

Dynamics System Modeling of Declining Agricultural Land Area Potentially Causing Jakarta Flood Disaster

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Abstract

The change or evolution of land use in the DKI Jakarta area has caused various environmental problems in the city that have an impact on disasters that occur from time to time. The conversion of agricultural land that has a relatively high ability to absorb water into built-up land has reduced the water absorption capacity because the built-up area is increasingly impermeable which is at risk of causing flood disasters. This research focuses on a simple dynamic system modeling approach to understand the cause-and-effect relationship of the decline in agricultural land area in the DKI Jakarta area. The method used in this research is a qualitative-based dynamic system, dynamic system is a method that can be used to form structures and predict behavior and feedback. Dynamic system modeling using Powersim Studi 10 Express software uses time specifications ranging from 2020 to 2070. The results of the dynamic system model of agricultural land decline can be said to be valid, where the dominant structure formed is Negative Feedback (Balancing Loop) with Exponential Decay behavior and Average Means Error (AME) test results obtained a value of 29.6%.

Keywords: *System Dynamics, Agricultural Land, Land Conversion, Flood Disaster*

INTRODUCTION

Dynamics or changes in urban areas are a response to basic human needs that must be met, including social and economic needs. These changes require adjustments in various types of community activities, such as changes from agrarian activities that utilize large agricultural land to activities with higher economic value, such as trade, services, and processing industries. According to Sutomo (2004); Irawan (2005) (in Mulyani et al., 2016), land needs are increasing along with population growth and economic development. Especially around urban and industrial centers, land is needed for infrastructure such as roads, tolls, airports, ports, industries, and offices, as well as for housing and residential areas. Unfortunately, intensive paddy fields that have been the center of rice production are also often targeted for conversion by developers. This is because paddy fields are generally flat, easily accessible, and close to water sources.

DKI Jakarta is the capital and center of government of Indonesia, divided into 1 regency and 5 municipalities and consists of 44 sub-districts and 267 villages. The population of DKI Jakarta in 2023 based on the results of population projections from SP2020 results by district / city in 2020-2035 amounted to 10,672,100 people with a population growth rate of 2023 against 2020 of 0.38 percent. The population density of DKI Jakarta in 2023 is 16,165 people per 1 km². This population growth causes high demand for residential areas. Susilowati (2016) said, after 1980, the development of settlements in DKI Jakarta was getting faster. The distribution of residential land use showed significant changes in various parts of the city and sub-districts. In 1988, residential areas covered around 60 percent of the total land area, which was around 38,785 hectares. These residential areas developed in all directions, especially in the western, southern and eastern parts which were previously agricultural areas or vacant land. Previously scattered pockets of settlement are now connected and form a more compact region.

According to Prihatin (2015), rapid population growth and development activities in various fields will lead to increased demand for land. This will encourage the conversion of agricultural land to non-agricultural land. Meanwhile, Prabowo, et al. (2020) mentioned that along with the increase in population, there was a decrease in the area of agricultural land due to the process of land conversion to meet residential needs. Land conversion that is carried out directly or indirectly, can be temporary or permanent. Land conversion is influenced by external factors including economic, socio-cultural, population increase and regulations while internal factors such as less productive land and farmers' economic pressure. The change or evolution of land use in the DKI Jakarta area has caused various environmental problems in the city that have an impact on disasters that occur from time to time. The conversion of green land (vegetation) that has a relatively high ability to absorb water into built-up land (with many buildings) has reduced water absorption capacity because built-up areas are increasingly impermeable (Kunu & Lelolterry, 2010).

The occurrence of floods is caused by natural conditions and phenomena (topography, rainfall), regional geographical conditions and human activities that have an impact on spatial or land use changes in an area (Rosyidie, 2013). According to Eldi (2020), the flood problem in DKI Jakarta is caused by several factors, namely urban dynamics and development which includes urban demography, land use and land function change, where these factors will have an impact on the environment and cause natural events, such as flooding. The decreasing agricultural area that functions as a water catchment area in DKI Jakarta has increased the risk of flooding.

