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System Dynamics Modelling for Increasing of Paddy Production with Land Suitability Level to Support Food Security

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ABSTRACT

Increasing the population of the population increased demand for agricultural production, so this has an impact on reducing the use of agricultural land. Identification of land suitability is important so that there is an evaluation of land use to increase land productivity now and in the future. the purpose of this study is to evaluate the suitability of agriculture land to increase the production of paddy harvest on each paddy field with physical constraints. therefore, that it can help the stakeholder of agriculture land to take sustainable strategic decision making. Therefore, dynamic system modeling is applied to analyze the level of land suitability for paddy based on plant requirements, quality and land characteristics. This study can be used as a condition forecast that develops a system dynamics model to learn about future patterns of change in land use management that can support multi-purpose analysis of the objectives for optimal agricultural productivity concerning food security.

Key words : Agriculture, Lan Suitability, Food Security, System Dynamic

1. INTRODUCTION

Agriculture is one of the factors that form the basis of Indonesia's economy as an agrarian country. The population will have an impact on increasing economic needs and competition on land use (agricultural production or non-agricultural production). Population growth is the main cause of the land system and increasing consumption of agricultural production [1]. The efficiency of agricultural land has an impact on the low expansion of agricultural land, this affects the production results and food security in an agrarian country [2]-[3]. Based on the Food and Agriculture Organization of the United Nations (FAO), food security in a country is determined by land resources for food crops in producing agricultural production. FAO predicts that the population will add 70-100% of global demand for food crop production in 2050 [4], It has revealed that an increase in population is expected to lead to an additional 9 billion increase in global demand for agricultural production on currently planted land by 2050 [5].

Increasing the capacity of rice food production can be done by increasing productivity in land cultivation through a consolidation program of land use [6]. Increasing agricultural production can be achieved by formulating strategies to analyze land suitability [7]. Government policies related to the consolidation program on the use of land use can be implemented with the issuance of laws, the existence of economic policies to benefit farmers, and the mechanism of land use that is used for cultivation. The land evaluation analysis functions to identify the suitability of land for certain types of plants to be an important part of increasing agricultural production [8], because of the sustainability in the agricultural land use system [9]. Changes in land use systems affect the functioning of socio-ecological systems, including changes in supporting factors, conditions, trends, and impacts on different land systems. [10]. Land suitability analysis can be used by government policymakers to increase land production through the development of the management of agricultural food crops, by increasing production through assessing the biophysical potential of an area to ensure food security and system sustainability [11].

Analysis of land evaluation to increase agricultural production based on plant growth requirements including land quality, and land characteristics [12]-[13]. The first step that can be taken for agriculture in the future is to define the relationship between soil characteristics and plant growth requirements [14]-[8]. Analysis of the evaluation of land allotment will guide policymakers to find out the optimal resources, because the information provided about the constraints and opportunities in land resources, this information will be used for planning materials and the development of land use functions. Strategic agricultural commodities such as rice types (Oryza sativa), land suitability criteria by the FAO for agricultural commodities Research and Development Center for Agricultural Land Resources in East Java, and the 2016 'Focus Group Discussion' scope of the Ministry of Agriculture and colleges [15].

Data is emerged amidst the most critical and valuable assets for organizations in each area [16]. Paddy land area in Indonesia has decreased by 0.65% based on a comparison of data in 2017 which reached 7.75 million hectares and in 2018 which was only 7.1 million hectares. This affects the production of crops. In 2018 agricultural productivity is 51.58 kW / ha and in 2017 it is 54.66 kW / ha. So, it experienced a decrease in agricultural productivity of 3.08% with an average of 0.42% per year [17], based on these data it can be said that the productivity of rice agricultural products each year is in an unstable condition. Research studies to assess the suitability of agricultural land types of lowland rice need to be done so that the utilization of lowland can be done optimally to increase the amount of agricultural crop production.

Several reviews of land suitability have been discussed previously. Evaluation of the suitability of agricultural land based on multi-criteria decision making (MCDM) including soil attributes, topography, climate, economy, land use, and accessibility using a GIS-based scoring method [3]. This study [3] has limitations invalidating and sensitivity to variations in the multi-criteria parameters used for evaluating certain types of plants. Modeling for identification of land use suitability zones for agricultural sustainability in watersheds using the MCDM Analytical Hierarchy Process (AHP) method, parameters used based on climate change in three scenarios 2030, 2050 and 2080 [18]. The results of this study [18] show that changes in land use suitability can occur due to rapid population growth, urbanization, and industrial development. This study [18] will be accurate when considering more parameter factors that play a role in modeling simulations.

