultural land to housing/settlements and also services. Based on data from the Surakarta City Population Administration and Civil Registration Service, in 2022 it was stated that Surakarta City had an area of 46.72 km2 with a population of 583,961 people. The population density of Surakarta City reached 12,499 people per km2 with a population growth rate in the period 2016 - 2022 of 0.81%. On the other hand, the economic growth of Surakarta City from 2016 to 2019 has always experienced an increasing trend, except in 2020 which experienced a decline due to the Covid-19 pandemic to -1.76% but then increased again to 4.01% in 2021 and is predicted to increase again in the following year to 6.25 (BPS Surakarta City, 2023).

Based on data from the Surakarta Regional Environmental Management Performance Information in 2022, land conversion is one of the priority environmental issues related to the availability of Green Open Space. This is because the condition of green open space in Surakarta City in 2018 - 2022 shows that the area of public green open space has not met the requirements of 20% of the city area. Based on research conducted by Hartanti (2020), the government needs to increase the need for green open space by 805.932 ha or 18.3% consisting of public green open space of around 371.69 ha or 8.44% and private green open space of around 434.234 ha or 9.86%. The difference in green open space needed to match the availability of green open space in Surakarta City is 415.58 ha.

A proper solution is needed to solve this problem. One of them is by using the Causal Loop Diagram (CLD) model to determine the supply and demand for land needs in Surakarta City. According to Suryani (2023), this model aims to understand the problems that arise in a closed-loop system where conditions are converted into observable information so that planning can be done to change the initial conditions. The same thing was also explained by Aulia (2024), where the development of the Causal Loop Diagram (CLD) diagram can help identify complex relationships and feedback cycles that affect urban development. The development of the Causal Loop Diagram (CLD) in Surakarta can provide significant benefits in identifying complex relationships and feedback cycles that affect urban development. By using the Causal Loop Diagram (CLD), the government and city planners can identify positive and negative feedback cycles that may not be visible in conventional analysis, such as how improving transportation infrastructure can accelerate urban sprawl which then affects air quality and people's lives (Darmono, 2005). Causal Loop Diagram (CLD) development involves identifying stakeholders and endogenous variables and formulating the causal relationships of the variables (Dhirasana & Oz, 2019). The novelty of using Causal Loop Diagram (CLD) in Surakarta lies in its ability to combine multiple stakeholder perspectives and generate a more holistic understanding of city dynamics, ultimately supporting more effective and sustainable urban planning.

2. Methods

This research activity was carried out in Surakarta City, Central Java Province, Indonesia, which is geographically located at 110° 45' 15" and 110°45' 35" East Longitude and between 7°36' and 7°56' South Latitude and is a lowland area with an altitude of 92 meters above sea level (BPS Surakarta City, 2024).

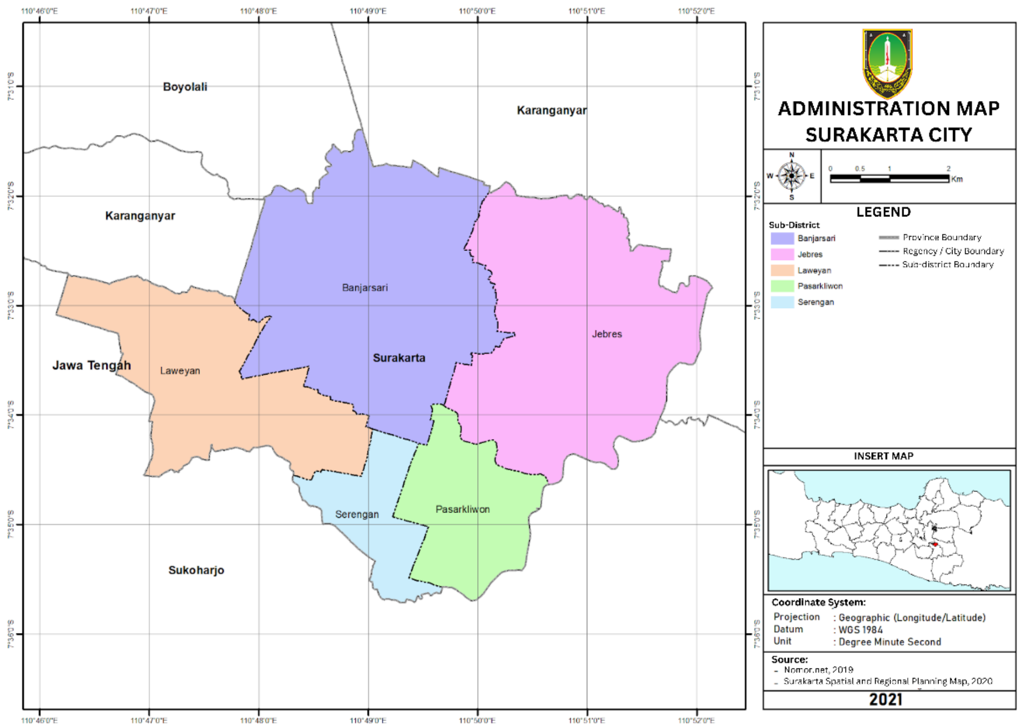

Figure 1. Administration map of Surakarta

From Figure 1. It is known that Surakarta City borders Karanganyar Regency and Boyolali Regency to the north, Karanganyar Regency and Sukoharjo Regency to the east and west, and Sukoharjo Regency to the south. Surakarta City has five sub-districts, namely Laweyan, Serengan, Pasar Kliwon, Jebres, and Banjarsari (Saeroji & Wijaya, 2017). Banjarsari District is the largest sub-district in Surakarta. From several sub-districts, it is divided into 51 urban villages with a total of 595 RW and a total of 2,669 RT. This city is one of the big cities in Central Java that supports other cities such as Semarang City.