In the system dynamics approach, the first step is to define the problem dynamically. We conceptualize a real system that involves variables that affect each other in a reciprocal manner. This concept is then represented in the form of a Causal Loop Diagram (CLD). Once the CLD is complete, the next step is to identify the independent stocks or accumulations in the system, as well as recognize the inflows and outflows. This information is used to formulate a behavioral model that can reproduce the dynamic problem within a predefined scope. This model is usually implemented in the form of a Stock and Flow Diagram (SFD) using a computer (Richardson, 2013).

Therefore, this research focuses on a simple dynamic systems modeling approach to understand the cause-and-effect relationship of the decline in agricultural land area in the DKI Jakarta region. Using this method, we can identify the factors that influence changes in agricultural land area and model them in the form of a Causal Loop Diagram (CLD) or Stock and Flow Diagram (SFD).

RESEARCH METHODS

Dynamic system methods allow us to model complex systems with respect to changes in system behavior over time. One of its main characteristics is the existence of feedback relationships between entities in the system (Karima et al., 2022). System modeling is a method to replicate real conditions for the purpose of, among others, predicting and analyzing policies. In system modeling, the system dynamics method is used, and one of the frequently used software is Powersim Studio 10 Express. Using the software makes it easy to design the model and analyze the output of the model. This study uses reference data with a time span of 2020 to 2022, in the form of data on the number of self-owned houses by household; agricultural land area; built-up land area; and flood-affected areas. This study uses time specifications ranging from 2020 to 2070.

Data processing involves creating a program or simulation model using Causal Loop Diagrams (CLD) and Stock and Flow Diagrams (SFD). These models use linear equations and are executed using a computer. After that, a verification stage is carried out to ensure the suitability of the data applied in the model with the observed system, as well as validation to evaluate the extent to which the model that has been created reflects the reality or system being observed.

The stages of the research flow include: (1) conduct a literature review to understand the theories that support the research; (2) collect reference data through the literature study that has been done previously; (3) perform data processing by creating a Causal Loop Diagram (CLD) simulation to understand the relationship between related variables, and form a simulation model using Stock and Flow Diagram (SFD) with linear equations and execution using a computer; (4) validation to ensure that the system or model complies with the standards and requirements that have been set previously; (5) analyze the diagram to examine the relationship between the variables contained in it, and finally (6) make conclusions based on the research results and provide suggestions

RESULT AND DISCUSSION

The results of the collected reference data were processed by the researcher to create a simulation model based on interconnected variables in the context of the cause-and-effect of reduced agricultural areas at risk of causing flood disasters. The creation of the CLD was based on the needs analysis that had been identified in the previous stage. From the observation results, there are three variables that have a significant effect on the decrease in agricultural land area, namely: (1) Agricultural land, (2) Residential land, and (3) Land conversion. These variables are then converted into variables that have independent values, but follow certain behavior patterns. Thus, changes in one variable will affect other variables according to the pattern. From the causal relationship between variables, the dominant structural pattern of the model is Negative Feedback (Balancing Loop). The visualization of the pattern is as shown in Figure 1 below:

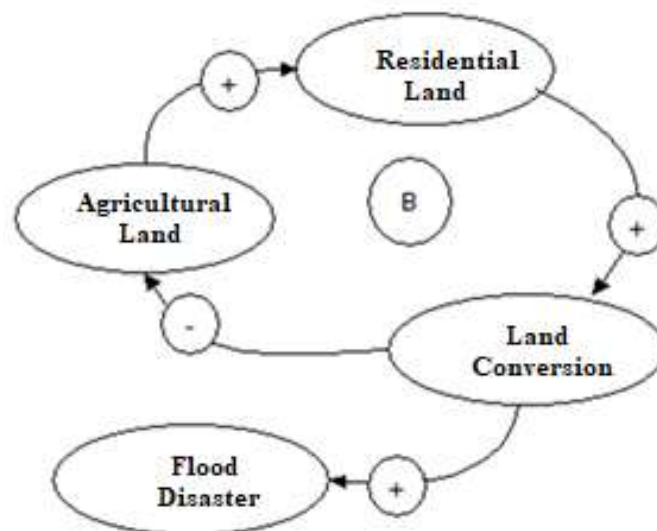


Figure 1. Causal Loop Diagram of Agricultural Land Decline
Source: Data Processing (2024)