Modelling land-use suitability for agricultural sustainability in [18] evaluation. This study identifies zones of future land use suitability using AHP in watersheds. Dynamic simulation models are used for future land suitability change scenarios, with analysis of climate change parameters with three scenarios in 2030, 2050 and 2080. The results of these studies change in land use suitability may occur due to rapid population growth, urbanization, and industrial development. The study revealed a limitation that would be more accurate if more factors were considered.

Assessment of the suitability of agricultural land in wetland rice types is a complex problem because it involves multi-criteria parameters based on the requirements/characteristics of land use of each class, soil texture, soil depth, land erosion, slope, flooding, and coarse plant fragments [8]. Therefore, it is necessary to make a model of agricultural land suitability system evaluate its suitability for each suitability class [19][20], which states that simulation models are tools that are flexible enough to solve problems that are difficult to solve.

Dynamic modeling and simulation are importance to both, industry and academia [21]. More effective simulation models are used for relatively complex systems for problem-solving from these models. This model helps the understanding of environmental influences, especially variations in elements of land characteristics that affect for predicting the suitability of agricultural land. Using simulations will provide broader insight on the part of management in solving a problem. Therefore, the benefits obtained by using the simulation method are as a system design tool or decision-maker, in this case, the manager creates a system with a certain performance both in the system design stage and operational stage.

This study presents a system dynamics approach to increasing rice production in food security efforts. This study identifies factors that influence rice production increase with agricultural land suitability. This study can be used as a condition forecast that develops a system dynamics model to learn about future patterns of change in management/land use and as a reference for stakeholders in planning strategies which serves to improve food security in a country by increasing rice yields.

2. BACKGROUND

2.1 Agriculture Land Suitability

Suitability of agricultural land in an area based on the main factor, namely land [21]. Assessment to determine the potential of agricultural land on certain types of plants to get the optimal type of land to produce crop productivity [22]-[23]. Types of land use in certain locations for different interests based on the socio-economic community by determining the overall competitive capacity [24]. The area of agricultural land has decreased every year as a result of land conversion, this is due to population growth followed by infrastructure development in urban areas and an increase in the number of industries that have an impact on food security due to decreased crop production on agricultural land [3].

Current land use is based on regional spatial plans based on land cover data, comparing optimal land for agriculture, and identifying locations of areas that are underutilized in land use [25]. Soil degradation as a result of environmental damage caused by human activities, this greatly affects the ability of land operations to produce optimal food production [26]. The main factors of land suitability are highly dependent on environmental conditions, including terrain conditions, temperature, topography, climate, soil moisture, slope, height, soil texture class, organic matter, depth, available water, drainage class, rainfall, and plant-specific features [3]-[23]. Previous research has discussed a lot about computational suitability of agricultural land based on class clusters [27]-[28]. Analysis to evaluate the suitability of land use becomes an environmental problem that involves many factors (multi-criteria parameters), where these factors are bound to one another [27]. The results of the suitability evaluation will be used in the development and planning of a region's land use, the information generated can guide policymakers to find out the obstacles and opportunities for suitable land to obtain optimal resources [8].

Global food security in a country can be done by ensuring that agricultural production yields for food crops always increase every year, this can be done by making plans to analyze the suitability of agricultural land through biophysical potential on certain land types and for certain crops [7]-[29]. Policy decision-makers regarding the allocation of agricultural land need to be carried out a study of human and environmental factors in order to produce efficient policies for food security [30].

2.2 System Dynamics

By using of a computer system, one might be able to understand this particular situation completely. By utilizing the computer system, it will provides efficient work [31]. One of them is systems dynamic approach to understand the complex management problems in computer systems, dynamic system modeling first proposed by Jay w. Forrester in the 1950s [32].

The approach taken by DS is to create a sustainable system modeling strategy [33]. A System Dynamic Modeling uses a loops system that describes a chain of cause and effect circles based on stock variables which are used to characterize the state or behavior of a system to be modeled, and flows which are variables in the modeling that affect the stock on the inflow or overflow of the system.[19].