This study uses a quantitative descriptive approach. Modeling with system dynamics requires quantitative data for computer simulation (Samudra, 2023). However, Rasyidi (2009) proposed combining qualitative and quantitative approaches because not all phenomena can be recognized through a quantitative approach and so that information can be developed more broadly and comprehensively. In this study, data was obtained from all identified variables which were then dynamically arranged using Causal Loop Diagram (CLD) analysis processed with Vensim PLE v9.3.5 software. Vensim software can be used to conceptualize, simulate, analyze, and optimize dynamic system models starting from creating causal node diagrams or from creating stock diagrams and flow diagrams (Almamalik, 2021). Ventana Simulation (Vensim) is a visual modeling tool that makes it easy for users to conceptualize, document, simulate, analyze, and optimize dynamic system models (Suryani, 2022). In general, Vensim PLE (Personal Learning Edition) is a fully functional dynamic system software, free for personal and educational users, shareware for commercial users, and equipped with model examples, help modules, and user guide documents. By mapping these relationships, one can gain a deeper understanding of the complex dynamics that occur and identify potential leverage points for intervention and improvement. The application of causal loop diagrams in urban development scenario analysis in Surakarta offers a unique opportunity to explore the complex interconnections between various factors that influence urban growth and sustainability. There are two steps in developing a Causal Loop Diagram (CLD), namely problem articulation and dynamic hypothesis formulation (Suryanendra & Suryani, 2021).

Problem articulation means the modeler identifies the research problem to be solved. Furthermore, it determines the system's key variables that significantly impact the problem at hand. Problem articulation is also called conceptualization and identification of problem definition (Dhirasana & Oz, 2019). The first step is problem articulation data that can be obtained through literature studies by studying the impact of urban development on land availability and studying the models used by previous researchers, discussions with related parties, seeking additional information on previously conducted research, collecting data, conducting interviews, and direct observation (Suryani et al., 2023). In this study, researchers used secondary data from 2016 - 2022 because this time span allows analysis of trends and changes that occur over a long enough period to identify relevant patterns in urban development in Surakarta. This period also includes recent developments that may better reflect current conditions and challenges, so that research results can provide more accurate and relevant insights for decision-making in the context of sustainable urban policy and planning.

The second step is formulating dynamic hypotheses that can explain the feedback structure that is expected to have the ability to influence problematic behavior. According to Suryani et al. (2023), after various internal and external variables have been determined, a causal model is compiled which is described through the Causal Loop Diagram (CLD). In this diagram, each variable that has been collected is connected based on a causal relationship and its polarity properties. The first step to formulating dynamic hypotheses is problem limitation is done by drawing a thinking framework, namely Big Picture Mapping (Thifalina, 2023). The second step is to develop of Causal Loop Diagram (CLD) because the Causal Loop Diagram (CLD) can help identify complex relationships and feedback loops between various factors that influence sustainable urban development (Dhirasana & Oz, 2019). By visualizing these interactions, policymakers and urban planners can better understand the potential impacts of their decisions and interventions on the environment, economy, and society. Causal loop diagrams are useful for representing conceptual models of system designers (models), representing hypotheses about the causes of system dynamics (models), and communicating important feedback aspects that are believed to be (very) important in a system (Prahasta, 2018). The last step is analysis, Causal Loop Diagrams (CLD) are good for improving and capturing models and communicating feedback involved in a defined problem. This variable is explained by a causal link indicated by an arrow symbol where each causal relationship has a polarity with a positive (+) or negative (-) symbol to show how the dependent variable changes when the independent variable changes (Permatasari, 2022). In a loop that has a repeating cycle, there is feedback in the form of reinforcement (R) and feedback (B) (Suryanendra & Suryani, 2021). To get a positive (+) or negative (-) sign in the Causal Loop Diagram (CLD), it is necessary to carry out several analysis steps to determine the causal relationship between the existing variables. Here are the steps that can be followed:

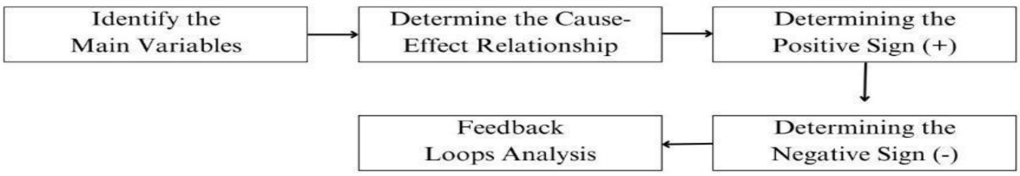

Figure 2. Steps Causal Loop Diagram (CLD) analysis

To effectively analyze a system, the first step involves identifying the key variables that influence the system's dynamics. These variables might include factors such as population growth, infrastructure development, pollution levels, and government policy. Each of these elements plays a critical role in shaping the behavior of the system. Once the key variables are identified, the next step is to determine the cause-effect relationships between them. For every pair of variables, it is important to assess how a change in one will influence the other. For instance, an increase in population may lead to greater pressure on infrastructure, or higher pollution levels could prompt policy changes. This process helps in understanding whether an increase or decrease in one variable will have a corresponding effect on the other. When assessing these relationships, a positive sign (+) is assigned if the two variables are mutually reinforcing, indicating a reinforcing (R) relationship. For example, if an increase in population leads to a rise in housing demand, this is a reinforcing relationship, and thus, a positive sign (+) is applied. Conversely, a negative sign (-) is assigned if the relationship between the variables is inversely proportional. In this case, a balancing (B) relationship exists. For instance, an increase in air pollution might result in a decline in public health quality, which would be marked by a negative sign (-). Finally, the analysis of feedback loops is essential to understand how the system behaves over time. A reinforcing loop, comprised of positive relationships, leads to a continuous growth or decline within the system, while a balancing loop, which includes one or more negative relationships, works to stabilize the system by counteracting the effects of change. These feedback loops provide insight into the long-term outcomes of the interactions between variables.

