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To cite this article: I Firmansyah *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **399** 012009

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The dynamic model of paddy field conversion control in Citarum watershed

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Abstract. The rate of population growth and the increase in food needs for consumption have made the need for paddy fields higher. On the other hand, the pressure on paddy fields is quite intense so that the conversion of paddy fields is quite challenging to be controlled. Moreover, the concerns about food security and food sovereignty have become critical issues. The high demand for land utilization has caused pressure on paddy fields in the Citarum watershed. The objective of this study is to build a model for maintaining paddy fields in the Citarum watershed. The study was conducted from June to September 2015. The method of this research is a modelling using system dynamics approach by simulating time series data. From the simulation, it can be concluded that the rate of conversion of paddy fields will still be high if there is no specific policy in its protection. This fact can be seen from various scenario conditions, either in existing circumstances, in the optimistic scenario, as well as in a moderate scenario. The strategy that can be done is that paddy fields should be specially protected or owned by the government to minimize the rate of conversion.

Keywords: food security, land-use change, system dynamics

1. Introduction

The need for paddy fields is getting higher. This is along with the rate of population growth and increasing food needs for consumption. However, the pressure on paddy fields is quite intense so that the conversion of paddy fields is quite difficult to be controlled. The threat in the future is that paddy fields will be even higher. Thus, concerns about food security and food sovereignty become essential issues.

Java Island has the most extensive paddy fields, compared to other islands in Indonesia. Paddy field in this island constitutes 39.83% or an area of 3,231,377 ha of all paddy fields in Indonesia, which covers an area of 8,112,103 ha (BPS 2015) [1]. On Java Island, West Java Province has the third-largest paddy field, with an area of 11.40% (or an area of 925,042 ha) after East Java (13.60% or an area of 1,102,863 ha) and Central Java (11.74% or an area of 952,525 ha). Based on the contribution of its production,

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West Java Province produces the largest one, which is 12,083,162 tones (16.95%), followed by East Java with 12,049,342 tones (16.90%) and Central Java with 10,344,816 tones (14,51 %). In West Java Province, the average of paddy field conversion to other land utilization is 4,994.7 ha per year. The conversion of paddy fields occurs a lot in suburban areas, especially along the northern coast of Java. This is caused by the development of cities (Santosa *et al.* 2014) [2].

The highly intensive land use has caused pressure on paddy fields, which become higher in the Citarum watershed. As an illustration, in 4 regencies in Citarum watershed (Bandung Regency, West Bandung Regency, Purwakarta Regency, and Karawang Regency), paddy fields are decreasing from year to year. The area of paddy fields in those four regencies decreased from 161,028.89 ha in 2000 to 145,903.98 ha in 2012. The paddy fields have been generally converted to off-farm land utilization. Meanwhile, the expansion of paddy fields through paddy field construction is minimal due to the inadequate development budget, in addition to land resources that are also more and more limited. According to research [3], actual land utilization changes in the Citarum watershed were dominated by shifts in plantation areas to dryland fields, dryland fields to settlements, and from paddy fields, which turned into built-up land. The conversion of paddy fields in the Citarum watershed is a threat to the stability of food security in the future because the Citarum watershed has been the center of rice production (Widiatmaka *et al.* 2014) [4]. Land use planning was then necessary to be done. This planning should take into account the land the conversion rate in Karawang Regency as calculated in other research (Widiatmaka *et al.* 2013) [5].

The research aimed to build a model that can describe the behavior of the existence of paddy fields, the availability of farm labor, the increase in farmers' income, the economic value of paddy fields, and the condition of food needs.