The form of dynamic system modeling is based on conceptual qualitative data (causal loop diagrams) and numerical quantitative data (stock-and-flow models). Causal loop diagrams can be used for system modeling that requires an understanding of conceptual systems [33]. Stock-and-flow models are used for modeling based on numerical data by visualizing simulation models Literature studies that discuss the use of dynamic systems modeling in agriculture have been carried out, including studies on the impact of population on the availability of land resources that affect the agricultural system [34], agricultural development in the Volta watershed through sustainable management of water resources [35], and modeling dynamic systems for the management of irrigation waterways that can be utilized by policymakers[36]. Development in land use management using dynamic system modeling is very important to do now, able to study patterns of change in agricultural land use by integrating between the parameter factors that play a role and integrating biophysical models. The possibility of land biophysical changes in rice plants aims to increase agricultural production to achieve good food security.

3. MODEL DEVELOPMENT

3.1 Problem Articulation

At this stage, the data collection is carried out to be an important part, because it is an input for the model to be built. Data collection was carried out through information gathering, surveys, interviews and direct discussions from several relevant sources, like as stakeholders from rice food farmers and policymakers in the East Java Provincial Health Office on the challenges in analyzing the suitability of agricultural land evaluation to increase agricultural production.. The data includes data on the area of paddy fields (ha), rice production (tons), rice productivity (tons), harvested area (ha) and other related data. In addition, other data sources used in modeling in analyzing the suitability of agricultural land were obtained from the Indonesian Central Java Province Statistics Agency and the Indonesian Ministry of Agriculture, data centers for information and research related to the application of system dynamics that will be used as material for modeling and for research reference purposes.

3.2 Formulating a Dynamics Hypothesis

At this stage, researchers identify variables or factors that have a significant effect on the output of the model being built. From the data and literature collected related to research and interviews on several stakeholders collected and analyzed to develop the Causal Loop Diagram model.

- Paddy Land Area Sub Model. The land is the most important aspect of sustainable agriculture. Land selection for agricultural production is an important area of research because accurate territorial determination is essential for successful product growth and for sustainable agriculture. Because of the need for land that is built, while the existing land area is very limited, so that land shortages will occur in the future [37]. The impact of agricultural land shortages will affect food production and food security [3]. The paddy land area sub-model consists of irrigated and non-irrigated rice fields. The total of paddy land area is influenced by additional areas in the form of land-use change and land addition. Some variable that affects paddy land area can be seen in table 1.

Table 1: Model Boundary Paddy Land Area

Sub Model	Endogen Variable	Exogen Variable
Paddy Land Area	Irrigation Land Non-Irrigation Land [4] [5] [6]	Additional Land Area [7] [6] [8] [9]

- Land Suitability level Sub Model. Land suitability based on the ability of the land to produce sustainable food crop production [8], to improve agricultural productivity can be formulated as a land suitability analysis strategy [7]. Planning for the use of agricultural land for the future is done by analyzing land suitability, describing or defining the relationship between soil characteristics and plant needs[14] Land suitability evaluation is affected by several variables such as soil biophysical potential, soil characteristics and climate for land suitability [1]-[11]-[62]. Here are variables that affect for land suitability level can be seen in table 2.

Table 2: Model Boundary Land Suitability Level

Sub Model	Endogen Variable	Exogen Variable
Land Suitability Level	Water Availbility [15] [37] [38] [47] [51] [52] [53][61] - Irrigation - Rainfal	Flood Hazard [7] [6] [8] [9] - Elevation - Puddle
	Nutrient Retention [15] [7] [55] [37] - C Organic - PH H2O - KTK Soil - Base Saturation	Land Preparation [11] [15] [56] - Surface Rock - Rock Outcrops
	Rooting Media [15] [23] [57] - Humidity	Errotion Risk [7] [15] [58][60] - slope
	Peat Land [11] [15] [56]	Sulfidic Risk [15] [7] [59]
	Oksigen Availbility [60] [56] [59] - drainase	Temperature [11] [15] [1]
	Nutrient [15] [37] - N Total - P2O5 - K2O	
	Toksisitas [11] [15] [59] - Salisitas	
	Sodisitas [11] [15] [59] - Alkalinitas / ESP	