3. Result and Discussion

3.1. Land Use Analysis in Surakarta

Based on the 2022 Environmental Management Performance Information data, it is known that land use is dominated by cultivation areas (78.93%) which include settlements (61.53%) and trade and services (15.51%) with a real conservation space pattern in Surakarta of only 21.07%. The dense land cover in the form of buildings and the lack of green open space areas have caused the Surakarta area to experience the Urban Heat Island (UHI) phenomenon or an increase in air temperature in urban areas with a trend that continues to increase from year to year (Putra et al., 2018). Data on the development of Surakarta City is presented in Table 1.

\

Table 1. The development of Surakarta City 2016 – 2022

Type	Unit	2016	2017	2018	2019	2020	2021	2022
Population*	people	570,876	562,801	569,711	575,230	578,350	578,906	583,961
Built-up land area**	m2	3,960.35	3,963.43	3,971.54	-	-	-	-
Public green open space***	m2	427.88	427.88	427.88	372.97	486.60	355.23	458.71
GDP****	Bilion (Rp)	29,975	31,685	33,509	35,441	34,815	36,211	38,475
Investment *****	Bilion (Rp)	5,233	3,580	6,145	1,824	3,461	4,560	18,242

Source :

* Population Administration and Civil Registry Service Institution of Surakarta, 2016 – 2022

** BPS Surakarta City, 2016 – 2018

*** data.jatengprov.go.id/dataset/rasio-ruang-terbuka-hijau-publik-di-kota-surakarta

**** GDP Series 2010 Based on Constant Prices by Sectors, BPS Surakarta City, 2016 – 2022

***** Invesment and One Stop Integrated Service Institution of Surakarta, 2016 – 2022

Based on Table 1, it can be seen that the development of population and built-up land area shows an increasing trend. The development of green open space showed an increase in 2020 but then decreased in 2021. The increase in green open space in 2020 was due to the city government's efforts to improve environmental quality, which may have been driven by awareness of the importance of green space during the COVID-19 pandemic. Greening programs and policies supporting the addition of green space may have been strengthened in that year to provide more safe and healthy public spaces for residents. However, in 2021, there was a decrease in green open space due to the continued increase in population, namely from 573,350 people to 578,906 and continuing to increase to 383,961 in 2022 (BPS Surakarta City, 2022). This certainly triggers a higher demand for housing and commercial facilities which causes the conversion of green land to built-up land.

Regarding the existence of public green open spaces, Surakarta City has not reached 20% of public green open spaces as mandated in the Regulation of the Minister of Agrarian Affairs and Spatial Planning.

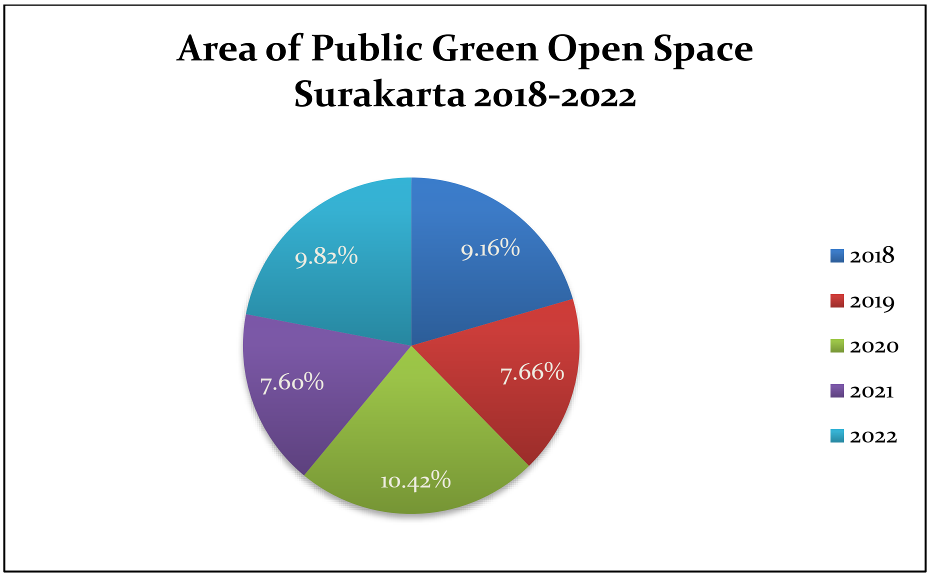

Figure 3. Area of Public Green Open Space Surakarta 2018-2022

In Figure 3 above, it can also be seen that since 2018 - 2022 the area of Public Green Open Spaces is 427.88 Ha (9.16%), 357.92 Ha (7.66%), 486.60 Ha (10.42%), 355.23 Ha (7.6%), and 458.71 Ha (9.82%). The area of green open spaces will affect the value of the Surakarta City Land Quality Index. Based on Wardani (2020), green open spaces are very necessary for a city area to control the microclimate in urban areas so that they can create an environment with comfortable conditions. In addition, green open spaces also function in water management by absorbing rainwater and reducing surface runoff, thereby reducing the negative impact on land quality. Surakarta's Environmental Quality Index (EQI) in 2022 showed a value of 59.42, indicating moderate conditions (50 < IKL < 70). This value was obtained from a combination of calculations of the Water Quality Index (50.98), Air Quality Index (80.06), and Land Quality Index (30.22) (Surakarta IKLH Report, 2022). From this data, it can be seen that the Environmental Quality Index shows a low range (25 < IKL < 50), and it was found that the land quality index component is the most depressed component and tends to be negatively impacted by the variables of increasing population, gross income, and per capita expenditure. On the other hand, GDP growth is getting higher and investment growth has exceeded the target set in 2022, namely from 220 billion to 535.6 billion (55.82%) (DPMPTSP Surakarta, 2022). Economic development is the main driver of a country's prosperity, but this progress also poses significant challenges, especially the impact of economic activities on environmental quality (Febriana, 2019).

In Surakarta City, there has been an increase in the area of settlements, indicating that the need for residential land is increasing due to the increasing population growth rate every year. This shows that there are 12 villages, namely Pajang, Kerten, Karangasem, Semanggi, Sangkrah, Pucang Sawit, Jebres, Mojosongo, Kadipiro, Manahan, Sumber and Banyuanyar which are experiencing an increase in population density. This is due to the increasing number of residents in limited residential areas (Koesuma et al., 2022). In addition, urban planning policies that may be less effective in controlling urban expansion or allocating land for housing contribute to the increase in population density in these villages.