Based on the CLD figure above, it can be seen that several factors can affect the area of agricultural land as a catchment area and result in the risk of flooding in DKI Jakarta, namely: the decreasing area of agricultural land, the increasing area of residential land and the resulting increase in land conversion from land that has a relatively high ability to absorb water into built-up land (with many buildings) has reduced water absorption capacity, thus causing the risk of flooding. The results of data and information input from each component are processed using a computer with the Powersim Stusio 10 Express application to form a Stock Flow Diagram (SFD) as shown in Figure 2 below:

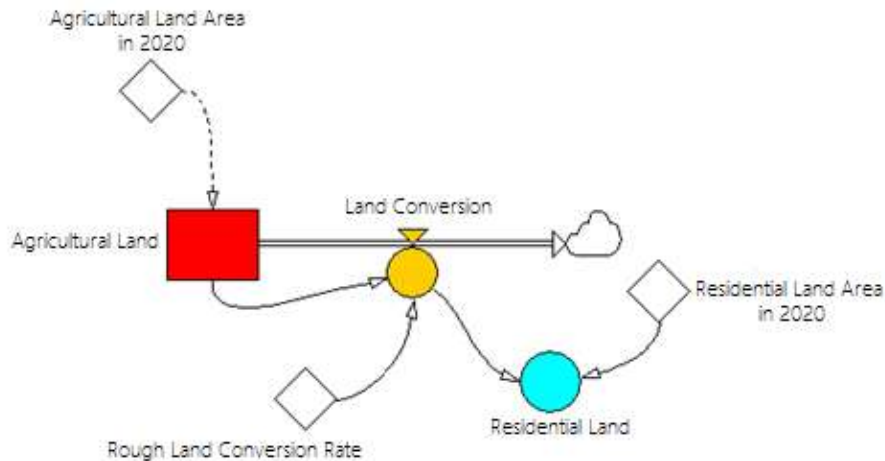


Figure 2. Stock Flow Diagram of Agricultural Land Decline
 Source: Data Processing (2024)

The process of modeling the decline in agricultural land area was carried out with the Powersim Studi 10 Express application tool. Simulation based on data with simulation time specifications (start-time and stop-time). This study uses time specifications ranging from 2020 to 2070 with the results in the form of time graphs as shown in Figure 3 and time tables as shown in Table 1 below:

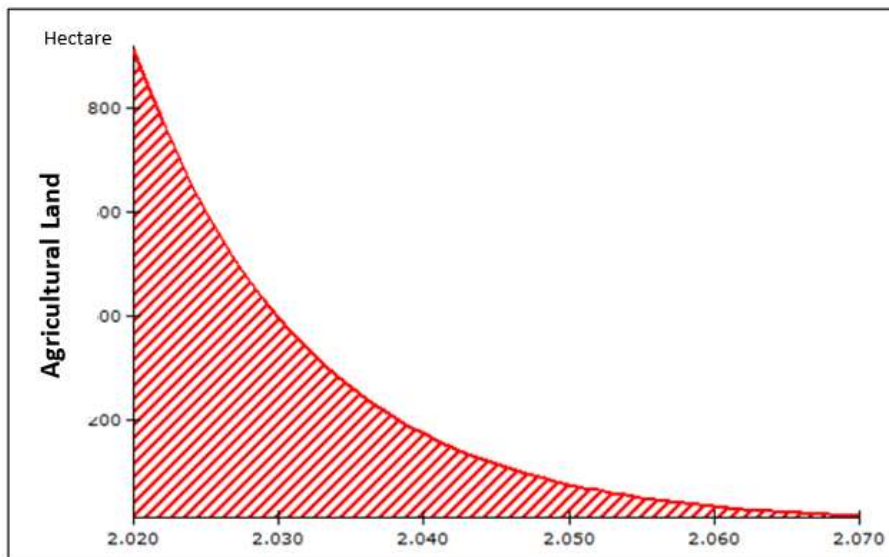


Figure 3. Simulation Time Chart of the Decline in Agricultural Land Area from 2020 - 2070
 Source: Data Processing (2024)