2. Method

In this research, a system dynamics approach was used by simulating time series data of four regencies in the Citarum watershed from upstream to downstream, including Bandung Regency, West Bandung Regency, Purwakarta Regency, and Karawang Regency. System dynamics analysis began with setting the goals in the system. Time series data retrieval was obtained from reports from relevant agencies, including the Agency for Regional Development, Ministry of Agriculture, and Central Bureau of Statistics (Sterman 2000) [6]. The next step was the determination of system requirements to achieve the objectives. The formulation of the problem was obtained from the results of other studies, brainstorming, and expert discussion. Problems in the system were used as constraints in the system. The next stage was the identification of the system by making input and output diagrams (causal loop diagram). This diagram makes it more comfortable to see the relationship between variables, input and output, and causal relationship. Moreover, the causal loop diagram can also be used to limit the system to be studied (Muhammadi *et al.* 2001) [7]. Technical analysis was done by building a structure in the form of a stock-flow diagram. Validation needs to be done so that the model can be scientifically valid.

System behavior can be seen from the factors/variables in the model, using important quantitative factors from the basic model and essential qualitative factors that have been quantified. Model evaluation was done by comparing the output of the simulation scenario and the expected output at the system identification stage. Next, a sensitivity test from the simulation and the risk of applying a scenario to the policy that will be implemented are carried out.

Model behavior validation is done by comparing the magnitude and nature of errors (Muhammadi *et al.* 2001) [8], namely: (i) Absolute Mean Error (AME), which is a deviation (difference) between the average value of the simulation results against the actual value, and (ii) Absolute Variation Error (AVE), which is a deviation of the simulation variance against the real. The acceptable deviation limit is <10%.

3. Result and Discussion

3.1. Needs Analysis and Problem Formulation

The analysis was done to know the level of interest of each stakeholder towards the existing variables. The primary needs in the sustainability system of paddy fields are the next generation of agricultural labor. The effort to maintain paddy fields will not be optimal if there are not exist future generations in the management and processing of paddy fields. The next need is the clarity of the paddy field layout. It is estimated that it will be hard to maintain paddy fields if the government's policies themselves encourage the use of these paddy fields for the benefit of development outside agriculture. Based on the result of the need analysis, some problems occurred. The need can be analyzed based on the level of demand as follows: (i) agricultural extension; (ii) Government; (iii) waste utilization; (iv) availability of waste product processing industry, and (v) law enforcement

3.2. System Identification

Factors reviewed were regulations and legislation, population growth, inflation, prices, counseling, government assistance, waste utilization, waste product processing industry, and law enforcement. Thus, the desired output is the controlled conversion of paddy fields, the availability of farm labor, the increasing farmer incomes, the economic value of waste benefits, and the adequacy of food needs. The undesirable factors are the rapid settlement growth, the reducing interest to become farmers, the number of farmers in the poor category, the high value of environmental damage, and the rice imports.

The description of the black box on variables affecting the system performance can be stated in a causal loop to see the relationships among variables in the system. From the causal loop in Figure 1, it is known that in the system, the social, economic, and environmental aspects are strongly influenced by land utilization.

The existence of paddy fields is strongly influenced by the pressure of residential land utilization and buildings. The settlement increased due to population growth. On the other hand, the number of farmers decreases due to the lack of paddy fields and the interest in becoming farmers. This will affect production. In optimizing the production, creativity and innovation to use waste can increase the added value of agricultural products. Furthermore, this act can improve the welfare of farmers and minimizing the amount of waste.

3.3. Validation and Model Scenario Simulation

3.3.1. Validation. Performance validation can be seen from the comparison value among real data in the region with the result of simulation data. Result of model validation concerning the number of farmers indicate that they have the AME value of 0.0069%, but for the AVE value, they have value of 0.0031%; for rice production, it has the AME value of 0.0001%, while for the AVE, it has 0.1406%; for environmental services, the AME value is 1.4438%, while the AVE is 3.0627%; for paddy fields based on two years' spatial map, they have an AME value of 0.0490%, while for the AVE value, it has 6.2765%. The simulation results showed the right level of validation because both values of performance validation were below 10%.

