Improved Dynamic Model of The North Sulawesi Province Food Security System

Robert Molenaar[11], *Lady* Lengkey[1], and *Erny* Nurali[1]

[1]Sam Ratulangi University, Manado, North Sulawesi, Indonesia

Abstract. Dynamics of the North Sulawesi food security system is studied in this research, where various factors related to food consumption and production are identified. Since rice is accepted as the main food commodity for the Indonesian population, the source of 50% of the average Indonesian's daily calorie intake, therefore, the behavior of the food security system studied is related to the condition of the availability of rice to meet the consumption of the population in North Sulawesi Province. System dynamics is used as the methodology with the objectives to identify the various factors that influence rice consumption and production in North Sulawesi Province, and develop model accordingly to simulate the dinamics of rice availability in response to changes in rice consumption and production factors. The simulation carried out for a period of 25 years, namely from 2022 to 2047, resulted that at the rice production side, the current productivity cannot meet the need of North Sulawesi Province population consumption, causing importing rice must be carried out to fill up the gap. By improving the production and consumption aspects, such as using high yield variety of rice and introducing food diversification, the availability of rice become sufficient to meet the consumption needs of the people of North Sulawesi. This study then recommends the improvement for sustainable development of food security system in North Sulawesi Province.
Keywords: Food security, System dynamics, Sustainability.

1 Introduction

The availability of food products and the sustainability of their production from time to time is a very strategic part in efforts to achieve food security in a region, such as North Sulawesi. There are many factors involved in efforts to build sustainable food security, including the level of utilization of agricultural technology and empowering the availability of local food products.

Agricultural technology plays an important role in increasing productivity both quantitatively and qualitatively related to production (on farm) and securing agricultural production (off farm) [1], while utilizing the availability of local food products will be able to reduce dependence on the main food products of the Indonesian people, namely rice [2].

[1] Corresponding author: robertmolenaar@unsrat.ac.id

In addition, the issue of food security also involves various related parties so that a proper perseption by all stakeholders of the dynamics of rice supply is a necessary condition for the successful realization of food security in a region such as North Sulawesi. Thus, this research aims to identify the various factors that influence rice consumption and production in North Sulawesi Province and develop model to use in simulating the dynamics of production and consumption of rice in response to changes of the related factors.

System dynamics is a method that is very helpful in trying to understand the dynamics of a problem that involves many components with various forms of interrelationships between components one to another [3]. With system dynamics, the issue of food security is seen as a system with many components that together determine the behavior of the food security system itself from time to time. With the help of a system dynamics, related stakeholders can clearly aware of their position and role in efforts to produce an appropriate and sustainable resilience system. System dynamic s allows a series of computer simulations to be carried out on the model that is structured as a representation of the actual condition of the food security system. The use of computers makes it possible to perform repeated simulations with various system scenarios to find the structural composition of the food security system that gives the most expected results and generates signals of the important system components that give magnitude effects on the dinamics of the system [4].

This research was conducted with North Sulawesi as the study location where this area has local food sources in the form of rice and non-rice, but this area has experienced various changes from time to time as a consequence of the development program related with industries and residential areas. In this study the availability of rice, in the midst of existing changes, to meet the consumption needs of the people of North Sulawesi is used as an indicator of food security. This condition is based on rice is the main source of food for the people of Indonesia, including the people in North Sulawesi. Thus, in this study, the dynamics of rice availability for the people of North Sulawesi from time to time, due to the influence of changes that occur in factors comprising the food security system, is used as a measurement of the condition of food security in the North Sulawesi.

2 Methodology

This study uses system dynamics as a method in which food security of North Sulawesi Province is seen as a system with many components and the relationships that exist between the components making up the system [5].

In system dynamic, the food security system of North Sulawesi Province is represented in a dynamic model where the structure of the dynamic model is formed to represent the real system so that the mathematical relationships that exist between the components of the system model also represent the relationships between the components of the realworld system [6]. The initial stage is to compile a causal loop diagram that describes the main variables and their relationships. The diagram referred to is then transformed into a stock and flow diagram in which each variable is represented by an appropriate mathematical equation so that changes that occur in each variable can be simulated to see the effect on system behavior.

The dynamic model of the food security system of North Sulawesi Province was developed in stages by initially compiling sub-system model of the population growth of North Sulawesi Province from time to time. The model is based on the real population data from the last ten years. Through computer simulations of the dynamics of population growth, it is possible to examine the behavior of the population sub-system from the simulations results to see its consistency with real world conditions [7]. A model of North

Sulawesi's population growth is needed to predict the behavior of the population's consumption needs from time to time. The next development is the dynamic sub-system model of rice production. The model is based on the real ricefields available, current paddy productivity and input technology. Through computer simulation of the model, it is possible to study the dynamics of rice production from time to time. The rice availability sub-system is the third model that was developed based on paddy productivity, input technology, and rice consumption. Through computer simulation of the model an overview of the dynamics of rice availability is obtained from time to time.