Through research conducted by Rahman et al. (2021), it was found that population growth is directly proportional to the consumption of natural resources. Increased consumption of natural resources over a certain period will exceed the environmental carrying capacity. This condition is called overshoot or exceeding the environmental carrying capacity (Fatimah et al., 2019). One approach to measuring environmental carrying capacity is the Supply-Demand balance approach. This approach is based on the balance between the availability or capacity of space/resources/areas with the needs of humans or other living things, so that there is a threshold of adequacy or inadequacy of resources or space to support human life (Muta'ali, 2019). The high population and economic density have resulted in water scarcity, land degradation, energy shortages, air pollution, and loss of biodiversity which are the main factors inhibiting social and economic development (Bao et al, 2022). The tendency of urban development that is expansive and spread basically leads to the unsustainability of the urban environment, which is characterized by a decrease in environmental carrying capacity (Kustiwan & Ladimananda, 2012).

3.2. Condition of Land Carrying Capacity in Surakarta

The results of the analysis with baseline data from 2022 using the Regulation of the Minister of Environment Number 17 of 2009 concerning Guidelines for Determining Environmental Carrying Capacity in Regional Spatial Planning, obtained the results that land availability (supply) in Surakarta City is 2,440 Ha and land requirements (demand) in Surakarta City is 243,317.08 Ha. The condition of land carrying capacity deficit in Surakarta City, where land availability (supply) of 2,440 Ha is much smaller than land requirements (demand) of 243,317.08 Ha, shows that the land available in this city is no longer able to meet various space needs, both for housing, infrastructure, and other activities. The correlation with current conditions is that Surakarta is facing serious challenges in maintaining urban sustainability. With a growing population, pressure on land is increasing, causing the conversion of green land into built-up areas, which in turn reduces the quality of the environment and reduces the capacity of the city's ecosystem. This condition also reflects the need for more careful and sustainable urban planning, where land allocation must be given more attention to avoid over-exploitation and irreparable environmental damage. The implementation of stricter policies on land use, along with efforts to optimize existing space, is crucial in dealing with the deficit of land carrying capacity (Putri & Yulia, 2024). Without proper intervention, Surakarta could face a degradation in the quality of life of its citizens, which ultimately hampers long-term economic and social growth.

Based on the calculation of land carrying capacity in 2022, there are 5 key variables (Table 2) that affect land carrying capacity in Surakarta City (IKLH Surakarta City, 2022). These five key variables include green open space, built-up land, population, gross regional domestic product (GRDP), and investment. Green open space is an important component in maintaining ecological balance in the city. Lack of green open space reduces the capacity of land to support a healthy life and increases the risk of environmental degradation (Bhakti, 2024). Built-up land refers to areas that have been developed for housing, industry, infrastructure, and public facilities (Mirah, 2017). Land that continues to be built without considering carrying capacity can cause over-utilization and reduce the land's ability to support long-term growth. Population growth directly affects the need for land for housing, public facilities, and infrastructure. The larger the population, the greater the demand for land, which can exceed the available carrying capacity (Rahman et al., 2021). GRDP reflects the level of economic activity in Surakarta. The increase in GRDP is usually associated with increased development and infrastructure activities that require more land (Wijayanti & Priyanto, 2022). Investment, especially in the property and infrastructure sectors, triggers the development of new land. The greater the investment that comes in, the greater the demand for land, both for commercial, industrial, and residential purposes (Ayuningtyas & Astuti, 2023).

Table 2. Variables that influence land carrying capacity in Surakarta City

No	Variable	Information
1	Green open spaces	- Publlic green space
2	Built	- Housing/settlements - Company - Service - Industry - Land conversion
3	Total population	- Birth - Death - Inbound migration - Outbond migration
4	Gross Regional Domestic Product (GRDP)	- Construction - Wholesale and retail trade, car, & motorcycle repair - Information & communication - Processing industry - Provision of food and drink accommodation - Inflation
5	Investment	- Microbusiness - Small business - Medium business - Big business

These five variables are interrelated and together determine the land capacity of Surakarta City to support sustainable growth. Good management of each of these variables is key to ensuring that the land-carrying capacity is not exceeded and that development can proceed without damaging environmental quality or public welfare. The variables that influence supply are the area of built-up land and the area of public green open space because these two factors determine the availability of land that can be used for various purposes. The larger the area of built-up land, the less land supply is available. Meanwhile, the variables that influence demand are population, investment value, and gross domestic product (GDP) because these three factors reflect the increasing need for land for various purposes. Thus, the interaction between these supply and demand variables determines the balance of land carrying capacity in Surakarta City, where an imbalance between the two can cause a deficit in carrying capacity that threatens environmental sustainability and the quality of life of the community.

3.3. Factors Affecting Land Carrying Capacity in Surakarta

Figure 3 below illustrates the complex relationship between various factors that influence land carrying capacity in Surakarta City with a focus on urban development and efforts to achieve the Sustainable Development Goals (SDGs).