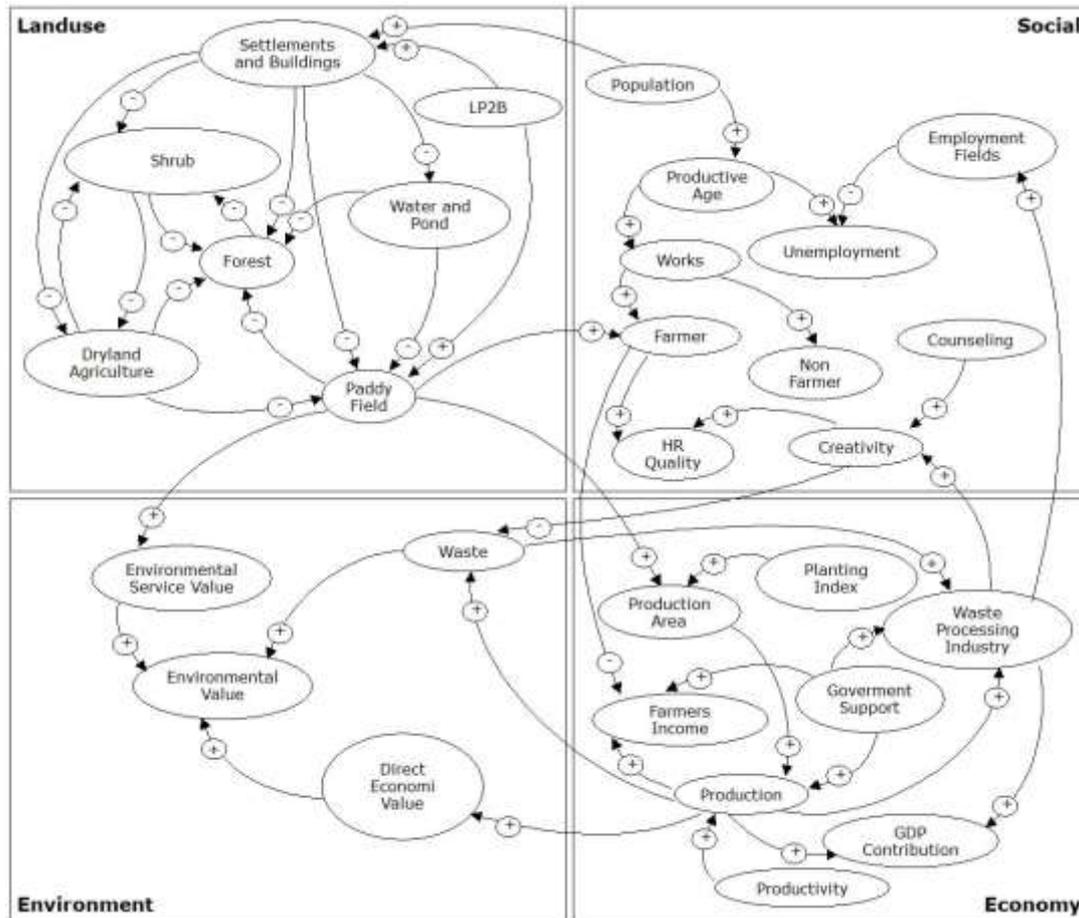


Figure 1. Causal Loops Model.

The presence of paddy fields strongly influences pressure on the use of residential land and buildings. The increase in population affects the growth in residential land. On the other hand, the number of farmers decreases because interest in becoming farmers is getting smaller and there is less paddy field. This phenomenon certainly will affect production. Creativity and innovation in the use of waste are needed to optimize and increase the value of output. Minimizing the amount of waste can also improve the welfare of farmers.

3.3.2. Model Scenario Simulation. The model scenario is simulated from controlled input, which is the main leverage factor in supporting the sustainability of paddy fields. Five influencing factors towards model behavior which are also the needs of the stakeholders in the system are: (i) agricultural counseling, (ii) government assistance, (iii) waste utilization, (iv) provision of industrial processing products, and (v) law enforcement. The scenario simulation model design is carried out on several conditions of the main influencing factors.

