Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 10, No. 02, February, 2024

Rice Self-Sufficiency and Optimization of Irrigation by Using System Dynamic

Asmelita [1*], Lily M. Limantara [2*], M. Bisri [2], Widandi Soetopo [2], Indra Farni [1]

[1] *Doctoral Program in Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia.*

[2] *Department of Water Resources Engineering, Faculty of Engineering, University of Brawijaya, Malang, Indonesia.*

Received 07 October 2023; Revised 21 December 2023; Accepted 04 January 2024; Published 01 February 2024

Abstract

This research intends to optimize the results of irrigation canals with the conversion of function to fisheries without reducing rice self-sufficiency regionally. However, irrigation is an infrastructure asset that needs to be used optimally. It is due to the water; water sources and irrigation infrastructure can provide more benefits to rice fields, which are to function as fisheries in the study location (West Sumatra Province). The aim of this research is to propose the optimal combinations of irrigated land planted with rice and those in the form of fisheries. The methodology uses System Dynamics due to the official BPS data. There are many tools that are used in this system dynamics approach, such as causal diagrams, archetype systems, diagrams of stock and flow, and the behavior of over-time graphs. The DSS generator for simulating the program in this study uses Stella, which is a new paradigm in the water resources system approach. The result shows that the potential increase in income that could be obtained by converting the rice fields to tilapia fisheries is about 126 million Rupiah per year per hectare. West Sumatra Province, as a national rice granary, has many districts that are more self-sufficient in rice, so it can be considered to utilize irrigation to become the irrigation for fisheries. The potential of rice fields that can be converted into fisheries while maintaining self-sufficiency in rice at the district/city level of West Sumatra Province is more than 61 thousand hectares, and it generates an increase in income of about 7.7 trillion per year.

Keywords: Water Resources System; Irrigation Optimization; Fisheries; Rice Self-Sufficiency; Aquaculture; System Dynamics.

1. Introduction

Food self-sufficiency is very important for the resilience of a nation. Post-reform Indonesia remains consistent with policies to maintain self-sufficiency in food [1]. Food self-sufficiency is even more important after the COVID-19 pandemic [2]. With the staple food of rice, self-sufficiency in rice is a strategic thing [3] that must be achieved nationally and regionally. On the other hand, the use of irrigation water to supply water other than rice crops, for example, for fisheries, can provide much higher financial returns compared to growing rice. The intended use of irrigation water is, of course, one that does not change the existing irrigation infrastructure so that there are no problems if, at any time, it is necessary to return to planting rice in its original condition. However, optimal water management for irrigation is going to be able to distribute water for irrigation at more rice fields [4, 5], as well as at more water demand for other water users like fisheries, plantations, urban and industrial areas, the environment, and households. Therefore, it does not even rule out the possibility of developing agricultural products to improve farmer welfare.

According to Ding et al. [6], System Dynamics is a theory of system structure and a tool collection for describing complex systems and then analyzing the behavior of the system dynamics. However, the benefit of system dynamics is

* Corresponding author: mel.asmelita@gmail.com; lilymont@ub.ac.id

http://dx.doi.org/10.28991/CEJ-2024-010-02-010

that it can completely explain the system structure and then further see the interrelation among the elements of the system. After that, if a decision is needed, it can try to change the various relationships. In addition, in system dynamics, the link between behavior and structure is due to the concept of feedback and control information [7, 8]. Further, a causal loop diagram is needed to state the mechanism of feedback, such as a positive feedback loop (mentioned as amplifying) or a negative feedback loop (mentioned as negating) for the changes in the variable system [9, 10].

Radhika & Hatmoko [11] said that the system dynamics approach concluded that there are three interventions to prevent the rate of conversion of irrigated land to other uses [12], namely by controlling population, controlling residential land with flats, and perpetual irrigation land. Thus, irrigation land and irrigation canal infrastructure need to be maintained. Inland fishing on irrigated land does not change the irrigation canal infrastructure, so it still maintains the land and irrigation canal systems. The possibility of optimizing the results of the irrigation canal has been discussed, among others, by Asmelita et al. [13, 14].

Agriculture and fisheries that use the same resources, namely irrigation canals, must be seen as an integrated unit [15]. The contribution of the fisheries sector to food security and poverty alleviation was also emphasized by Béné et al. [16]. The use of irrigated rice fields for fishery development is a good combination. Optimization of water resource infrastructure is urgently needed to increase farmers' income and alleviate poverty within the framework of the nexus of water, food, and energy [17]. Blanchard et al. [18] emphasize the need to calculate trade-offs between agriculture, fisheries, and biodiversity.

For this reason, it is necessary to examine the possibility of optimizing the increase in farmers' income [19] by converting rice fields into fisheries without changing existing irrigation infrastructure, and also without reducing rice self-sufficiency regionally.

2. Material and Methods

This study examines the optimization of irrigation network yields by changing functions in fisheries without reducing rice self-sufficiency regionally. The purpose is to be able to propose a combination of irrigated land planted with rice and in the form of fisheries optimally.

2.1. System Dynamics

The dynamics system approach is suggested by Asmelita et al. [14] that the system of structure is illustrated as a diagram. The system dynamics can be used to collaborate and communicate with other parties and can seek high-leverage interventions for solving many problems. There are many tools that are used in this approach, such as causal diagrams, archetype systems, diagrams of stock and flow, the behavior of over-time graphs, and the DSS generator for simulating the program, such as Madonna, Stella, Vensim, Powersim, and Dynamo. The DSS generator is an object-oriented program. The simulation program can be used to solve the problems of water resource management that are full of non-linear objective functions and constraints.

Figure 2 presents the system dynamics, which consists of flow, stock, connector, and converter. Stock shows the resource condition and accumulation; for example, to state that the population is increasing. However, flow indicates the action of how something happens that is average measured; converter is for inputs accommodating and creating the outputs. Meanwhile, the connector is utilized to establish the relationship between flow and stock with the converter [14].

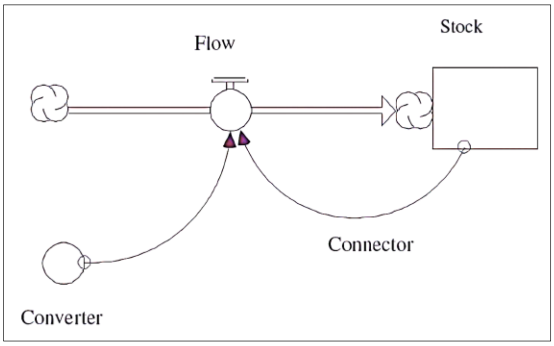


Figure 1. System dynamics model

This research examines the literature on self-sufficiency in food, especially rice, and what other alternatives are significantly more profitable than growing rice. The data is generally official from the Central Bureau of Statistics (BPS).

Based on official data from the Central Bureau of Statistics, several calculations are then carried out as follows:

- Rice surplus calculation
- Calculation of the potential increase in farmer income.

The study locations are all regencies and cities in West Sumatra Province. The location of districts and cities in the province of West Sumatra is presented in Figure 1.