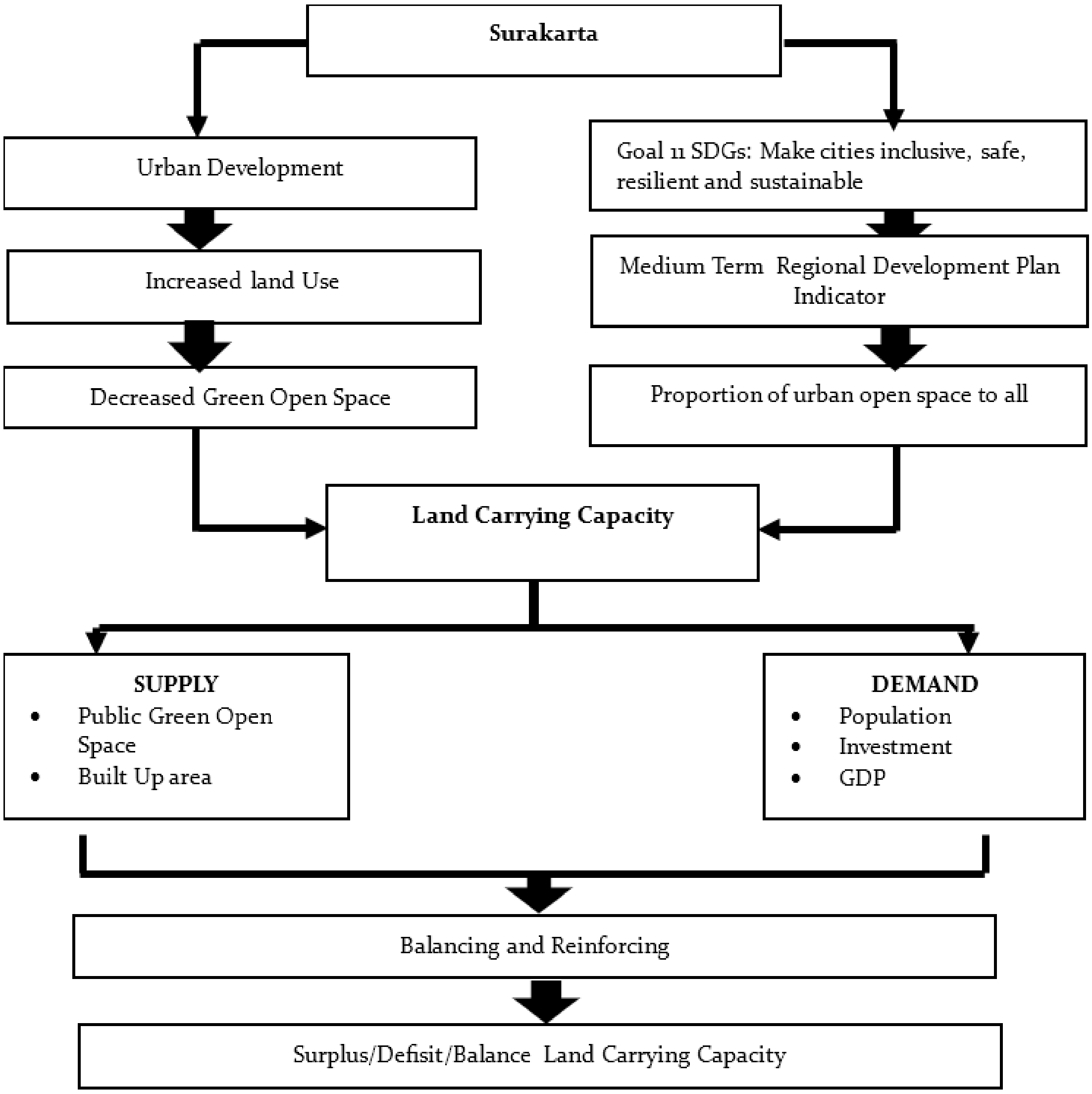

Figure 4. Factors influencing Land Carrying Capacity in Relation to Urban Development and Sustainable Development Goals in Surakarta City

At the top, the diagram shows two main factors affecting Surakarta, namely Urban Development and the SDGs (specifically Goal 11 which aims to make cities more inclusive, safe, resilient and sustainable). Urban development leads to increased land use which causes a decrease in Green Open Space. The decrease in green open space has a direct impact on the carrying capacity of the land which is the center of this entire diagram. On the right side, the SDGs are linked to the Regional Medium-Term Development Plan which emphasizes the proportion of urban green open space to total land. This means that the achievement of the SDG targets, especially those related to green open space, plays a significant role in determining the carrying capacity of the land.

3.4. Causal Loop Diagram (CLD) Results

Land carrying capacity is influenced by two main groups of variables, namely supply and demand. Supply includes public green open spaces and built-up land. Meanwhile, Demand includes population, investment, and gross domestic product (GDP). Supply indicates the availability of existing land, while demand describes the pressure on land due to development needs, economic needs, and population growth. This diagram also shows the balancing and reinforcing processes that occur in the land-carrying capacity system. When there are changes in supply and demand, the system will experience adjustments that can lead to a surplus, deficit, or balance in land carrying capacity. Overall, this diagram provides a comprehensive picture of how various development factors and policies in Surakarta interact to affect land carrying and shows the importance of balancing development needs and preserving green open space to ensure sustainable urban life.

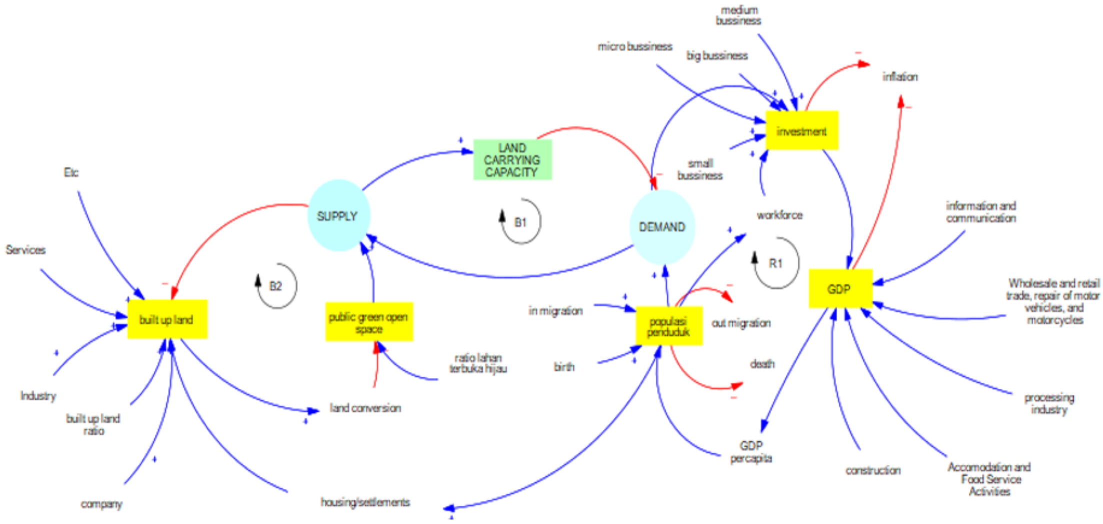

Figure 5. Causal Loop Diagram of City Development and Land Carrying Capacity in Surakarta