The above processes were carried out using dynamic system software Vensim PLE (Ventana Systems, inc.) that allows structural and behavioral tests of each sub-system to be performed before and after being combined into one food security system model of the North Sulawesi Province. Computer simulation was carried out which allows several scenarios to be carried out to understand existing problems and the best solution to produce a sustainable North Sulawesi Province food security system.

Mean Absolute Percentage Error (MAPE) method [8] was used in validating the model, with a formula as in equation (1).

$$MAPE\ (\%) = \left(\frac{100}{n}\right) \sum_{t=1}^{n} |Dt - Ft|/Dt \quad (1)$$

with Dt as the actual value of year t while Ft is the estimated value of year t with n as number of data used. MAPE value less than 10% indicates that the model estimation is said to be accurate, while a MAPE value greater than 10% indicates that the model estimation is less accurate.

3 Results and discussions

3.1 North Sulawesi Province

North Sulawesi Province is located at 0°15' - 5°34'N and between 123°07' - 127°10'E., with the boundaries of the Sulawesi Sea, the Pacific Ocean and the Philippines (North), the Maluku Sea (East), Maluku Bay (South) and Gorontalo Province (West). It has an area of 15,500.28 km2, with a population in 2020 of 2,621,923 people or the equivalent of a population density of 183 people/km2 (Anonymous, 2022). The contribution of the agricultural sector to total GRDP is 21% with 40.72% of agricultural lands are food crops, 12.95% estate crops, and 17.30% for other forms of agricultural activities, including inland fisheries. With a rice field area of 46,803 hectares, where in 2021 the rice harvest area reached 59,514.72 hectares with a production of 228,995.95 tons of dry milled grain or equivalent to 128.02 thousand tons of rice [9]. At present the area has mixed irrigation system, where some rice fields have the potential of planting index greater than 1. However, the condition of rice fields in North Sulawesi from 2008 – 2021 shows the potential for a decrease mainly due to land conversion to non-rice fields or even non-agricultural usage.

The average production of lowland rice per hectare in North Sulawesi is 4 tons of dry milled grain. With a conversion rate of of 56% from dry milled grain to rice, it produces 2.6 tonnes of rice per hectare. The region has a wet tropical climate with rainfall ranging from 2000-3000 mm, with number of rainy days per year is at the average of 90-130 days.

3.2 Dynamic model of North Sulawesi rice supply system

The dynamic model for rice availability in North Sulawesi Province was developed from three sub-systems namely, the population growth sub-system, the rice grain production sub-system, and the rice consumption and availability sub-system [10].

The combination of the three sub-systems will produce a food security system for North Sulawesi Province as shown in Figure 1.

