System dynamics modeling of agricultural land conversion in Aceh Besar District

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Abstract. The purpose of this study is to design a sub-model as a policy strategy alternative in controlling agricultural land conversion. Method applied in this study is system dynamics, a modelling approach based on systems thinking which uses the perspectives of information feedback and delay to understand the complex behavior of physical, biological, and social systems in agricultural land conversion. The study utilized Vensim DSS software to perform the model formulation and the simulation. The computation obtained six main sub-models applicable in the design process of control models for the transfer of functions of agricultural land in Aceh Besar District. The sub-models concern population, settlements, industry, rice fields, forests and fields, and rice stock.

1. Introduction
The relatively fast population growth accompanied by increased development activities in various sectors has become one of the driving factors for the rising demand for land, especially for settlements. As such, land conversion emerges to meet the demand, and this has been going on for a long time following the surge in population. Land conversion may become a big issue when it results in environmental damage and touches the issue of human survival due to the development to support a new human civilization. Recently, land conversion has been increasing from year to year that it becomes a particular concern, as there is no standard regulation from the government that supports landowners to defend their land better.

Land conversion refers to a change in the function of a part or all of the land area from its original function (as planned) to other functions that have negative impacts (or problems) on the environment and the potential of the land itself [1]. One type of land conversion most commonly carried out is the shift of agricultural land to non-agricultural land. Here, the agricultural land under study is rice fields. Various effects of land-use changes involve micro, meso, and macro aspects. At the micro level, the conversion of rice fields connects directly with farmers who own the land or indirectly by other parties who have previously conducted rice field sale and purchase transaction. At the meso level, land conversion occurs because of the dynamics of urban, demographic, and economic growth, as well as the policies at the regional level related to the conversion of rice fields. At the macro level, land conversion happens due to the policy issue, such as regulations issued by the central government [2].
Aceh Besar (Greater Aceh) District, one of the rice-producing areas in the province of Aceh and one of the national rice contributors in Indonesia, has a strong interest in maintaining the area of rice fields. This is because rice fields is a scarce resource; their numbers are relatively constant while the need for rice fields, as a source of rice production, continues to increase. Over the past seven years, from 2010 to 2016, there has been a change in the function of the rice fields in Aceh Besar District covering an area of 1823,285 hectares, with an average reduction of 260.46 hectares/year or 0.81 percent/year. In 2010, the total area of rice fields was 44,761 hectares, whereas in 2016, the area declined to 31,998 hectares [3].

Nevertheless, agricultural land conversion is unavoidable due to the transformation process in terms of allocating land resources to other uses. However, the rate of land conversion is still controllable through policy-making, such as creating a recommendation not to sell certain agricultural land by attaching cultural values to the land, apart from being crop-producing land. Further, such policies should mention compensation for farmers who own the land so that they can keep their welfare and obtain more efficient economic values when their land is used for non-agricultural purposes [4].

The relevant authorities have formulated several policies related to controlling the conversion of agricultural land functions, especially the rice fields. At the national level, the policies regulating the control over the functions of agricultural land include Law Number 5 of 1960 concerning Basic Agrarian Regulations, Law Number 7 of 1996 concerning Food, Law Number 26 of 2007 concerning Spatial Planning, and Law Number 41 of 2009 concerning Protection of Sustainable Food Agricultural Land. These regulations are also followed by implementation instructions and technical instructions such as Regulation of the Minister of Agriculture Number 41/Permetan/OT.140/9/2009 concerning Technical Criteria for Agricultural Allocated Areas.

In practice, the policy design should take into account a number of aspects. System dynamics is a systems thinking method that can see various aspects integrally and can explain structurally the land conversion phenomenon that occurs. The structural explanation is generative and has a high ability to redesign the system structure, which produces the resulting behavior as desired. The policy on controlling land conversion using the system dynamics model should provide some effectiveness in preventing improper conversion of agricultural land functions.

2. Research methods
This study uses a system dynamics approach, which is a system thinking method that can connect various aspects integrally and can explain a phenomenon structurally. The phenomenon in this case is the conversion of agricultural land into other functions. The main problem that arises because of this land conversion is that Aceh Besar District, a rice surplus area, will turn into a rice deficit area if the conversion rate of the rice fields is not controlled. The structure of the land use conversion from rice fields to other uses consists of the physical structure of land and the decision-making structure, which is the decision to convert the land.

Types of data displayed in this study are numerical data, written data (literature), and mental model data [5]. The numerical data used are parameters contained in the physical structure such as land area, land productivity, rice production, and others. Written data come from relevant literature including books and scientific articles, as well as policies related to the conversion of agricultural land functions. The mental model is a rule that underlies decision-making by the actors in carrying out the conversion of the rice fields [6]. The mental model is derived from interviews with specified respondents.

The mental model, written (literature), and numerical data are processed into a model design by using the system dynamics method (Figure 1). The method produces a cause and effect diagram, a flow chart, or a sub-model diagram (level and rate) of the system studied, and the stages of model development of a system, testing model assumptions, as well as simulation stage [7].
3. Results and discussion

3.1. Model structure

The behavior of a system or a model is highly dependent on its structure. The structure is components that exist and have interrelationships between these components. Parameters attached to each component also play an important role. In a simple sense, building a model structure is making a causal loop diagram that can reflect the real system. The behavior of each variable observed is then developed and studied. Later, the studied behavior of each variable is formulated so that it can be simulated to determine the behavior of variables under review with changes in time.

3.2. Diagram of the subsystem

The subsystem diagram consists of a causal loop diagram of several subsystems that interact with each other to form the whole system. Each subsystem, apart from interacting with other subsystems, also has internal interactions among the structural components of the subsystem concerned. The subsystem diagram itself shows the system boundary, which describes the variables that are in the system or outside the system. In this case, some variables are outside the limit that is not included (ignored) as presumed that they do not affect the system, whereas some affect the system exogenously.