Table 1. Simulation Time Table of Agricultural Land Degradation for the period 2020 - 2070

(Hectare)	
Year	Agricultural Land
2.020	914,50
2.021	841,34
2.022	774,03
2.023	712,11
2.024	655,14
2.025	602,73
2.026	554,51
2.027	510,15
2.028	469,34
2.029	431,79
2.030	397,25
2.031	365,47
2.032	336,23
2.033	309,33
2.034	284,59
2.035	261,82
2.036	240,87
2.037	221,60
2.038	203,88
2.039	187,57
2.040	172,56
2.041	158,76
2.042	146,05
2.043	134,37
2.044	123,62
2.045	113,73

(Hectare)	
Year	Agricultural Land
2.045	113,73
2.046	104,63
2.047	96,26
2.048	88,56
2.049	81,48
2.050	74,96
2.051	68,96
2.052	63,44
2.053	58,37
2.054	53,70
2.055	49,40
2.056	45,45
2.057	41,82
2.058	38,47
2.059	35,39
2.060	32,56
2.061	29,96
2.062	27,56
2.063	25,35
2.064	23,33
2.065	21,46
2.066	19,74
2.067	18,16
2.068	16,71
2.069	15,37
2.070	14,14

Source: Data Processing (2024)

The simulation results of the model created, obtained the dominant structure is Negative Feedback (Balancing Loop) with Exponential Decay behavior. The simulation results illustrate that the area of agricultural land per year has decreased by 8%. The area of agricultural land in 2020 amounted to 914.5 hectares and is expected to continue to decline every year to 14.14 hectares in 2070.

Before it is considered to match the real system, the model must be tested. This testing consists of verification and validation stages. When the model is simulated, it must be ensured that the model has no bugs or other programming logic errors and runs without errors. Furthermore, simulation results must be validated with actual systems or data, namely by using average comparisons (Adipraja, 2018). To ensure that the system performs as expected and meets the predetermined requirements, validation of the created model is carried out with the following results:

AME (Average Means Error)

$$AME = \frac{[\bar{S} - \bar{A}]}{\bar{A}} \times 100\% = \frac{[843,3 - 650,6]}{650,6} \times 100\% = 29,6\%$$

\bar{S} = average value of simulation results

\bar{A} = average value of the data

The *Average Means Error* (AME) test results obtained a value of 29.6%, so the model can be categorized as VALID, because the model is made based on a real scale, where the AME test value limit for models made based on a real scale is 30%.

Based on the simulation results of the model created with reference data, it is illustrated in time graphs and time tables how the decline in the area of agricultural land that is converted into built-up land such as residential land. Every year the area of agricultural land has decreased considerably. The reduction in the area of agricultural land causes a reduction in water catchment areas because agricultural land is an area that has a relatively high ability to absorb water. On the one hand, the area of residential land is increasing, one of which comes from the conversion of agricultural land. The more housing that is built, the more areas that are impermeable to water due to closed open land. The decrease in agricultural land due to land conversion has the risk of causing flooding, especially during the rainy season, especially the rainy season with high rainfall intensity.