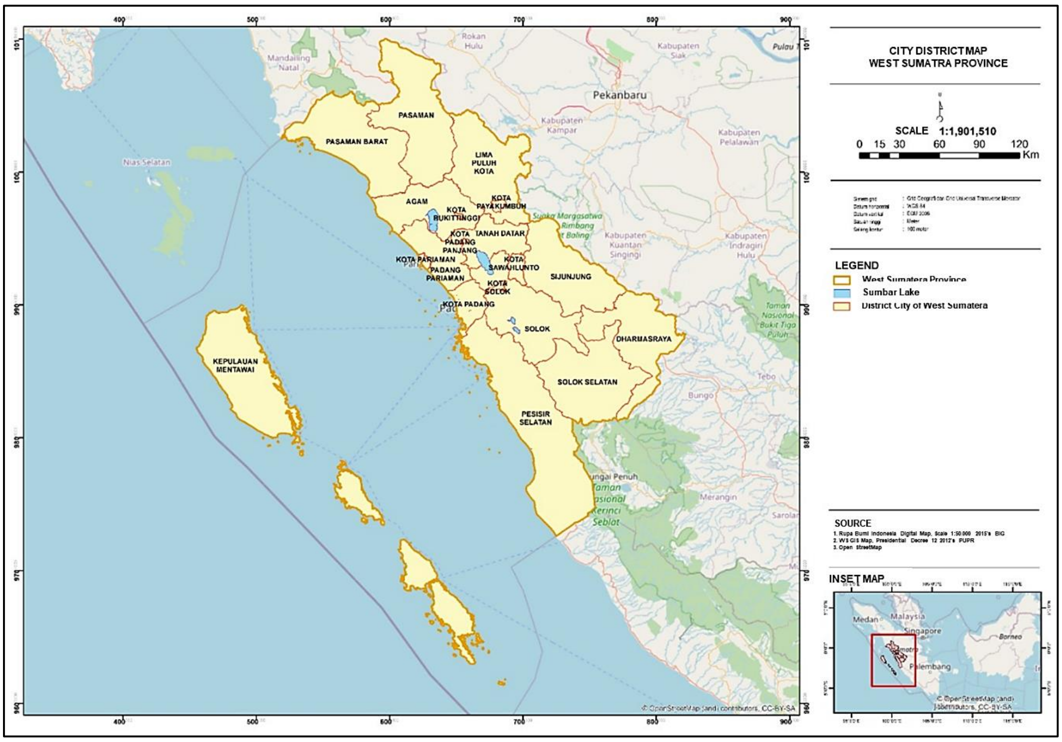


Figure 2. Regencies/ Cities in West Sumatra Province

2.2. Rice Surplus Calculation

The surplus of rice in each Regency/City is:

$$S = P_r - D_r \tag{1}$$

where S is Annual rice surplus, P_r is Annual rice production, D_r is Annual rice requirement, District/City annual rice needs are $D_r = P \times D_{r1}$, where D_r is Annual rice requirement, and D_{r1} is Rice consumption per year per person, assumed to be 120 kg.

2.3. Calculation of Potential Revenue Increase

The area of rice fields that can be developed for non-rice cultivation is:

$$Area_{free} = S / Prod \tag{2}$$

where Area $_{free}$ is Potential area of paddy fields that can be developed for non-rice cultivation (ha), and Prod is Productivity (ton/ha).

The potential for increased revenue is:

$$Gain = Area_{free} \times Gain\_Index \tag{3}$$

where Gain is Potential for increased revenue, Area $_{free}$ is free rice field area, and $Gain\_Index$ is potential increase in income/year/ha.

The potential increase in annual income per hectare is the difference between fishery net income and paddy net income:

$$Gain\_Index = Net\_Income\_Fish - Net\_Income\_Paddy \tag{4}$$

where $Gain\_Index$ is Potential increase in income/year/ha, Net_Income_Fish is Fisheries net income/year/ha, Net_Income_Paddy is Paddy net income/year/ha.

Meanwhile, the net income from fishery and paddy is the production value minus the respective production cost.

$$Net\_Income\_Fish = Gross\_Income\_Fish - Cost\_Fish \quad (5)$$

where Net_Income_Fish is Fisheries net income/year/ha, $Gross\_Income\_Fish$ is Fishery production value, $Cost\_Fish$ is Fishery production costs.

$$Net\_Income\_Paddy = Gross\_Income\_Paddy - Cost\_Paddy \quad (6)$$

where Net_Income_Paddy is Paddy's net income, $Gross\_Income\_Paddy$ is Paddy production value, and $Cost\_Paddy$ is Paddy production costs.

Figure 3 shows the flowchart of the research methodology through which the objectives of this study were achieved.

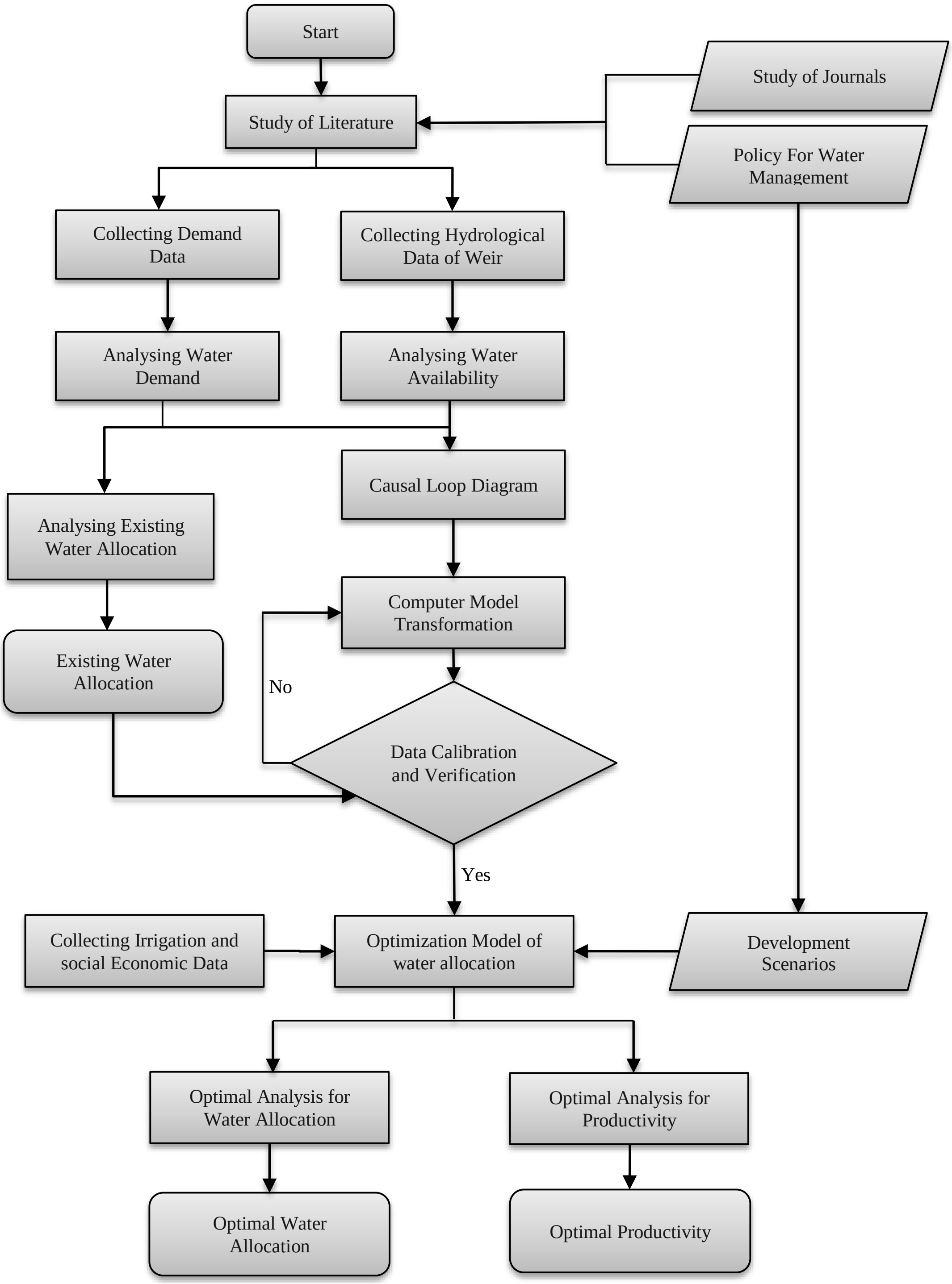


Figure 3. Flowchart of the methodology

3. Results and Discussion

3.1. Water Availability and Irrigation Water Requirement

The water distribution (allocation) for functional irrigation based on the existing fishery indicates that there is a deficit condition throughout the year. However, there is about 80% reliable water availability; the average is 11.97 m^3/s, and it has to fulfill about 20.22 m^3/s of water requirements. Figure 4 presents the water availability in Panti Rao Weir, and Figure 5 presents the water availability and water requirement in Panti Rao Weir [13].