The results of the design and the combination of several factors resulted in a comparison of the results of the scenario simulation. This scenario is the dominant condition that will occur in the future, from the results of expert discussions and the ability to apply in the future.

3.3.3. Social Sub-Model. Simulations on the social sub-model are carried out with the initial assumption that the number of farmers is influenced by paddy field area, population growth (from birth, death, immigration, and emigration) which are considered to follow existing growth. The availability of diminishing farm labor needs an intervention to make future generations interested in farming. Changes in livelihoods from current farmers tend to remain the same even though the paddy fields are converted

because farmers generally do not have other skills. Based on the results of the optimistic scenario simulation, the number of farmers themselves increased because the interest of farmers begun to increase with the use of waste that can provide additional income. In the optimistic scenario, the number of farmers reaches 464,202 people, and in moderate conditions, there are 446,665 people, while the existing conditions are only 400,357 people.

3.3.4. Economic Sub Model. Assumptions on the economic sub-model are built using average productivity growth data and the conversion rate of milled dry rice (GKG) into rice, that is 62.74% (BPS and Ministry of Agriculture 2007) [9]. Rice consumption per capita is based on the calculation of rice consumption of 84.63 kg person⁻¹ year⁻¹ (Ministry of Agriculture 2014) [10]. Land values in this model do not take into account land rent directly. The welfare of farmers can be seen from their income. Today, farmers' income from farming tends to decrease. This is due to the downfall of the land area with the number of farmers, which tend to remain the same. The management of paddy fields per farmer is getting narrower. Based on the simulation results, the farmers' income goes down, which will become Rp. 13,955,216 per year in 2030. In conditions of an optimistic policy scenario, revenues can reach Rp. 32,014,957 per year. This value is obtained from the added value of waste utilization as well as the larger amount of production in one year. In moderate conditions, farmers' income is Rp. 15,926,441 per year. The comparison illustration of income values among conditions is shown in Figure 5. Policies can be done to intervene in optimistic scenarios. In this scenario, the average planting index is increased to 2.3 times a year, while counselling on matters relating to waste utilization and conversion of paddy fields is carried out twice a year. In the existing conditions, the projected rice demand from the simulation results in 2030 is 1,202,510 tons; in the optimistic scenario, rice production reaches 1,419,048 tons, while in moderate and existing conditions, it still cannot meet the needs, which is 918,748 tons and 823,496 tons. The simulation results of rice requirements and rice production are presented in Figure 6. Research by Hendrawan and Widianty (2013) [11] showed that the rate of conversion of paddy fields was 0.15% and the rate of new paddy field creation was 0.001%. With the improvement in productivity of paddy fields, in 2031 rice will be available at 17,547,696 kg of grain. With a yield of 60%, there will be 10,528,618 kg of rice available. With a population increase of 1.49% year⁻¹ and consumption of 113 kg capita⁻¹ year⁻¹, the need for rice will be as much as 6,539,647 kg. Thus, until the next 20 years, there will be a surplus of rice. Research on the relationship between population pressure and productivity in Minggir and Moyudan Regencies in 2010 showed a positive relationship (Ariani 2012) [12]. The higher the value of population pressure, the lower the value of productivity, and vice versa, if the value of population pressure is getting lower, the value of productivity is higher.