The Causal Loop Diagram (CLD) shown illustrates the complex interactions between various variables that affect land carrying capacity in Surakarta City. This diagram highlights the relationship between the main variables, namely built-up land, public green open space, population, investment, and Gross Domestic Product (GDP), and how these variables influence each other through feedback cycles that can be reinforcing or balancing. The Causal Loop Diagram (CLD) shows the relationship between variables that influence each other and illustrates the causal relationship in Surakarta's Land Carrying Capacity.

Loop B1 which contains Land Carrying Capacity - Demand - Supply - Land Carrying Capacity, shows that carrying capacity is influenced by Land Availability (Supply) and Land Needs (Demand). If supply increases, land carrying capacity will increase, while if demand increases, land carrying capacity will decrease (Aswad & Kesaulya, 2023). This loop produces negative feedback/Equilibrium (B). Loop B2 which contains Supply – Built-up Land – Land Conversion – Green Open Space – Supply, shows that built-up land will increase land conversion. This will reduce green open space, causing land supply/availability to decrease (Mubarokah & Hendrakusuma, 2022). This cycle produces negative feedback/equilibrium. Loop R1 which contains Population – Demand – Investment – GDP – GDP per capita – Population, shows that the carrying capacity of the city is unable to support the scale of urban growth, thus posing a major challenge to the sustainability of urban development. The increasing population will increase the need for land (demand), and the population will also increase population consumption (Afni, 2016). In addition, population growth will also create a diversity of ideas and innovations, increase the workforce, and provide adequate infrastructure that will increase investment. This investment creates new jobs, increases productivity, and drives consumption, all of which contribute to GDP growth (Pardede et al., 2024). The growing business fields in Surakarta are construction, wholesale and retail trade, car & motorcycle repair, information and communication, processing industry, and provision of food and beverage accommodation. Sustainable GDP growth will increase per capita income and the overall quality of life of the community (Winarni et al., 2023). This circle produces positive feedback/Reinforce.

The description of the five variables in the Causal Loop Diagram (CLD) in Figure 4 above is as follows four points. Firts, built-up land increases along with the increase in industrial activities, companies, and other services that require land for development. This increase in built-up land is inversely proportional to the area of public green open space because the land used for development is usually taken from land that was previously green open space (Sukrisna, 2022). This process is known as land conversion. When green open space decreases, this can reduce the overall supply of land carrying capacity, which has a negative impact on the city's ability to support a growing population (Akhirul et al., 2020). Second, land carrying capacity is an indicator of the balance between the supply of available land and the demand for land from various human activities (Aryo, 2024). In this diagram, two main feedback cycles affect land carrying capacity. Cycle B1 is a balancing loop that tries to maintain a balance between land supply and demand. Meanwhile, Cycle B2, which is also a balancing loop, shows how increasing built-up land reduces green open space, which in turn reduces the supply of land carrying capacity. Third, land demand is influenced by population, investment, and GDP variables (Batik, 2013). Population increases through in-migration and births, while population decline can occur through out-migration and deaths. Population growth drives demand for land for housing, public facilities, and other infrastructure (Dengah et al., 2014). Four, investment from various business sectors such as small businesses, medium businesses, and large businesses also increases demand for land, because each investment usually requires additional land for expansion or new development. In addition, GDP as a measure of overall economic activity contributes to increased demand for land, especially when the economy is growing, and sectors such as construction, manufacturing, trade, and accommodation services require more land to support this growth (Tampubolon & Kurniasih, 2022). Cycle R1 is a reinforcing loop that illustrates how increasing GDP and investment reinforce each other, which then increases the demand for land.

Land carrying capacity of Surakarta City is influenced by Supply and Demand (loop B1). To ensure that the Environmental carrying capacity is not exceeded, two scenarios can be carried out. First, from the demand side, namely by holding back the rate of increase in natural resource consumption by changing people's consumption patterns to be more efficient and wise and utilizing technological interventions that can help support the availability of natural resources. Second, from the supply side, namely by holding back the rate of decline in carrying capacity to ensure that environmental processes, functions, and productivity run well, including by improving the quality of environmental services, and utilizing resources according to their capacity (Muta'ali, 2019). Meanwhile, supply is influenced by Built-up land and green open space (loop B2). Based on Prabowoningsih (2018), the main factor that influences the availability of green open space in residential and service trade areas is the allocation of green open space in spatial planning. Changes in built-up land in Surakarta City and the reduction in open land have a high influence on increasing temperatures which lead to the Urban Heat Island (UHI) phenomenon (Putra et al., 2018).

Population growth, GDP, and investment are variable demands (loop R1). Population and economic subsystems are sources of pressure throughout the urban ecosystem (Fang et al, 2017). Factors that cause a city to grow and develop in addition to urbanization are the development of urban population activities in all aspects of life (especially the economic aspect) and the process of concentrating population activities in the city concerned (agglomeration) (Ghalib, 2005). The increasing demand for urban residents creates pressure on existing resources and causes fragmentation of green open spaces. This trend is more common in developing countries and especially in Asian cities (Siddique & Uddin, 2022). Factors that influence the lack of availability of green open spaces in Surakarta City are budget availability, allocation of green open spaces in spatial planning, implementation of work plans related to green open spaces, awards in greening programs, program implementers, community participation, influence of community leaders, the existence of green communities, the absorption capacity of trees for CO_2, land availability, land value, and supervision of land use control (Prabowoningsih, 2018).