- Paddy Productivity and Production Sub Model. Several factors that influence rice production are (i) land availability is the most important because it is a medium for growing paddy. (ii) the quality seeds originating from superior varieties of seeds with good management from an early age will be able to face obstacles and competition in the field so that it can produce high production. (iv) the influence of harvest area, with an increase in harvest area the level of rice production, will increase. (v) increasing cropping intensity with increasing the amount of crop on the same land will increase rice production. (vi) the effect of land suitability on rice production is referring to the ability of land for crop production by knowing the biophysical potential of the land. Land use that is not in accordance with the potential and capability of land causes low agricultural production and productivity. One of the factors that can increase paddy productivity by specifically controlling pests is the focal point for sustainable crops. The following are some of the variable efforts that affect paddy production can be seen in table 3.

Table 3: Model Boundary Paddy Productivity

Sub Model	Endogen Variable	Exogen Variable
Paddy Productivity	Quality Seeds [10][11]	Pest Attack [10][11] [12][13]
	Harvest Area [14][15][17]	
	Cropping Intensity [5] [14] [15]	
	Paddy Production [18]	
	Land Suitability [19] [20] [21]	

4. RESULT AND DISCUSSION

In this study, we propose a System Dynamics (SD) approach based on the consideration that this framework offers the ability to model highly nonlinear behavior and to incorporate expert knowledge into the model. In the system dynamics, there is a Causal Loop Diagram which is a flexible tool that is useful in describing the diagramming the feedback structure of the system [19]. In this diagram, the system elements are connected by arrows. Positive links show variable parallel behavior in case of increasing causative variables, effect variables also increase. Negative links indicate a decrease in the causative variable implying a decrease in the affected variable. The total of paddy land area is influenced by the additional area in the form of land conversion and land addition (B). When there is land conversion in the rice area, this will affect the amount of rice land available and will affect the harvest area. If there is a new land opening for paddy, it will increase the availability of paddy land and affect the harvest area. When pests attack will affect reducing rice production.

The land suitability level will affect the area of harvest and harvest area can reduce the level of land suitability because cropping intensity that is done can reduce the nutrition of land in its suitability to plants (B). The land suitability level itself is influenced by several variables including temperature, oxygen availability such as drainage, water availability such as irrigation systems and rainfall, root media such as humidity, peat, Nutrient retention, Nutrient, toxicity, sodicity, sulfidic hazard, erosion hazard such as slope, flood hazards such as elevation and land preparation. This will affect the increase in rice production, in addition to the quality seeds from superior seed varieties with good management from an early age, will be able to face obstacles and competition in the field, so as to produce high production. The following Causal Loop Diagram Land Suitability Level can be seen in Figure 1.

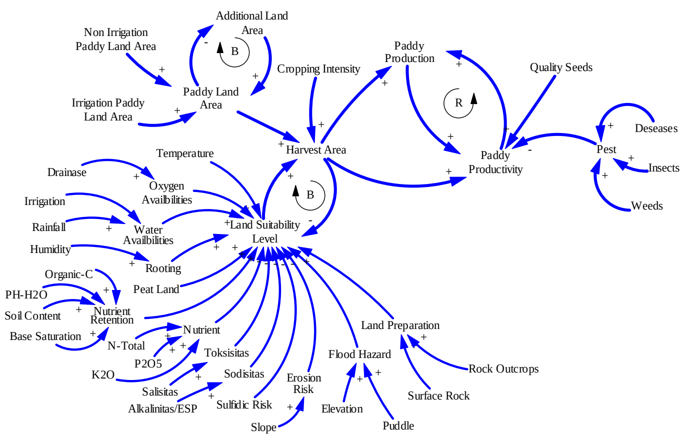

Figure 1: Causal Loop Diagram of Land Suitability Level

5. CONCLUSION

In developing a system dynamics model, understanding the system is needed to build a model that can represent the real system. After that understand the significant variables that affect the system. This study presents an analysis using system dynamics as a way of describing behavior patterns in food security systems. This study was intended to provide valuable information to policy-level decision-makers on the potential suitability of agriculture land. Modeling and identification of suitable areas can inform program planners and investors regarding the optimal location for intensification of agriculture to increase paddy productivity to achieve food security aims. Studies that apply methods such as System Dynamics can be relevant tools for the future forecast.

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