3.3.5. Environment Sub-Model. Environment sub-models are developed from the benefits of paddy fields, both intangible and tangible, including waste produced that can be utilized. Economic value is directly seen from the product value while environment services are seen from the value of conservation of water resources, erosion control value, landslide control value, recycling value of organic waste, air purification value, recreation value, and preventive value of temperature increase. Scaria *et al.* (2014) [13] stated that ecosystem components in paddy fields have unique and irreplaceable natural functions. Converted paddy fields will cause loss of feed chain and feed network in the ecosystem. According to Nishantha *et al.* (2015) [14], the multifunctional paddy fields include groundwater filling and surface water cleaning. Zhang *et al.* (2015) [15] stated that the effects of human activities and climate change around paddy fields enable changes in agroecosystems, biogeochemical cycles, and food security. In this study, the value of waste was calculated on the value of benefits from straw, husks, bran, and groats. The assumptions used for the assessment of environmental services are based on the multifunctional value of agricultural land in the Citarum watershed (Agus *et al.* 2002) [16]. If 15% of the paddy field is converted to other uses, this will result in the loss of benefit value of US \$ 39,447,130 per year. The economic value of the benefits of waste can be seen in addition to the income of farmers. Waste that is used includes husks, straw, bran, and groats. Based on the simulation results, the value of waste in existing conditions tends to decrease, which is Rp. 841,379 per farmer in 2030. Utilization of waste in

an optimistic scenario can provide added value up to ten times of the existing condition, where the value of the benefits of waste in 2030 is Rp. 8,029,813 per farmer, while in the moderate scenario, the value is only Rp. 1,606,056 per farmer.

3.3.6. Land Sub Model. Model simulation is carried out to see the pressure on paddy fields in the future. The simulation is carried out until 2030 because, generally, the Spatial Official Land Use Planning is up to 2030. Data from paddy fields are taken from the results of spatial analysis in 2009 and 2012 by regressing during such period. Policy interventions show that the conversion rate of paddy fields can be slowed, from the projected area of 107,383 ha of paddy fields in 2030, to become only an area of 124,508 ha in optimal conditions. In moderate conditions, the deceleration covers an area of 119,805 ha. The settlement land area that has increased to an area of 95,764 ha can be controlled to 85,455 ha in optimistic conditions, while in the moderate scenario it is 88,287 ha. For dryland agriculture, from an area of 119,626 ha in 2009, it became 144,022 ha in optimistic conditions, and an area of 145,890 ha in moderate conditions in 2030. Hadinata and Sugiyantoro (2013) [17] stated that the potential conversion of agricultural land occurring in Bandung Regency in 2011-2027 amounting to 9,940 ha had an impact on the loss of rice production of 204,876 tons year⁻¹ in total. In Karawang Regency (Widiatmaka *et al.* 2014) [18], land use that increased very significantly was settlements from 20,588 ha in 2000 to 38,025 ha in 2011. This has implications for reducing the contribution of Karawang Regency to national food security, in which the reduction in production was around 10% in the past 11 years. The simulation results show that settlements and buildings are very significant develop until 2030. This is different from paddy fields that continue to experience a widespread decline, especially in rural areas that are located not far from urban and metropolitan areas, or area which has good accessibility to urban areas. This fact is being in line with the research carried out in the Lamongan Regency (Kurniasari and Ariastita 2014) [19] where the variables that affect the conversion of paddy fields are the ratio of land prices and regional accessibility ratios. Regarding this accessibility, Widiatmaka *et al.* (2013) [20] shows the analysis, based on distance from toll roads and national roads. Up to a distance of 3 km from the road, the largest increase in residential land occurs at the closest distance 1 km from the highway. This functional land shift can occur both voluntarily and forcibly. The functional shift of land that occurs voluntarily is the conversion of functions that occur based on the wishes of farmers to fulfill their needs. In the Puspasari research location (2012) [21] in East Karawang Subdistrict, the voluntarily functional shift of land occurred as many as 43.33%, while as many as 56.67% occurred due to coercion by other parties or the influence of regional conditions.