4. Conclusions

There are 5 key variables that affect the land carrying capacity in Surakarta City which are divided into supply and demand models. The supply model is influenced by the area of built-up land and the area of green open space, while the demand model is influenced by the population, investment, and GDP. The relationship between variables that influence each other and describe the causal relationship in Surakarta's Land Carrying Capacity is divided into three rounds, namely loop Land Carrying Capacity - Demand - Supply - Land Carrying Capacity - B1, loop Supply - Built-up land - Land conversion - Green open space - Supply – B2, and loop Population - demand - investment - GDP - GDP per capita - population - R1. The causal loop diagram is then used as a basis for building a simulation model that can be used to develop and test various alternative management policies, where it is necessary to develop a simulation with a scenario of increasing demand for green open space so that the growth rate of green open space can reach a minimum of 20% of the area of Surakarta.

Future research is expected to deepen the analysis of the interaction between key variables such as green open space, built-up land, and economic growth. This research can also be expanded by using simulation models to predict future scenarios related to land carrying capacity, as well as identifying the most effective policies to manage urban growth sustainably.

References

Afni, N. 2016. Environmental carrying capacity of Pattalasang District, Takalar Regency. Plano Madani: Jurnal Perencanaan Wilayah dan Kota, 5(1), 74-85.

Akhirul, Wita, Y., Umar, I., & Erianjoni. 2020. Negative impacts of population growth on the environment and efforts to overcome them. Jurnal Kependudukan dan Pembangunan Lingkungan, 1(3), 76-84.

Almamalik, L. 2021. Introduction to dynamic system modeling using vensim personal learning edition. Guepedia: Bogor.

Aryo, L. 2024. Analysis of carrying capacity and land capacity for settlements in Bawen District. Universitas Islam Sultan Agung Semarang: Semarang.

Astuti, S. W., Sodikin, S., & Bahar, S. 2024. Spatial analysis of the need and availability of green open space in Cakung District, East Jakarta. Jurnal Konservasi dan Rekayasa Lingkungan, 1(1), 38-47.

Aswad, W. O. S. J. & Kesaulya, H. M. 2023. Analysis of the carrying capacity and environmental capacity of the Demak urban area with a supply and demand approach. Innovative: Journal of Social Science Research, 3 (2), 7772-7789.

Aulia, I. 2024. Development of a dynamic system model of waste management policy in the city of Cilegon. Universitas Sultan Ageng Tirtayasa: Serang.

Ayuningtyas, F. J. & Astuti, I. P. 2022. The impact of migration, consumption expenditure, and per capita income on the demand for perum perumnas houses in the special region of yogyakarta province. Jurnal Ilmiah Ekonomi Bisnis, 28(2), 272-289.

Bao, C., Wang, H., & Sun, S. 2022. Comprehensive simulation of resources and environment carrying capacity for urban agglomeration: A system dynamics approach. Ecological Indicators, 138, 108874.

Batik, K. 2013. Analysis of the influence of investment, gross regional domestic product, population, development revenue, and inflation on local real income in West Lombok Regency. Jurnal Ekonomi Pembangunan, 11(1), 125-147.

Bhakti, D. R., Mumpuni, N. W. R., & Hamrany, A. K. 2024. The formulation and influence of the conception of green constitution in regional regulations is a form of the state's commitment to preserving the environment. Jurnal Global Ilmiah, 1(7), 505-511.

Budiyanti, N. Y., Safitri, D., & Sujarwo, S. 2024. The effect of urbanization on changes in social and economic conditions in Indonesia. Triwikrama: Jurnal Ilmu Sosial, 3(6), 41-50.

Central Statistics Agency of Surakarta City (BPS). 2013. Surakarta city in 2013 figures. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2016. Surakarta city in 2016 figures. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2017. Surakarta city in 2017 figures. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2018. Surakarta city in 2018 figures. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2022. Surakarta city in 2022 figures. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2023. Economic growth of the city of surakarta in 2023. Badan Pusat Statistik Kota Surakarta.

Central Statistics Agency of Surakarta City (BPS). 2024. Surakarta city in 2024 figures. Badan Pusat Statistik Kota Surakarta.

Darmono, R. 2005. System dynamics modeling in urban spatial planning. Seminar Nasional Aplikasi Teknologi Informasi (SNATI).

Dengah, S., Rumate, V., & Niode, A. 2014. Analysis of the Influence of Per Capita Income and Population on Housing Demand in Manado City in 2003-2012. Jurnal Berkala Ilmiah Efisiensi, 14(3), 71-81.

Dhirasasna & O, I. 2019. Multi-methodology approach to creating a causal loop diagram. MDPI Journal Systems, 7(3), 42.

Fang, W., An, H., Li, H., Gao, X., & Sun, X. 2017. Urban economy development and ecological carrying capacity: taking beijing city as the case. Energy Procedia, 105, 3493-3498.

Fatimah. 2019. Guidelines for determining the carrying capacity and carrying capacity of the regional environment. Kementerian Lingkungan Hidup dan Kehutanan: Jakarta.

Febriana, S., Diartho, H. C., & Istiyani, N. 2019. The relationship between economic development and environmental quality in East Java province. Jurnal Dinamika Ekonomi Pembangunan, 2(2), 58-70.

Ghalib, R. 2005. Regional economy. Pustaka Ramadhan: Bandung.

Hartanti, D. A. 2020. A study of green open space in the city of surakarta, central java province in 2020. Universitas Muhammadiyah Surakarta: Surakarta.

Koesuma, S., Ramelan, A. H., & Sutarno, D. 2022. Identification of land use and land change due to its impact on groundwater level in surakarta city. IOP Conference Series: Earth and Environmental Science, 989.

Kustiwan, I. & Ladimananda, A. 2012. Modeling of urban development dynamics and land carrying capacity in the bandung basin area. Tata Loka, 14(20), 98 – 112.

Li, G., Kou, C., Wang, Y., & Yang, H. 2020. System dynamics modelling for improving urban resilience in Beijing, China. Resources, Conservation and Recycling, 161, 104954.