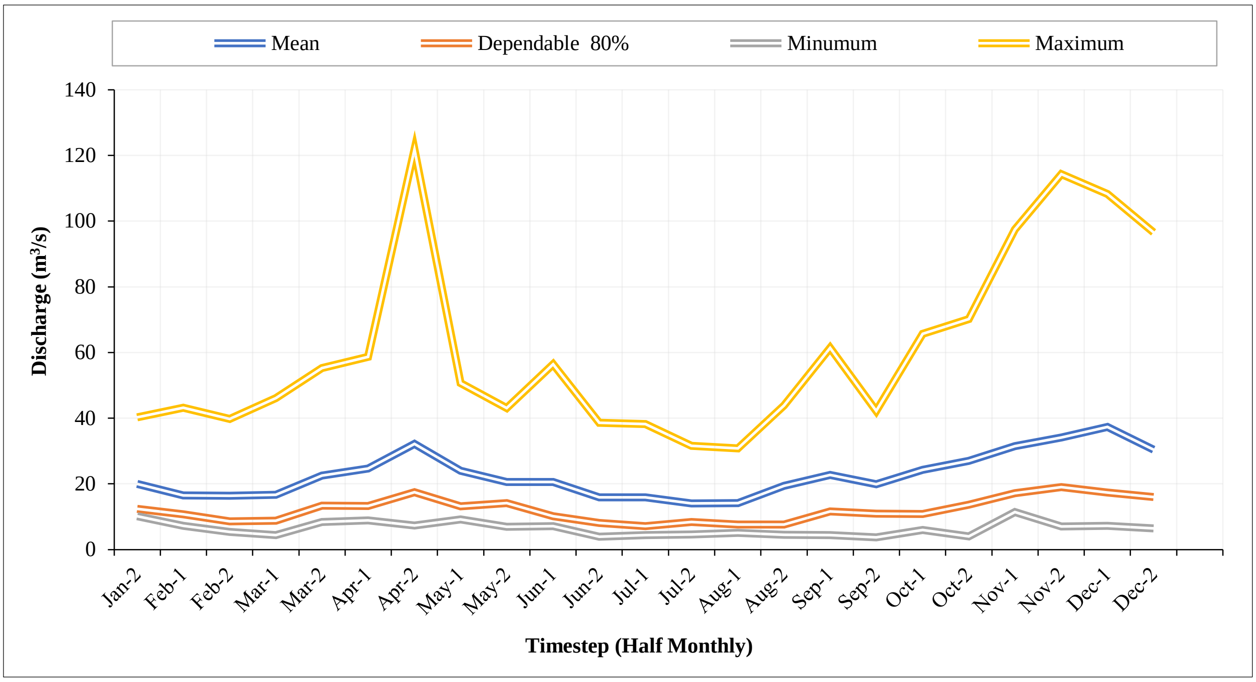


Figure 4. Water Availability in Panti Rao Weir

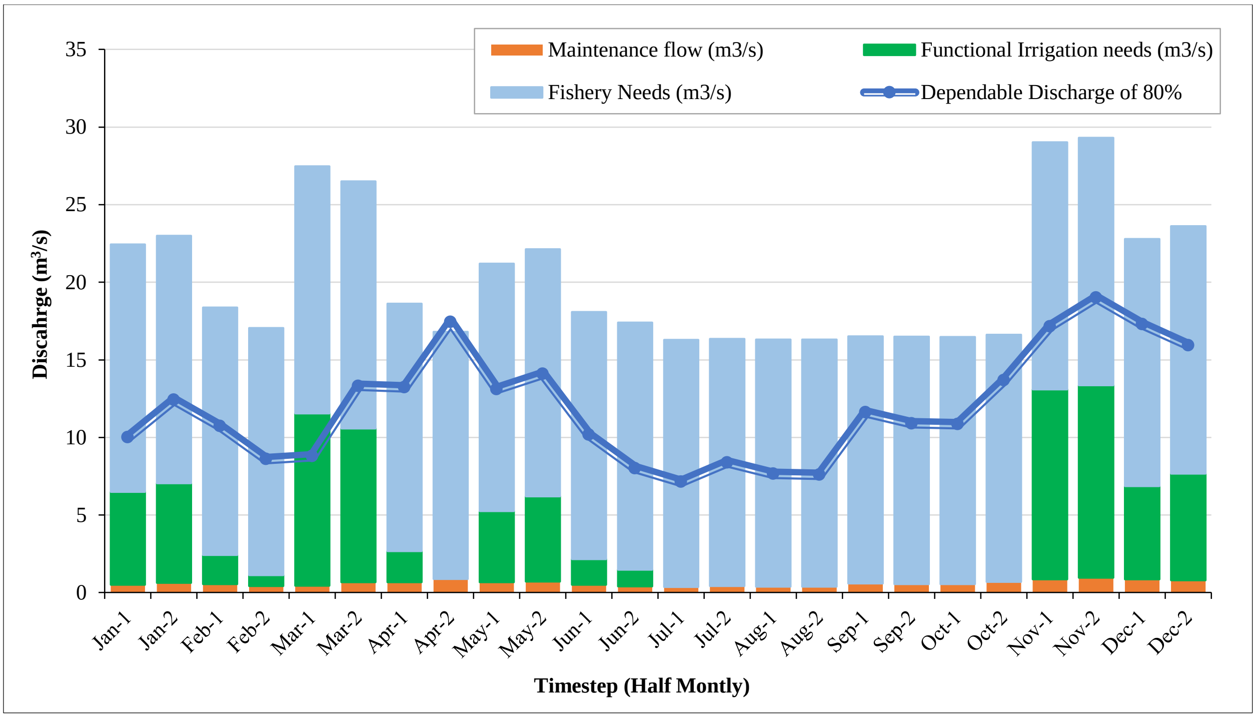


Figure 5. Water Availability and Water Requirement in Panti Rao Weir

3.2. The priority for 100% (fully) Irrigation

The condition for 100% (fully) irrigation can be seen in Figure 6 [14].