CONCLUSION

The model of agricultural land decline can be said to be valid, where the dominant structure formed is Negative Feedback (Balancing Loop) with Exponential Decay behavior. This is in accordance with the fact that the area of agricultural land in DKI Jakarta has decreased and converted into residential land. The simulation results illustrate that the area of agricultural land per year has decreased by 8%. The area of agricultural land in 2020 amounted to 914.5 hectares and is estimated to continue to decline every year to 14.14 hectares in 2070. Land conversion from agricultural land to residential land, where the function of agricultural land which has a relatively high ability to absorb water into built-up land (with many buildings) has reduced water absorption capacity, thus causing the risk of flood disasters, especially during the rainy season with high rainfall intensity.

REFERENCES

- Adipraja, P. F. E., & Sulisty, D. A. (2018). *Pemodelan Sistem Dinamik untuk Prediksi Intensitas Hujan Harian di Kota Malang*. Jurnal Ilmiah Teknologi Informasi Asia, Volume 12, No. 2.
- BPBD DKI Jakarta. *Riwayat-Banjir-Jakarta-5-Tahun-Terakhir-Membaik-Atau-Memburuk*. <https://databoks.katadata.co.id/datapublish/2023/02/27/riwayat-banjir-jakarta-5-tahun-terakhir-membaik-atau-memburuk>
- BPS Provinsi DKI Jakarta. *Provinsi DKI Jakarta Dalam Angka*. Badan Pusat Statistika.
- Eldi. (2020). *Analisis Penyebab Banjir Di DKI Jakarta*. Jurnal Inovasi Penelitian, Vol. 1, No. 6.
- Irawan, B. (2005). *Konversi lahan sawah: potensi dampak, pola pemanfaatannya dan faktor determinan*. Forum Penelitian Agro Ekonomi, volume 23, No. 1. Jakarta Satu. (2023). *Perhitungan Lahan Terbangun*. <https://jakartasatu.jakarta.go.id/portal/apps/sites/#/public/pages/publikasi>
- Karima, H. Q., Saputra, M. A., & Romadlon, F. (2022). *Analisis Kapasitas Produksi dan Pemenuhan Permintaan dengan Model Sistem Dinamis pada Industri Semen*. Jurnal Pendidikan dan Software Industri, Vol. 9 No. 1.
- Kunu, J. P. & Leloltery, H. (2010). *Penggunaan Lahan dan Evolusi Penggunaan Lahan di Provinsi DKI Jakarta*. Jurnal Agroforestri, Volume V Nomor 3.

- Prabowo, R., Bambang, A. Z., & Sudarno. (2020). *Pertumbuhan Penduduk Dan Alih Fungsi Lahan Pertanian*. MEDIAGRO: JURNAL ILMU ILMU PERTANIAN, Volume 16, No. 2.
- Prihatin, R. B. (2015). *Alih Fungsi Lahan Di Perkotaan (Studi Kasus Di Kota Bandung Dan Yogyakarta)*. ASPIRASI: Jurnal Masalah-Masalah Sosial, Vol. 6, No. 2.
- Richardson, G. P. (2013). *System Dynamics*. In S. I. Gass & M. C. Fu (Eds.), *Encyclopedia of Operations Research and Management Science (3rd ed., pp. 1519–1521)*. New York: Springer.
- Rosyidie, A. (2013). *Banjir: Fakta dan Dampaknya, Serta Pengaruh dari Perubahan Guna Lahan*. Jurnal Perencanaan Wilayah dan Kota, Vol. 24 No. 3.
- Susilowati, D., M., H. (2016). *Perkembangan Permukiman di DKI Jakarta*. Laboratorium Sosial Ekonomi, Jurusan Geografi, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Indonesia. <https://ppgt.ui.ac.id/wp-content/uploads/62/2016/09/MH-Dewi-Perkembangan-permukiman-di-DKI-Jakarta.pdf>
- Sutomo, S. (2004). *Analisa Data Konversi dan Prediksi Kebutuhan Lahan*. Hal 135-149 Dalam Hasil Round Table II Pengendalian Konversi dan Pengembangan Lahan Pertanian. Direktorat Perluasan Areal, Ditjen Bina Produksi Tanaman Pangan, Departemen Pertanian, Jakarta.