Mardiansjah, F. H. 2018. Urban population growth and the development of its distribution pattern in the Surakarta metropolitan area. Jurnal Wilayah Dan Lingkungan, 6(3), 215-233.

Ministry of Environment. 2009. Regulation of the minister of environment number 17 of 2009 concerning guidelines for determining the carrying capacity of the environment in regional spatial planning. Kementerian Lingkungan Hidup: Jakarta.

Mirah, E. M., Mononimbar, W., & Tilaar, S. 2017. Changes in land use in strategic areas are growing rapidly kapitu – teep of south minahasa regency. Spasial, 4(1), 159-172.

Mubarokah, A. & Hendrakusumah, E. 2022. The effect of plantation land conversion on the environmental ecosystem. Jurnal Riset Perencanaan Wilayah dan Kota, 2(1), 1-16.

Muta'ali, L. 2019. Carrying capacity and environmental carrying capacity based on ecosystem services for environmental planning. Fcaulty of Geografi Gadjah Mada University: Yogyakarta.

Pardede, A. P., Sitepu, A. A., Selviae, Rianansyah, E. Y., Rolensa, V., Rianto, S., Kurniawan, N., & Ompusunggu, D. P. 2024. Analysis of the influence of economic variables on the growth of gross regional domestic product in Gunung Mas Regency in 2016-2017. Neraca: Jurnal Ekonomi, Manajemen, dan Akuntansi, 2(1), 474-489.

Surakarta City Regional Regulation Number 6 of 2021 concerning the Regional Medium-Term Development Plan for 2021-2026.

Permatasari, N. & Suryani, E. 2022. Analysis of simulation development strategies to increase the value of the palm oil industry supply chain. Jurnal Teknik Informatika dan Sistem Informasi, 9(1), 301-314.

Pertiwi, N. 2017. Implementation of sustainable development in Indonesia. Pustaka Ramadhan: Bandung.

Prabowoningsih. 2018. Factors that affect the availability of green open space in each land use dominance (case study: Surakarta city). Region, 13(2). 133-151.

Prahasta, E. 2018. System thinking and dynamic system modeling. Penerbit Informatika: Bandung.

Putra, A. K., Sukmono, A., & Sasmito, B. 2018. Analysis of the relationship between land cover change and surface temperature related to the urban heat island phenomenon using landsat images (case study: Surakarta City).Jurnal Geodesi Undip, 7(3), 22-31.

Putri, F. A. J. & Yulia, A. 2024. Practical problems of land management in the era of globalization based on the principle of Pancasila for the benefit of industry and society. Journal of Innovation Research and Knowledge, 4(2): 1195-1212.

Rahman, R. & Putri, D. Z. 2021. Analysis of the influence of minimum wage, economic growth, population and inflation on provincial income inequality on the island of Sumatra. Jurnal Kajian Ekonomi dan Pembangunan, 3(3), 37-48.

Rasyidi, M. S. 2009. Towards sustainable water availability in the upstream cikapundung watershed, a system dynamics approach. Institut Teknologi Bandung: Bandung.

Ridwan, M. 2022. The effect of the availability of green open space on the quality of the micro environment in balekambang park, banjarsari district, surakarta city. Universitas Islam Sultan Agung: Semarang.

Saeroji, A. & Wijaya, D. A. 2017. Mapping of culinary tourism typical of the city of surakarta. Jurnal Pariwisata Terapan, 1(1), 13-27.

Samudra, A. A. & Hertasning, B. 2023. A study on motor vehicle control modeling to reduce air pollution in jakarta. Jurnal Penelitian Transportasi Darat, 25(2), 149-159.

Siddique & Uddin. 2022. Green space dynamics in response to rapid urbanization: patterns, transformations and topographic influence in chattogram city, bangladesh. Land Use Policy, 114, 1 – 12.

Sukrisna, A. C. 2022. Development of the new riverbank as a public open space and plaza in the city of solo. Universitas Muhammadiyah Surakarta: Surakarta.

Surakarta City Environmental Agency (DLH). 2022. Information on the performance of environmental management in Surakarta city in 2022.

Surakarta City Environmental Agency (DLH). 2023. Surakarta city environmental quality index in 2022.

Surakarta City Investment and One-Stop Integrated Services Office (DPMPTSP). 2022. Report 2022.

Suryanendra, A. & Suryani, E. 2021. The analysis of coffee productivity and production improvement strategies in indonesia: a system thinking approach. AIP Conference Proceedings, 2329.

Suryani, E., Hendrawan, R. A., Viontita, S. C., Muhayat, H., Aziz, F. N., Rafi, H., Mufliq, A., & Chandra, A. A. 2023. Increase in sales of mysneakersby products through e-commerce platforms with a dynamic system approach. Sewagati: Jurnal Pengabdian Kepada Masyarakat, 7(5), 830-838.

Tampubolon, D. & Kurniasih, C. E. 2022. Effects of sectoral composition of economic growth on poverty in Riau. Ekonomi, Keuangan, Investasi, dan Syariah (Ekuitas), 3(3), 521-530.

Thifalina, F. D., Zaman, B., & Sarminingsih, A. 2023. Pollution load analysis of wonokromo river with program system dynamics (stella). Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan, 20(1), 1-10.

Wardani, A. A. K. 2020. Analysis of the existence of green open space on the comfort index in the city of surakarta in 2019. Universitas Muhammadiyah Surakarta: Surakarta.

Wijayanti, D. E. & Priyanto, M. W. 2022. The effect of urbanization on cultivated fields in indonesia. Agriscience, 3(1), 230-239.

Winarni, E., Sari, Y., & Amali, M. 2023. Analysis of the influence of minimum wage, local income, labor force and economic growth on the gross regional domestic product per capita of jambi province. Ekonomis: Journal of Economics and Business, 7(2), 1182-1188.

Zhou, Y., Huang, Y., & Liu, W. 2024. Understanding the conflict between an ecological environment and human activities in the process of urbanization: a case study of ya'an city, china. Sustainability, 16(15), 6616.