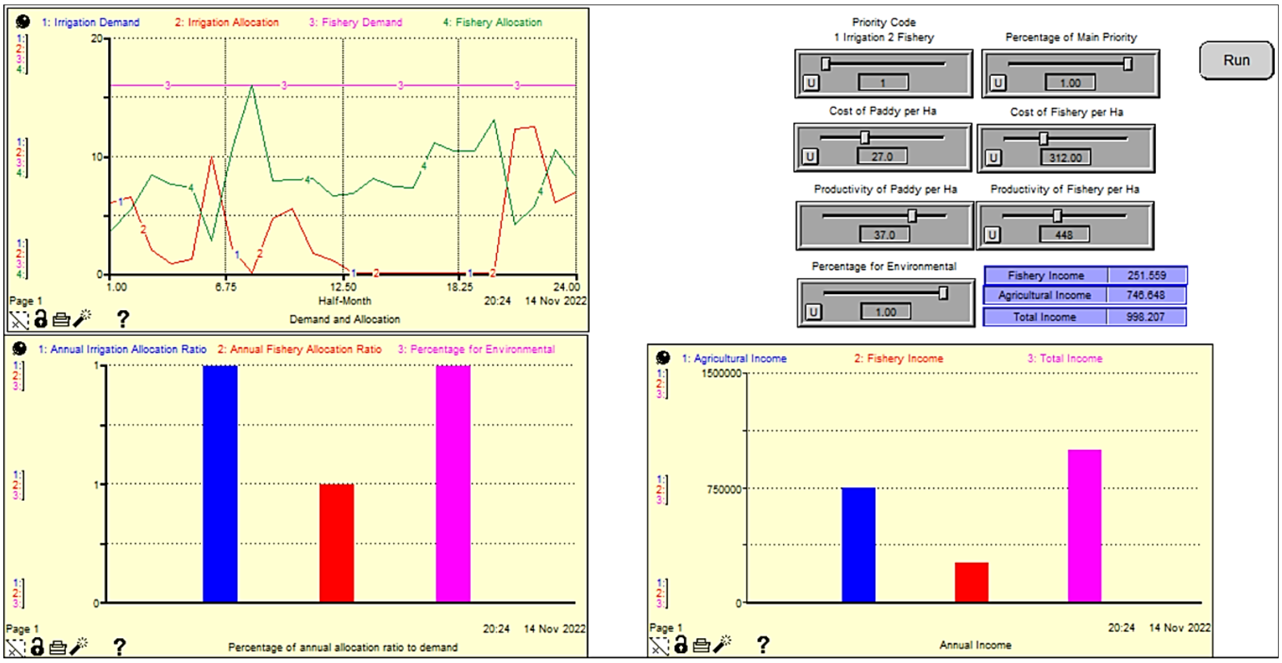


Figure 6. Water Allocation and Water Availability of 100% (fully) Irrigation

To calibrate the system dynamics model, it has already been transformed into a computer model by comparing the existing water allocation that is being operated in the weir and the water allocation from the system dynamic with first priority water for irrigation. The water allocation should be the same, and if not, there must be something wrong with the transformed model. In this case, the water allocation that is manually calculated as an existing water allocation is less than the same as the water allocation that is produced by the model, and as shown in Figure 7, that means that the model already follows the right calculation.

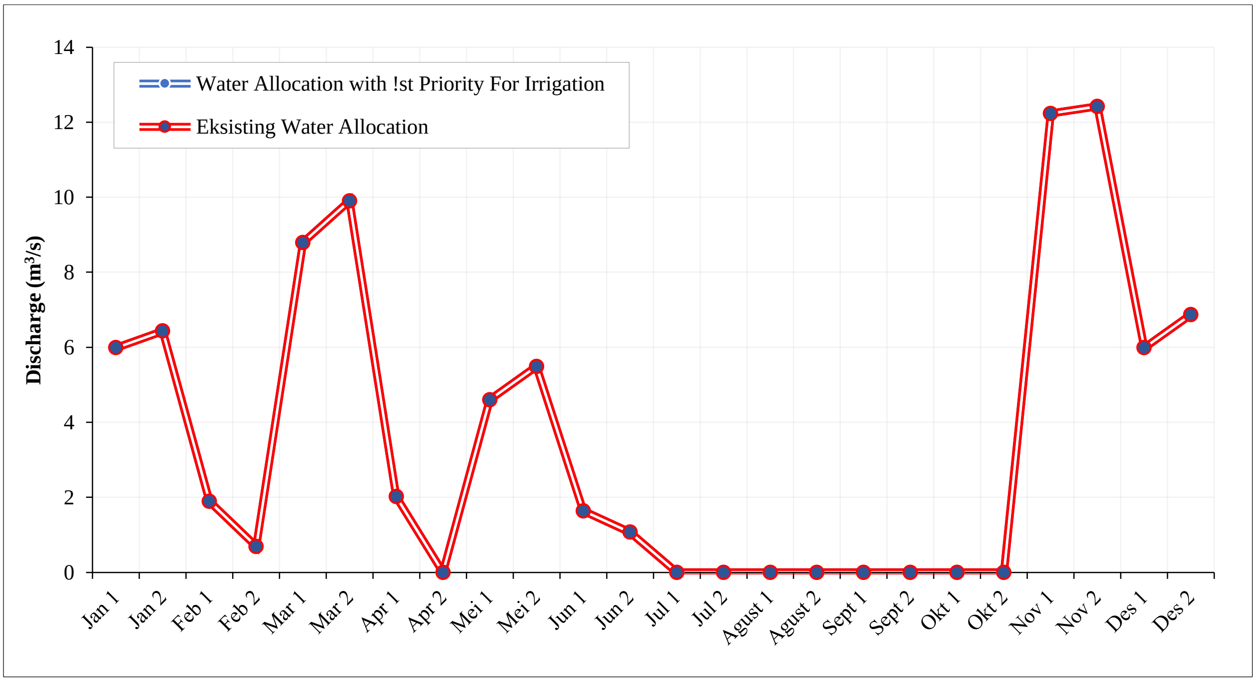
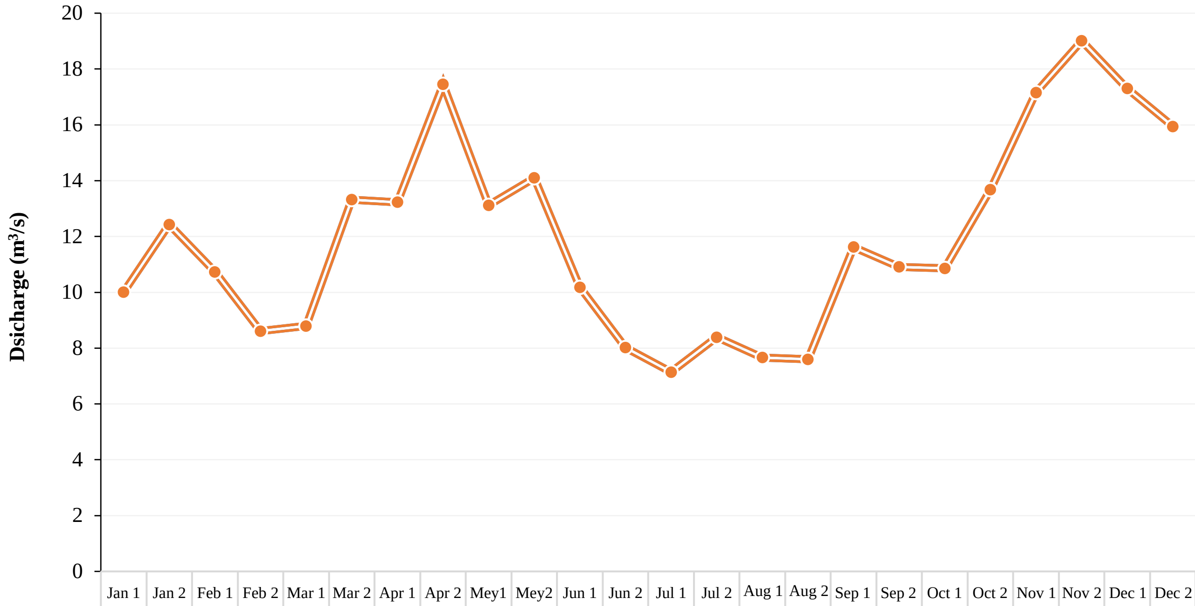


Figure 7. Model calibration

The validation results in Figure 8 show that the water availability is the same as the water allocation because the water availability is always below the water demands, which is in accordance with the calculation results, so the calculation can be stated to be running well.