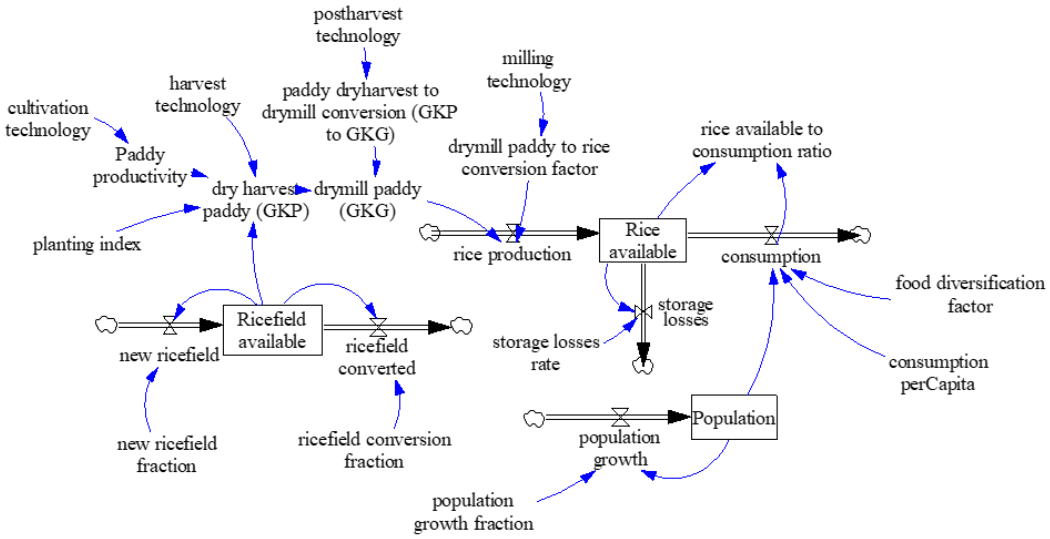

Fig. 1. Dynamic system model for rice availability in North Sulawesi Province

The system in question is actually the result of developing a model that was produced before [10], especially through the addition of components to the rice production subsystem and rice availability subsystem. Modifications were made by completing the existing model through the addition of cultivation technology variables and harvest and postharvest technology.

The three basic sub-systems that make up the food security system for North Sulawesi Province can then become the basis for developing a more complex system model by adding components such as various variables related to imports and exports of rice when there are surplus and deficit conditions in the availability of rice in North Sulawesi Province. Table 1 presents the parameters used in the model.

Table 1. Initial parameters of North Sulawesi food security system model

No	Parameter	Values	Unit
1	Area	15.500, 28	Km^2
2	Population in 2022	2.805.290	People
3	Population growth fraction	1.5	%/year
4	Rice consumption perCapita	0.114	ton/people/year
5	Ricefields area in 2022	46803	hectare
6	Ricefield conversion fraction	-	%/year
7	New ricefields fraction	-	%/year
8	Paddy productivity	5	ton/hectare

9	Planting index	1.5	Times/year
10	Harvest technology	90	%
11	Postharvest technology	83	%
12	Milling technology	56	%
13	Food diversification factor	-	%
14	Cultivation technology	1	-
15	Harvest technology level	90	%
16	Storage loss	2	%

3.3 Population and consumption dynamic of North Sulawesi

The simulation results of the North Sulawesi's population growth model is shown in Figure 2.

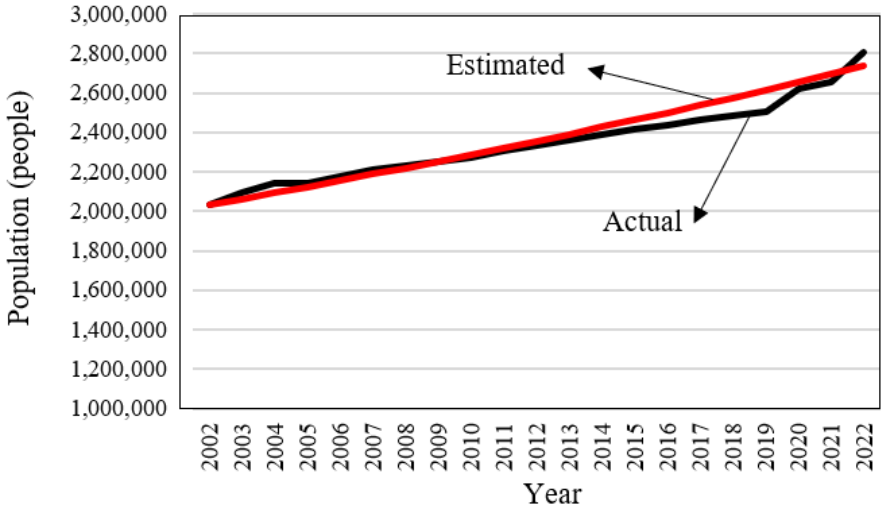

Fig. 2. Population based on estimation and actual data

where the estimated and the actual values of the North Sulawesi Province over time resulted MAPE value of 1.61% which means that the model has a high level of accuracy in predicting the population growth. Furthermore, the model is used to estimate the growth of North Sulawesi population for the period of 25 simulation years as shown in Figure 3 where the population growths from 2.805.290 in 2022 towards 4,070,320 people in year 2047.

In line with the growth in the population of North Sulawesi, Figure 3 also shows an increase in the rice consumption by the people of North Sulawesi which is calculated based on the current parameters in Table 1 for the period of 15 years, which shows an increase in the need for rice consumption from the initial amount of 319,803 tons of rice per year in 2022 to 464,017 tons of rice per year in 2047. This condition is in accordance with the estimated real condition of an increase in the population which is positively correlated with an increase in consumption.