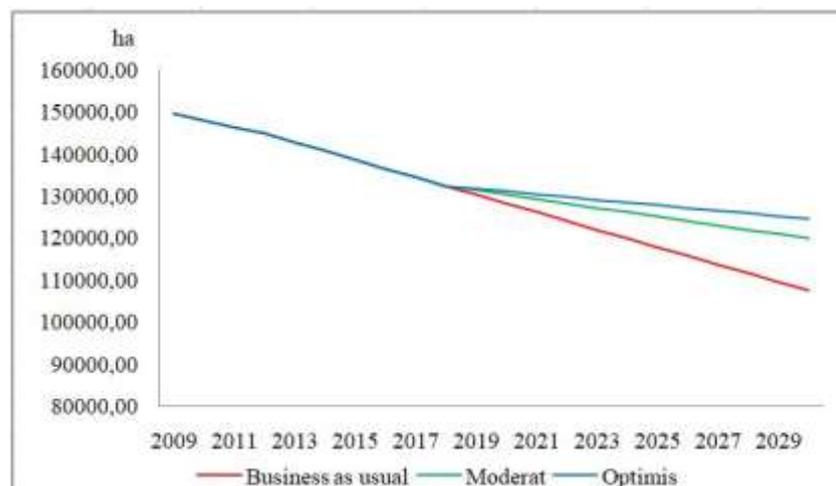


Figure 2. Paddy Fields Simulation.

4. Policy Strategy in the Rice Field Conversion Control Model

Based on the conditions of various scenarios and leverage factor simulations, a description of the behavior conditions of each sub-model can be seen in the future. The sensitivity of the scenario is obtained from the existing variable.

Based on the sensitivity value between variables in the optimistic and moderate scenario, a good ratio of optimistic and moderate values is 2:1. The 2:1 is a comparison to the effectiveness of the scenario, where the optimistic scenario should be twice the moderate scenario. If a comparison of more than 2, this means that an optimistic scenario is more effective than a moderate scenario. This is because the optimistic scenario policy is twice the moderate value so that the assessment will be more sensitive to the optimistic scenario. The calculation results show a ratio of 5.51, illustrating that optimistic scenarios can be an option in implementing policies and will provide good changes to several variable conditions. The conditions that become a focus in consideration of the conversion control model of paddy fields include: (i) in optimistic conditions, three variables exceed the value of 2, namely rice production, environmental economic losses, and farmer income. Moreover, the value is very much higher than the moderate value; (ii) policies for general strategies for controlling the conversion of paddy fields should pay more attention to the ratio values below 1.

From these conditions, consideration in the design of policy strategies should be as follows: (i) in optimistic states, there are area of paddy fields which need to be given a special attention because in any situation the conversion rate is still high, so the paddy fields need to be protected or owned by the government; (ii) paddy fields need special attention because, in any condition, the conversion rate is still high, so the paddy fields need to be protected or owned by the government; (iii) there are generally no many changes in the number of farmers, while the paddy fields themselves are getting smaller. For this reason, optimizing the management of paddy fields needs to be directed at managing a group of farmers as far as possible; (iii) the loss of environment economic value due to the conversion of paddy fields is very high. Therefore, it is necessary to give the direction of the paddy field protection, for example, by using waste from the waste production source; (iv) in triggering the desire of farmers to utilize rice waste, it is necessary to develop a product processing industry that can be optimized by business actors.

5. Conclusion

Simulation results of the paddy field show that conversion of the paddy field will still be high if there is no specific policy to protect the paddy fields. This can be seen from various scenario conditions, in which in the existing condition, the conversion of paddy fields from 2009 to 2030 was 42,189.04 ha, with the best scenario in the optimistic because the conversion was 25,064.57 ha and in moderate conditions, the conversion was 29,768.23 ha. In this condition, paddy fields should be specially protected or owned by the government to minimize conversion rates.

The utilization of waste into derivative products will provide additional income for farmers. Increased income is expected to minimize the desire of farmers to sell their paddy fields. Extension of increased production and benefits of waste is very crucial. It should be given an overview to farmers about the prospect of managing paddy fields in the future, in the perspective of increasing the interest of future generations to manage paddy fields.

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