	Jan 1	Jan 2	Feb 1	Feb 2	Mar 1	Mar 2	Apr 1	Apr 2	Mey1	Mey2	Jun 1	Jun 2	Jul 1	Jul 2	Aug 1	Aug 2	Sep 1	Sep 2	Oct 1	Oct 2	Nov 1	Nov 2	Dec 1	Dec 2
Water Availability	10.01	12.43	10.73	8.61	8.79	13.32	13.23	17.45	13.12	14.1	10.18	8.02	7.14	8.39	7.66	7.6	11.62	10.91	10.86	13.68	17.16	19.01	17.3	15.94
Water Allocation	10.01	12.43	10.73	8.61	8.79	13.32	13.23	17.45	13.12	14.1	10.18	8.02	7.14	8.39	7.66	7.6	11.62	10.91	10.86	13.68	17.16	19.01	17.3	15.94

Figure 8. Validation Model

3.3. Rice Self-sufficiency Concept

A country is said to be self-sufficient if its production can be met entirely by national production. This concept can be extended to the provincial and district/city levels. So, a Regency/City in West Sumatra can be said to have reached the level of self-sufficiency in rice if all the rice needs can be supplied by the Regency/City itself. If a Regency/City has achieved self-sufficiency in rice, it is the right of the farmers to cultivate their irrigated land with more profitable commodities, for example, fisheries. The Causal Diagram of rice self-sufficiency in the Province of West Sumatera is presented in Figure 9, and the program is in Figure 10. This causal diagram is used due to System Dynamics, and then it is compiled by Stella software.

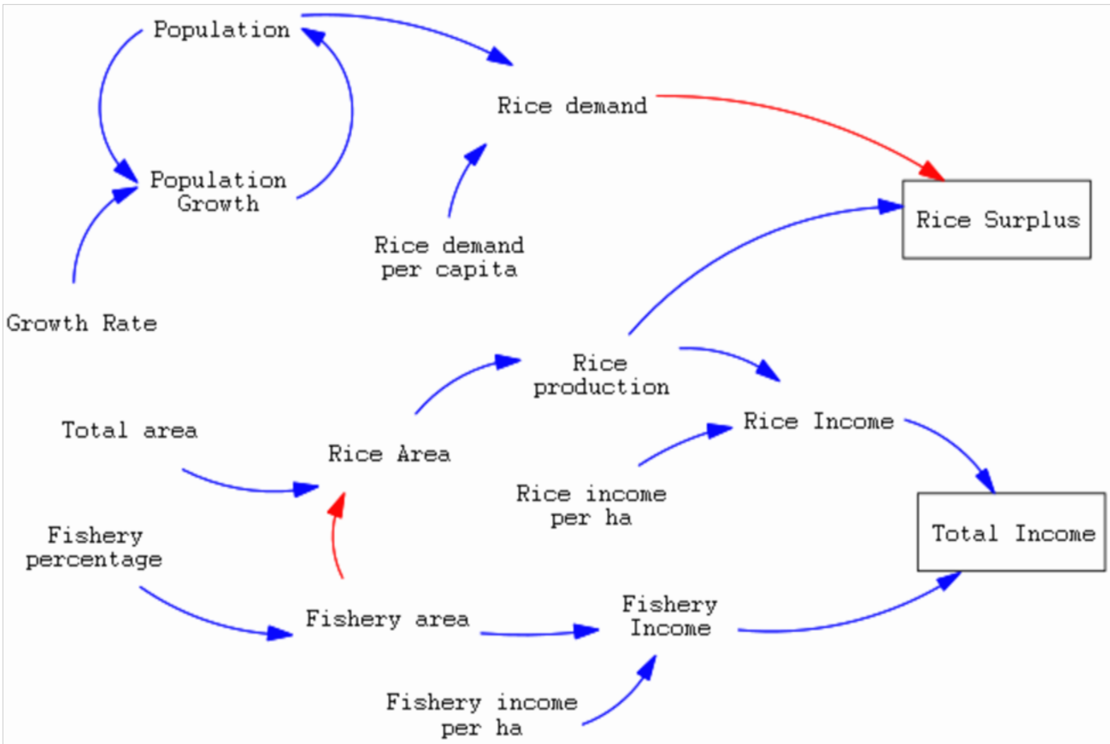


Figure 9. Causal Diagram Self-sufficiency in Rice

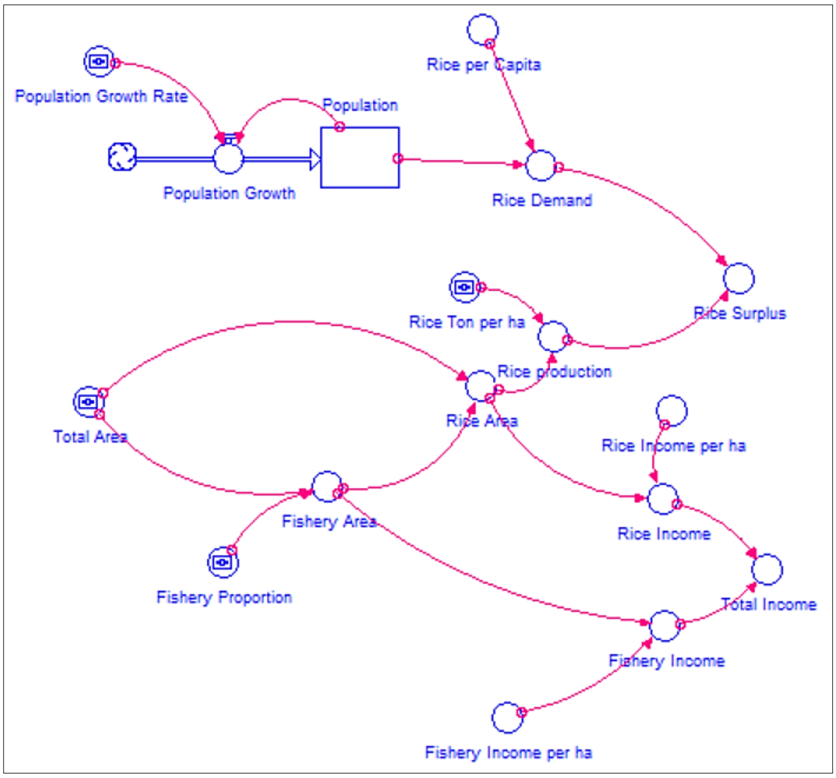


Figure 10. System Dynamics Model of Self-Sufficiency in Rice

However, the formula of rice-self-sufficiency in the province by using System Dynamics presented as in the Figures 11 and 12 presents the performance of control and result of the Dynamics System model.

```
Population(t) = Population(t - dt) + (Population_Growth) * dt
INIT Population = 5580232
INFLOWS:
  Population_Growth = Population_Growth_Rate*Population/100
Fishery_Area = Total_Area*Fishery_Proportion
Fishery_Income = Fishery_Income_per_ha*Fishery_Area/1000000
Fishery_Income_per_ha = 136
Fishery_Proportion = 0.11
Population_Growth_Rate = 1.29/100
Rice_Area = Total_Area-Fishery_Area
Rice_Demand = Population*Rice_per_Capita/1000
Rice_Income = Rice_Area*Rice_Income_per_ha/1000000
Rice_Income_per_ha = 10
Rice_per_Capita = 120
Rice_production = Rice_Area*Rice_Ton_per_ha
Rice_Surplus = Rice_production-Rice_Demand
Rice_Ton_per_ha = 3.82
Total_Area = 199451
Total_Income = Fishery_Income+Rice_Income
```

Figure 11. The Formula of Rice-Self-Sufficiency in the Province by Using System Dynamics

3.4. The Condition of Rice Self-sufficiency in Districts/cities in West Sumatra

West Sumatra Province, which consists of 12 regencies and 7 cities, is one of the national rice granaries. With a rice surplus of 93 thousand tons/year, it exports excess rice production to other provinces that need it.

Table 1 presents data on population and rice production for the province of West Sumatra obtained from Badan Pusat Statistik Provinsi Sumatera Barat [20–23]. Furthermore, the condition of the surplus and the potential for increased income are calculated in this study. Assuming the consumption of rice per year is 120 kg, the province of West Sumatra has a surplus of rice production of more than 93 thousand tons every year. Nearly all districts also had a surplus, namely Pesisir Selatan District, Solok District, Sijunjung District, Tanah Datar District, Padang Pariaman District, Agam District, Lima Puluh Kota District, Pasaman District, and Solok Selatan District. In districts with rice surplus conditions, it can be proposed to increase the income of farmers by converting rice fields into inland fisheries.