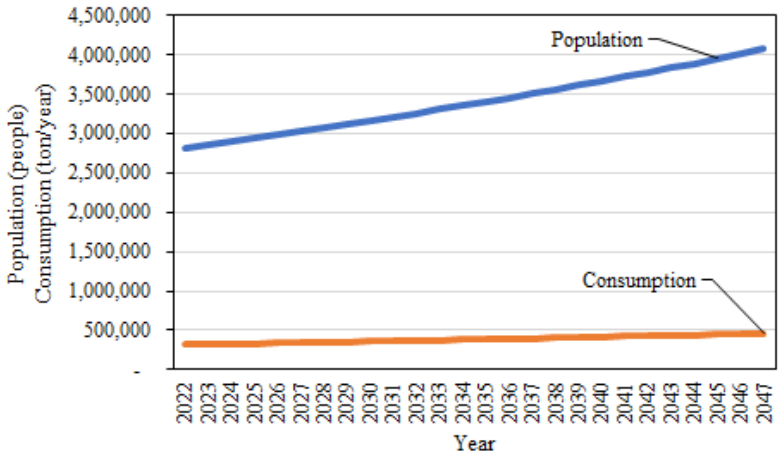

Fig. 3. Estimated population and rice consumption growth from 2022 to 2047

Figure 4 shows the effect of food diversification to rice consumption of population of North Sulawesi from year 2022 to 2047.

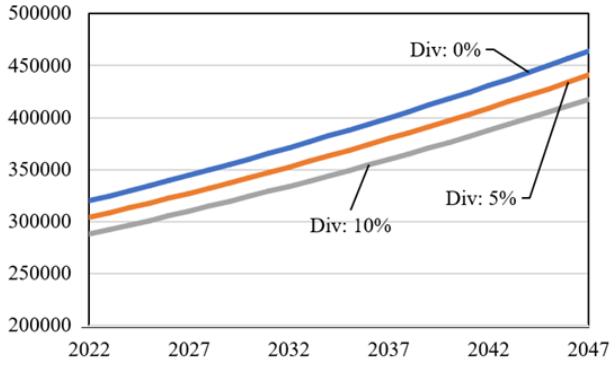

Fig. 4. Effect of food diversification on rice consumption

Efforts to meet the demand for rice in North Sulawesi Province can also involve developing food diversification by empowering the potential of locally available food sources. These efforts will have an impact on reducing the level of dependence on rice. Figure 4 shows the possible decrease in population rice consumption when consumption needs are met through food diversification where 5% to 10% of rice needs is substituted with other kinds of source of food such as cassava, maize, or sweet potato that are available in the area. Other similar studied by [11] also found identical result by lowering the rice consumption per capita.

3.4 Dynamic of locally rice supply in North Sulawesi

In terms of production, at present conditions with average productivity level of 4.5 tonnes of harvested dry grain per hectare, followed by a once a year planting index, and by relying on the existing level of harvesting, post-harvest and milling technology, the ability of North Sulawesi to provide rice locally for the consumption of the population is only sufficient earlier than 2024 before further consumption fulfillment need to be met through imports (Figure 5). Meanwhile, with several improvement efforts in the form of increasing the intensity of planting to 2 times a year, using the available rice variety having an average yield of 6 tons per hectare, coupled with increased application of harvesting,

post-harvesting and milling technologies which can reduce yield losses [12], [1], followed by food diversification efforts that are able to reduce the need for rice consumption by up to 5%, the ability to supply rice locally for the population of North Sulawesi will increase but will still be limited until 2037 before further supply of rice must be met through import (Figure 5).