In this study, the subsystem diagram consists of six sub-models, namely: sub-model of population, sub-model of settlements and settlement land, sub-model of industry and industrial land, sub-model of rice fields, sub-model of forests and fields, and sub-model of rice stock. Land conversion occurs from fields to rice fields and settlements and from fields to settlements and industry. The fields and rice fields are a production factor for rice production while the population is a source of labor for rice fields, fields, and industry. Settlements and settlement land are space for activities for residents, whereas rice is food for residents. For more details, the subsystem diagram is in Figure 2.

Figure 1. Model design of system dynamics.
3.3. Sub-model of population

In this model, population is a level (accumulation) that can increase and decrease due to certain processes. Technically, a flow that causes increasing and decreasing of a level is flow and rate. In this model, processes that cause population to rise are birth and in-migration, and those making population decline are death and out-migration. The sub-model of population is in Figure 3.
The sub-model behavior of population in Aceh Besar District is in the following Figure 4.

![Population Graph](image)

**Figure 4.** Sub-model behavior of population.

Figure 4 shows the total population in Aceh Besar District is 400,913 people with a fertility rate of 0.0238 per year. With an estimated mortality rate of 0.0015 per year, there will be an increase in the population in Aceh Besar District each year.

3.4. **Sub-model of settlements**

Settlement land is an area that continues to rise because the number of residential units always increases. This is the result of the growth in population and in need of residence. To fulfill the need, one feasible act is to shift rice fields and fields into settlement land. The conversion of rice fields and fields to settlement land happens because the land rents of rice fields and fields are lower than that of settlements [8]. The sub-model of settlements and settlement land and its sub-model behavior are in Figures 5 and 6.

![Diagram of the sub-model of settlements](image)

**Figure 5.** Diagram of the sub-model of settlements.
3.5. Sub-model of industry

Industrial land is the land in which the area is expanding because the number of industrial units keeps growing. To meet this need, one feasible attempt is to convert rice fields into industrial land. The conversion of rice fields to industrial land comes about because the land rent of rice fields is low-priced compared to that of industrial land. The sub-model of industry and industrial land and the sub-model behavior of industry are in Figures 7 and 8.

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**Figure 6.** Sub-model behavior of settlements.

**Figure 7.** Diagram of the sub-model of industry.

**Figure 8.** Sub-model behavior of industry.
3.6. **Sub-model of rice fields**

Rice fields are one of the production factors of rice production, whose existence is declining due to conversion to settlements and industrial land. When the need for settlements and industrial development arises, rice fields are very likely to be converted according to the development of these needs. The increase in rice fields is related to the increase in fields. However, the rise in fields is smaller when compared to that in rice fields, whose use turns to residential and industrial land. As a consequence, the existence of rice fields steadily declines. The reduction in rice fields will have a major effect on rice production. The sub-model of rice fields and the sub-model behavior of rice fields are in Figures 9 and 10.

![Diagram of the sub-model of rice fields.](Image)

**Figure 9.** Diagram of the sub-model of rice fields.

![Sub-model behavior of rice fields.](Image)

**Figure 10.** Sub-model behavior of rice fields.
3.7. Sub-model of forests and fields
In this model, the forest area drops due to the conversion of forestland into fields. Likewise, fields keep decreasing due to the change in the function of land to rice fields and settlements. Yet, the conversion of forestland into fields is smaller than that of rice fields and settlements; and thus, the field area is reducing. Land conversion from forests to fields takes place because the forestland rent is lower than the field rent. Fields are also one of the production factors of rice production despite its small area and low productivity. The sub-model of forests and fields and its sub-model behavior are in Figures 11 and 12, respectively.

![Diagram of the sub-model of forests and fields.](image)

**Figure 11.** Diagram of the sub-model of forests and fields.

![Field: sensitivity](image)

**Figure 12.** Sub-model behavior of forests and fields.

3.8. Sub-model of rice stock
Rice stock refers to the production of lowland rice and upland rice, and as the area of rice fields and fields keeps reducing, rice stock shows a decline. The increase in rice stock relates to lowland rice production and upland rice production, while the decrease in rice stock connects with consumption and a drop in rice due to rot. All rice fields can be planted with rice with a cropping intensity of 1.75,
whereas not all fields can be planted with rice having a cropping intensity of 1. Based on the data obtained, the largest area of field rice planting is 30.65 percent of the existing fields. The sub-model of rice stock and its sub-model behavior can be seen in Figures 13 and 14.

![Diagram of the sub-model of rice stock.](image)

**Figure 13.** Diagram of the sub-model of rice stock.

![Sub-model behavior of rice stock.](image)

**Figure 14.** Sub-model behavior of rice stock.

### 4. Conclusion

Land use planning in Aceh Besar District has been oriented towards meeting the needs of the population including settlements, school buildings, shops/industry, and government offices. Yet, it is not oriented to meet the needs of the population for food, especially rice. If the construction of settlements and shops/industry only follow the predetermined plan without any effort to change, the area of rice fields in Aceh Besar District will decline considerably and rice stock will eventually lessen.

This study produces a policy model in controlling the conversion of agricultural land functions that is applicable in Aceh Besar District. The authors hope that the implementation of such a model can become a useful effort to create national food security. The findings of the engineering model show that six sub-models are very influential on the conversion of agricultural land in Aceh Besar District, they are: sub-model of population, sub-model of settlements, sub-model of industry, sub-model of rice fields, sub-model of forests and fields, and sub-model of rice stock.
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