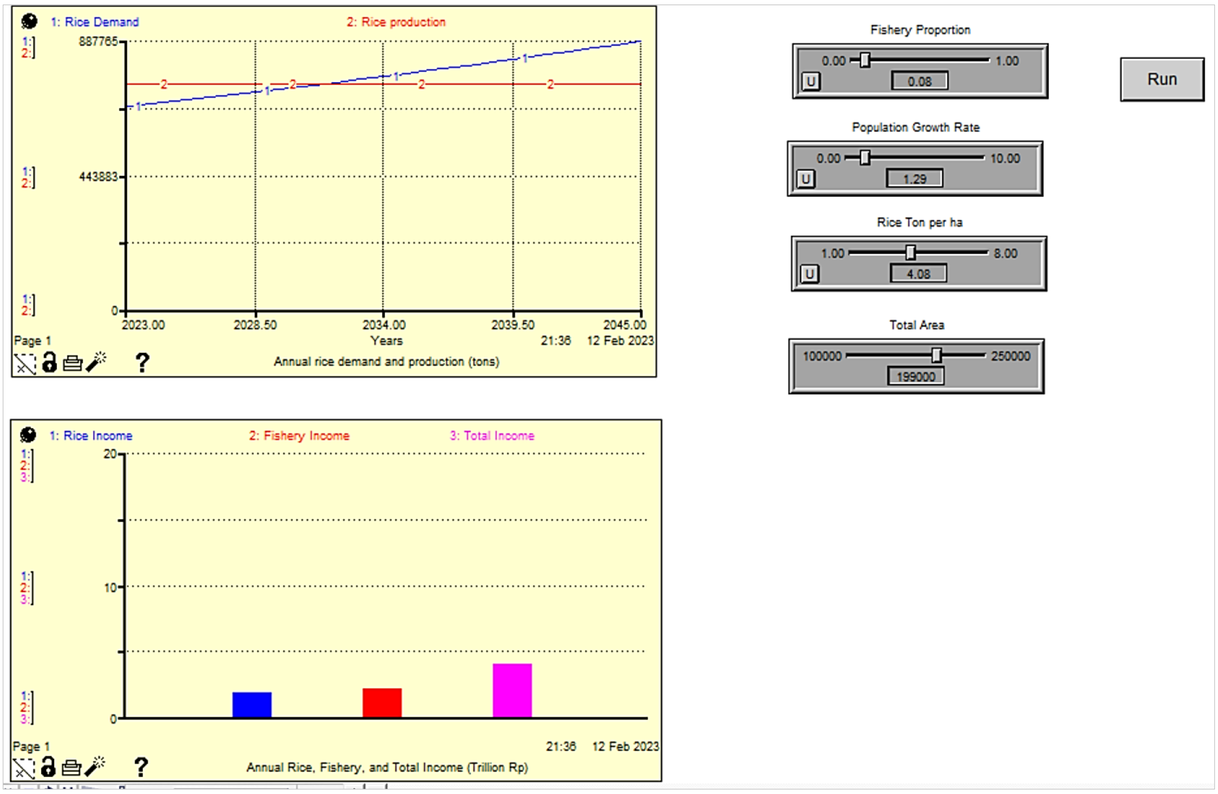


Figure 12. Performance of Control and Result of the System Dynamics Model

Table 1. The condition of rice self-sufficiency in West Sumatra Province

No	Regency/City	Rice Production (ton/year)	Total population	Rice Needs/Year	Rice surplus/deficit (ton/year)	Rice Field Area (ha)	Productivity (ton/year/ha)	Fisheries Potential (ha)	Potential Revenue Increase (Million IDR)
1	Kep. Mentawai Regency	544.84	88,389	10,606.68	-10,061.84	1,842.00	0	0.00	0.00
2	Pesisir Selatan Regency	84,618.80	509,618	61,154.16	23,464.64	23,885.00	4	6,623.27	834,531.67
3	Solok Regency	99,207.04	394,237	47,308.44	51,898.60	20,959.47	5	10,964.62	1,381,541.68
4	Sijunjung Regency	28,857.07	237,313	28,477.56	379.51	10,790.00	3	141.90	17,879.81
5	Tanah Datar Regency	105,709.95	373.693	44,843.16	60,866.79	22,170.00	5	12,765.28	1,608,424.83
6	Padang Pariaman Regency	66,894.07	433,018	51,962.16	14,931.91	18,289.00	4	4,082.42	514,384.91
7	Agam Regency	88,362.79	534,202	64,104.24	24,258.55	26,330.13	3	7,228.50	910,791.50
8	Lima Puluh Kota Regency	71,627.06	385,634	46,276.08	25,350.98	19,122.77	4	6,768.13	852,783.86
9	Pasaman Regency	75,058.35	303,103	36,372.36	38,685.99	19,415.00	4	10,006.73	1,260,847.73
10	Solok Selatan Regency	31,770.47	184,854	22,182.48	9,587.99	8,560.00	4	2,583.32	325,497.94
11	Dharmas raya Regency	14,786.98	231,217	27,764.04	-12,959.06	6,023.00	2	0.00	0.00
12	Pasaman Barat Regency	30,252.57	436,313	52,357.56	-22,104.99	8,873.00	3	0.00	0.00
13	Padang City	27,363.05	913,448	109,613.76	-82,250.11	5,216.11	5	0.00	0.00
14	Solok City	7,397.41	74,469	8,936.28	-1,538.87	875.92	8	0.00	0.00
15	Sawahlunto City	4,572.50	65,687	7,882.44	-3,309.94	1,571.00	3	0.00	0.00
16	Padang Panjang City	2,856.81	56,971	6,836.51	-3,979.71	552.00	5	0.00	0.00
17	Bukittinggi City	1,925.39	121,588	14,590.56	-12,665.17	388.67	5	0.00	0.00
18	Payakumbuh City	14,393.25	141.184	16,942.08	-2,548.83	2,803.09	5	0.00	0.00
19	Pariaman City	6,495.10	95,294	11,435.28	-4,940.18	1,785.00	4	0.00	0.00

3.5. Increased Income from Rice to Fisheries

Data on the harvested areas of districts/cities in West Sumatra were obtained from Badan Pusat Statistik Provinsi Sumatera Barat [22].

3.5.1. Rice Production Yield and Cost

Data from the Central Bureau of Statistics (Badan Pusat Statistik) [20–23] states that rice plants for each growing season will produce an average production of Rp. 18,514,840.00, while the cost of production is Rp. 13,559,300.00. If there are two growing seasons in a year, the production yield is around 37 million rupiah, and the production costs are around 27 million rupiah. Thus, the net production value of paddy is 10 million Rupiah/year/ha.

3.5.2. Fishery Production Yields and Costs

Tilapia is very popular in Indonesia because it tastes good, grows fast, and can withstand various conditions. Tilapia is also popular in various parts of the world, such as Bangladesh [12, 24], the Nil River [19, 25], and South Africa [26]. For fisheries production, namely tilapia, based on data from the Ministry of Maritime Affairs and Fisheries [27], the production cost per hectare is around 312 million Rupiah per year, while the production yield per year is 448 million Rupiah. Thus, the net production value is 136 million Rupiah/year/ha.

3.5.3. Revenue Increase Potential

Table 2 presents a summary of the income comparison between irrigated rice fields planted with rice and tilapia reared. It can be seen that the potential for increasing the net income of farmers is 126 million Rupiah per hectare per year.