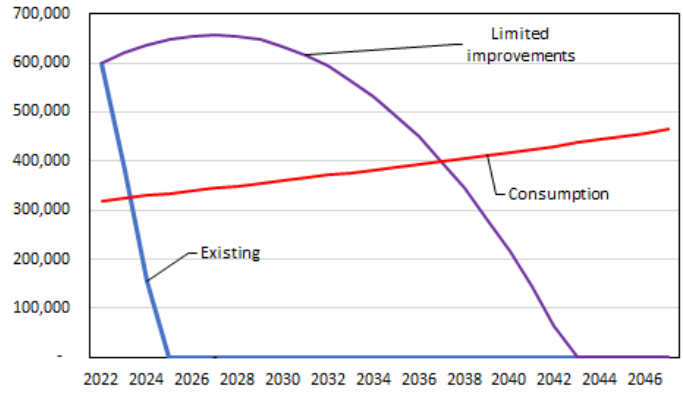

Fig. 5. Existing and limited improvements of rice supply in North Sulawesi

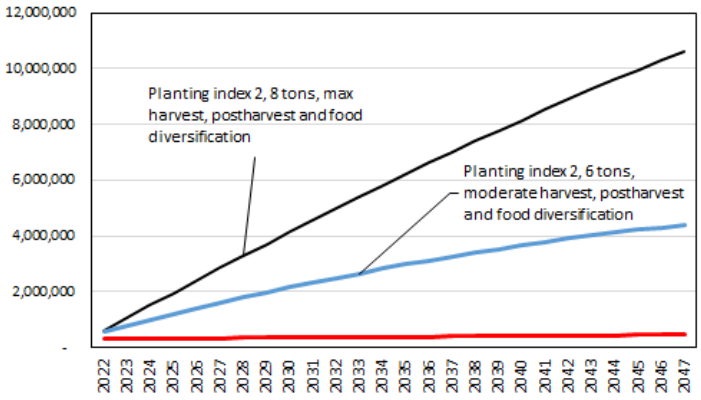

Fig. 6. Optimum and maximum improvements of rice production technology on rice supply in North Sulawesi

Figure 6 shows the possibilities of meeting the need of locally rice supply for the North Sulawesi population from year 2022 to year 2047 and beyond. With those improvements North Sulawesi will be able to sustain its local rice supply far above the real consumption level, meaning that North Sulawesi can export its rice product to other part of the country or even abroad. Similar study by [13] also concluded that introduction of high yield Paddy variety and improving harvest and postharvest technology can be a good scenario in improving ability of a region in producing enough rice for the population.

4 Conclusion

Improved dynamic model of the North Sulawesi Province food security system has been resulted in this research having three sub-systems that at first were tested separately and later united into a. single system. System dynamics proved as a method that is very helpful in producing a comprehensive understanding on the behaviour of food security system of North Sulawesi Province. This reseach found that with some structural improvements in the

system, North Sulawesi will be able to increase its capability to locally produce rice to supply the need of local population and beyond. The improvement will be in the area of cultivation technology as well as harvest and postharvest technology. The implementation of food diversification is also considered important in decreasing dependency on rice. What is also important is how to avoid a land conversion from paddy to non paddy or even to non agricultural usage.

References

[1] R. Molenaar, "Panen dan pascapanen Padi, Jagung dan Kedelai," Jurnal EUGENIA, vol. 26, no. 1, 2020.
[2] H. P. S. Rachman and M. Ariani, "Penganekaragaman Konsumsi Pangan di Indonesia: Permasalahan dan Implikasi untuk Kebijakan dan Program," Jurnal Analisis Kebijakan Pertanian, vol. 6, no. 2, 2008.
[3] R. Molenaar and E. Nurali, "Study of Food Security in South Minahasa Regency Using System Dynamics," Proceeding of The International Conference on Natural Sciences, Mathematics, Applications, Research, and Technology, vol. 1, 2021.
[4] J. D. Sterman, "Business Dynamics: System Thinking and Modelling for a Complex World," Mc.Graw Hills, Boston, USA, 2000.
[5] J. W. Forrester, "Principle of Systems," Cambridge, MIT Press, 1968.
[6] S. Petiwi, "A system dynamic model for policy analysis in the food security system in Indonesia," Proceedings of the 4th International Symposium-Workshop in Southeast Asia, Thailand. Journal of Agriculture Development in the Tropics and Subtropics. Kassel University Press, 2003.
[7] M. P. Bach and V. Peric, "Developing system dynamics models with 'step-by-step' approach," Journal of Information and Organizational Sciences, vol. 31, no. 1, 2007.
[8] W. Budiawan, A. Arvianto, and M. N. Hadi, "Analisis Kebijakan Persediaan Beras Provinsi Jawa Tengah Menggunakan Pendekatan Sistem Dinamik," Seminar dan Konferensi Nasional IDEC 2017 ISSN: 2579-6429 Surakarta, Mei 2017.
[9] "Propinsi Sulawesi Utara dalam Angka 2022," Badan Pusat Statistik Sulawesi Utara, 2022.
[10] R. Molenaar and E. Nurali, "Study of Food Security in South Minahasa Regency Using System Dynamics," Proceeding of The International Conference on Natural Sciences, Mathematics, Applications, Research, and Technology, vol. 1, 2021.
[11] A. Dwi Wibowo, "Dinamika ketersediaan beras: Studi Kasus Di Kalimantan Selatan," Ziraa'ah, vol. 41, no. 2, 2016.
[12] E. Hartulistiyoso, "The role of postharvest handling system in the Indonesian food security program," Proceedings of the 4th International Symposium-Workshop in Southeast Asia, Thailand. Journal of Agriculture Development in the Tropics and Subtropics. Kassel University Press, 2003.
[13] A. P. Somantri and R. Thahir, "Buletin Teknologi Pascapanen Pertanian," vol. 3, 2007.