Table 2. Increased Income from Paddy Conversion to Fisheries

Commodities in irrigated paddy fields	Production Value (million IDR/ha)	Production Cost (Million IDR/ha)	Net Production Value (Million IDR/ha)	Increased Income (Million IDR/ha)
Paddy	37	27	10	126
Fish	448	312	136	

For districts with a surplus of rice, it is possible to cultivate tilapia in the remaining potential rice fields, namely the area of rice fields after the total area of rice fields in the district is reduced by the area of rice fields needed to achieve self-sufficiency in rice. Table 3 presents the area of rice fields with potential for fisheries, i.e., the total area of rice fields is reduced by the quotient between surplus and productivity. The last column is the multiplication of the area of rice fields with fishery potential and increased income, as calculated in Table 2. The result is that the potential for increasing the income of farmers in surplus rice districts in West Sumatra is estimated to reach a value of 7.7 trillion Rupiah per year. However, of course, the Provincial Government of West Sumatra still has to consider the food security of the province by regulating how much rice surplus districts can grow tilapia. Figure 13 presents the relationship between rice surplus and income increase.

Table 3. Potential Increase in Farmers' Income

No	Regency/City	Rice surplus/deficit (ton/year)	Rice Field Area (ha)	Productivity (ton/year/ha)	Fisheries Potential (ha)	Potential Revenue Increase (Million IDR)
1	Kab Kep. Mentawai	-10,061.84	1,842	0.30	0	0
2	Kab Pesisir Selatan	23,464.64	23,885	3.54	6,623	834,532
3	Kab Solok	51,898.60	20,959	4.73	10,965	1,381,542
4	Kab Sijunjung	379.51	10,790	2.67	142	17,880
5	Kab Tanah Datar	60,866.79	22,170	4.77	12,765	1,608,425
6	Kab Padang Pariaman	14,931.91	18,289	3.66	4,082	514,385
7	Kab Agam	24,258.55	26,330	3.36	7,229	910,791
8	Kab Lima Puluh Kota	25,350.98	19,123	3.75	6,768	852,784
9	Kab Pasaman	38,685.99	19,415	3.87	10,007	1,260,848
10	Kab Solok Selatan	9,587.99	8,560	3.71	2,583	325,498
11	Kab Dharmasraya	-12,959.06	6,023	2.46	0	0
12	Kab Pasaman Barat	-22,104.99	8,873	3.41	0	0
13	Kota Padang	-82,250.11	5,216	5.25	0	0
14	Kota Solok	-1,538.87	876	8.45	0	0
15	Kota Sawahlunto	-3,309.94	1,571	2.91	0	0
16	Kota Padang Panjang	-3,979.71	552	5.18	0	0
17	Kota Bukittinggi	-12,665.17	389	4.95	0	0
18	Kota Payakumbuh	-2,548.83	2,803	5.13	0	0
19	Kota Pariaman	-4,940.18	1,785	3.64	0	0
West Sumatra Province		93,066.26	199,451	3.82	61,164	7,706,684

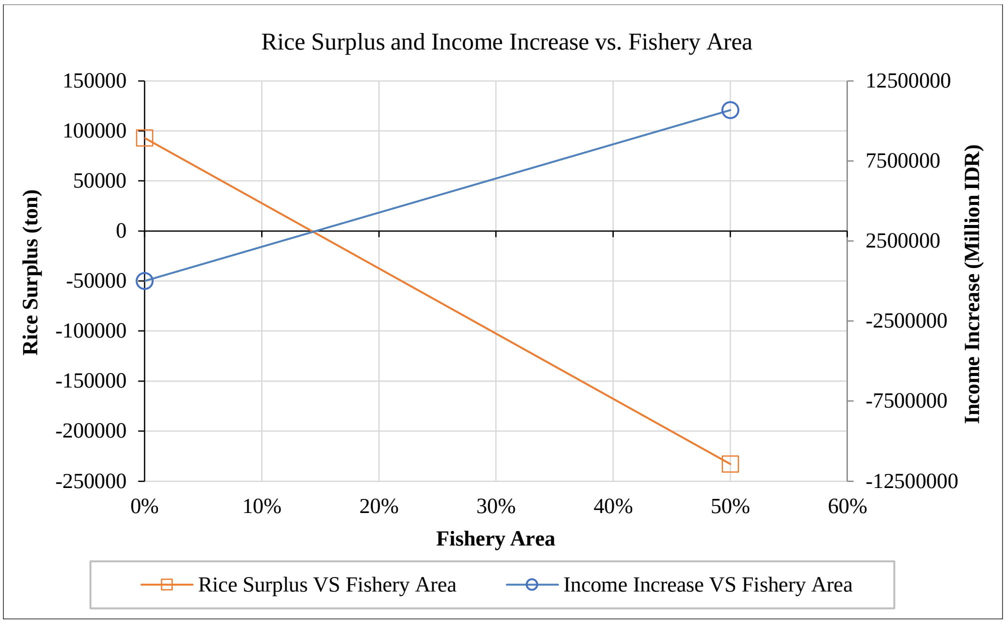


Figure 13. The Relation between Rice Surplus and Income Increasing

4. Conclusion

Based on the analysis and discussion above, it can be concluded that irrigation is an infrastructure asset that needs to be optimized for use. However, water, water sources, and irrigation infrastructure can provide more benefits to rice fields that function as fisheries. Nevertheless, it is necessary to consider the government's mission to maintain rice self-sufficiency. West Sumatra Province, as a national rice granary, has many districts that are more self-sufficient in rice, so that it can be considered to utilize irrigation to become irrigation for fisheries. There is about 80% reliable water availability; the average is 11.97 m^3/s, and it has to fulfill about 20.22 m^3/s of water requirements.

The Causal Diagram of rice self-sufficiency in the Province of West Sumatera is carried out using System Dynamics, and it is compiled by Stella software. West Sumatra Province, which consists of 12 regencies and 7 cities, is one of the national rice granaries. With a rice surplus of 93 thousand tons/year, it exports excess rice production to other provinces that need it. However, of course, the Provincial Government of West Sumatra still has to consider the food security of the province by regulating how much rice surplus districts can grow tilapia. The result shows that the potential increase in income that can be obtained by diverting rice-planted rice fields to tilapia fisheries is around 126 Million Rupiah per year per hectare. In addition, the potential of paddy fields that can be converted into fisheries while maintaining self-sufficiency in rice at the district/city level of West Sumatra Province is more than 61 thousand hectares, which generates an increase in income of around 7.7 trillion per year.

The implementation of this irrigation optimization needs to first carry out coordination between the Provincial Government of West Sumatra, the District Governments in West Sumatra, and the Central Government regarding the amount of rice normally supplied by regencies in West Sumatra.

5. Declarations

5.1. Author Contributions

Conceptualization, A. and L.M.L.; methodology, A.; validation, A.; formal analysis, A.; investigation, A. and I.F.; resources, A. and L.M.L.; data curation, A. and I. F.; writing—original draft preparation, A. and M.B.; writing— review and editing, M.B. and W.S.; visualization, M.B. and W.S. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Hamilton-Hart, N. (2019). Indonesia's Quest for Food Self-sufficiency: A New Agricultural Political Economy? Journal of Contemporary Asia, 49(5), 734–758. doi:10.1080/00472336.2019.1617890.

[2] Rozaki, Z. (2021). Food security challenges and opportunities in Indonesia post COVID-19. Advances in Food Security and Sustainability, 119–168. doi:10.1016/bs.af2s.2021.07.002.

[3] Purwadi, H., Montarcih Limantara, L., Suhartanto, E., & Rispiningtati. (2020). Optimization of Water Distribution to Support the Balance of Water Usage: A Case Study of the Sempor Irrigation System, Central Java, Indonesia. IOP Conference Series: Earth and Environmental Science, 437, 012030. doi:10.1088/1755-1315/437/1/012030.

[4] Wang, F., Chen, Y., Li, Z., Fang, G., Li, Y., & Xia, Z. (2019). Assessment of the irrigation water requirement and water supply risk in the Tarim River Basin, Northwest China. Sustainability (Switzerland), 11(18), 4941. doi:10.3390/su11184941.

[5] Ding, Z., Gong, W., Li, S., & Wu, Z. (2018). System dynamics versus agent-based modeling: A review of complexity simulation in construction waste management. Sustainability (Switzerland), 10(7), 2484. doi:10.3390/su10072484.

[6] Dolgui, A., Ivanov, D., & Rozhkov, M. (2020). Does the ripple effect influence the bullwhip effect? An integrated analysis of structural and operational dynamics in the supply chain. International Journal of Production Research, 58(5), 1285–1301. doi:10.1080/00207543.2019.1627438.

[7] Olivares-Aguila, J., & El-Maraghy, W. (2021). System dynamics modelling for supply chain disruptions. International Journal of Production Research, 59(6), 1757–1775. doi:10.1080/00207543.2020.1725171.

[8] Hiver, P., Al-Hoorie, A. H., & Larsen-Freeman, D. (2021). Toward a transdisciplinary integration of research purposes and methods for complex dynamic systems theory: beyond the quantitative–qualitative divide. International Review of Applied Linguistics in Language Teaching, 60(1), 7–22. doi:10.1515/iral-2021-0022.

[9] Rathore, R., Thakkar, J. J., & Jha, J. K. (2020). Impact of risks in foodgrains transportation system: a system dynamics approach. International Journal of Production Research, 59(6), 1814–1833. doi:10.1080/00207543.2020.1725683.

[10] Hiver, P., Al-Hoorie, A. H., & Evans, R. (2022). Complex Dynamic Systems Theory in Language Learning. Studies in Second Language Acquisition, 44(4), 913–941. doi:10.1017/S0272263121000553.

[11] Radhika & Hatmoko, W. (2017). Study of controlling irrigation land conversion using a system dynamics approach. Land Conversion Anthology: Food (in) Security, 109–122. Andi, Sleman, Indonesia.

[12] Ibrahim, L. A., Abu-Hashim, M., Shaghaleh, H., Elsadek, E., Hamad, A. A. A., & Alhaj Hamoud, Y. (2023). A Comprehensive Review of the Multiple Uses of Water in Aquaculture-Integrated Agriculture Based on International and National Experiences. Water (Switzerland), 15(2), 367. doi:10.3390/w15020367.

[13] Asmelita, Limantara, L. M., Bisri, M., Soetopo, W., & Farni, I. (2022). Allocation of Existing Water Irrigation in Panti Rao. Journal of Southwest Jiaotong University, 57(3), 355–362. doi:10.35741/issn.0258-2724.57.3.29.

[14] Asmelita, Limantara, L. M., Bisri, M., Soetopo, W., & Farni, I. (2022). Dynamics System Model for the Optimization of Irrigation Water Allocation. Journal of Hunan University Natural Sciences, 49(12), 45–55. doi:10.55463/issn.1674-2974.49.12.5.

[15] Pueppke, S. G., Nurtazin, S., & Ou, W. (2020). Water and land as shared resources for agriculture and aquaculture: Insights from asia. Water (Switzerland), 12(10), 2787. doi:10.3390/w12102787.

[16] Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D., Thilsted, S. H., Troell, M., & Williams, M. (2016). Contribution of Fisheries and Aquaculture to Food Security and Poverty Reduction: Assessing the Current Evidence. World Development, 79, 177–196. doi:10.1016/j.worlddev.2015.11.007.

[17] Cameira, M. do R., & Pereira, L. S. (2019). Innovation issues in water, agriculture and food. Water (Switzerland), 11(6), 1230. doi:10.3390/w11061230.

[18] Blanchard, J. L., Watson, R. A., Fulton, E. A., Cottrell, R. S., Nash, K. L., Bryndum-Buchholz, A., Büchner, M., Carozza, D. A., Cheung, W. W. L., Elliott, J., Davidson, L. N. K., Dulvy, N. K., Dunne, J. P., Eddy, T. D., Galbraith, E., Lotze, H. K., Maury, O., Müller, C., Tittensor, D. P., & Jennings, S. (2017). Linked sustainability challenges and trade-offs among fisheries, aquaculture and agriculture. Nature Ecology and Evolution, 1(9), 1240–1249. doi:10.1038/s41559-017-0258-8.

[19] Rahman, M. L., Shahjahan, M., & Ahmed, N. (2021). Tilapia farming in Bangladesh: Adaptation to climate change. Sustainability (Switzerland), 13(14), 1–20. doi:10.3390/su13147657.

[20] BPS-Statistics Indonesia. (2019). Value of Production and Cost of Production per Planting Season per Hectare of Wetland Paddy, Dryland Paddy, Maize, and Soybean, 2017. Available online: https://www.bps.go.id/id/statistics-table/1/MjA1NSMx/nilai-produksi-dan-biaya-produksi-per-musim-tanam-per-hektar-budidaya-tanaman-padi-sawah--padi-ladang--jagung--dan-kedelai--2017.html (accessed on February 2024).

[21] Statistics Indonesia. (2022). Number of Population by Type of Sex and Regency/City (People), 2020-2022. Badan Pusat Statistik Provinsi Sumatera Barat, Indonesia. Available online: https://sumut.bps.go.id/indicator/12/65/1/jumlah-penduduk-menurut-jenis-kelamin-dan-kabupaten-kota.html (accessed on February 2024).

[22] Statistics Indonesia. (2024). Harvested Area, Production, and Productivity of Paddy by Regency/Municipality Result of Area Sampling Frame (ASF) 2021-2023. Badan Pusat Statistik Provinsi Sumatera Barat, Statistics of Sumatera Barat Province, Indonesia. Available online: https://sumbar.bps.go.id/indicator/53/276/1/luas-panen-padi-menurut-kabupaten-kota-hasil-ksa.html (accessed on February 2024).

[23] Statistics Indonesia. (2023). Rice Production by Regency/Municipality Result of Area Sampling Frame (ASF) (Tons), 2021-2023. Badan Pusat Statistik Provinsi Sumatera Barat, Statistics of Sumatera Barat Province, Indonesia. Available online: https://sumbar.bps.go.id/indicator/53/278/1/produksi-beras-menurut-kabupaten-kota-hasil-ksa.html (accessed on June 2023).

[24] Mojjada, S. K., Divu, D. N., Sudhakaran, P. O., Sundaram, S. L. P., Menon, M., Mojjada, R. K., ... & Gopalakrishnan, A. (2024). An integrated techno-economic decision-support fiscal forecast model for sea cage mariculture enterprises for Asian sea bass production in Indian territorial waters. Aquaculture, 580, 740351. doi:10.1016/j.aquaculture.2023.740351.

[25] Rakib, M. R. J., Miah, S., Hossain, M. B., Kumar, R., Jolly, Y. N., Akter, S., ... & Idris, A. M. (2024). Delineation of trace metal level in fish feed and farmed fish, Tilapia (Oreochromis mossumbicus) and their consequences on human health. Regional Studies in Marine Science, 71, 103403. doi:10.1016/j.rsma.2024.103403.

[26] Salie, K. (2014). Aquaculture practices in irrigation reservoirs of the Western Cape Province of South Africa in relation to multiple resource use and socio-ecological interaction. Ph.D. Thesis, Stellenbosch University, Stellenbosch, South Africa.

[27] Soetjipto, W., Andriansyah, R., Qurrata, R. A., Setiadi, T., Susanto, H., Solah, A., Hasan, U., Khaerawati, U., Aryshandy, C., Moriansyah, L., Purnama, N. D., Wahyuni, S., Horida, E., & Kurnia, I. (2019). Value Business and Investment Opportunities. Directorate of Investment Business, Directorate General of Strengthening the Competitiveness of Marine and Fishery Products, Ministry of Maritime Affairs and Fisheries, Central Jakarta, Indonesia.