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Dynamic model engineering of sustainable agriculture as a pragmatic concept of critical land management

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Abstract: According to many experts, the water crisis will be one of the most important challenges in the coming years on the planet. Watershed management is one of the most effective ways to conserve rainwater and develop water resources. The purpose of the study was to obtain a model of critical land management in the Welang watershed area. This study uses a dynamic systems approach based on a causal philosophy (cause and effect) through a deep understanding of how a system works. The parameters used are based on sustainable agriculture in terms of physical sustainability aspects/critical land from erosion factor indicators. Model validation is done by comparing the behaviour of the model with a natural system (quantitive behaviour pattern comparison), namely the Mean Absolute Percentage Error (MAPE) Middle-Value Test. Modelling is supported by Powersim Studio Express Software ver. 10. The results show that the physical sustainability model/critical land using a simulation scenario of 25% erosion control funds shows a trend of increasing production land area and tackled land area followed by a decrease in annual erosion weight. The economic sustainability model obtained results at the end of the projected year showing farm revenues IDR 63,591,396 (USD1 ≈ IDR14.27 thous. in average in 2021). This means that the higher the acceptance value, the farming can provide economic welfare for farmers.

Keywords: critical land, erosion area, sustainable agriculture, watershed area

INTRODUCTION

Watershed management aims to produce and protect water resources, including erosion and flood control, and maintain the aesthetic values of the waters. Management of natural resources that can be recovered, such as water, soil, and vegetation, to improve, support, and protect the condition of watersheds to produce water for agricultural purposes [Moges, Dinka 2021; Molajou *et al.* 2021; Yavari *et al.* 2022]. Explained that a watershed with a dense population by efforts to preserve soil and water has a high environmental carrying capacity, compared to a large watershed, sparsely populated, but practising shifting cultivation in hilly areas and giving birth to grasslands vast and unproductive reeds [Ulibarri, Garcia 2020].

Watersheds in several areas in Indonesia are experiencing land degradation. Apart from Indonesia, land degradation and erosion are the most critical environments in other countries [Satriawan *et al.* 2021]. The driving factors include climatic factors and human activities such as land management that does not consider sustainability, changes in land function (i.e., plantations, settlements), high rainfall, which causes erosion [Doyle *et al.* 2021]. Critical land is productive in terms of agricultural use because its use does not or ignores land conservation rules. Soil conservation and reclamation of critical land are decided by considering land capability and use [Wijitkosum 2021].

The research objective is to obtain critical land management to realise a sustainable agricultural model in the Welang watershed area because of it is necessary to find a policy model that can optimise the development of potential watershed areas based on local resources to economic growth. This research has a new concept that uses a dynamic system based on the concept of three. The sustainability dimension consists of economic sustainability, community social life, and ecology in the watershed. However, empirically it is still rarely done so that practical actions appear in land management through efforts to realise sustainable agriculture [GONZALEZ-REDIN *et al.* 2018; HUNING, WAHL 2021]. The research objective is to obtain critical land management to realise a sustainable agricultural model in the Welang watershed area.

MATERIALS AND METHODS

This research was conducted in the watershed Welang River, Pasuruan Regency, Indonesia. The data used are primary data and secondary data. Primary data consists of rainfall factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), ground cover vegetation factor, plant management (C), and soil conservation action factor (P). It is used as a predictor of erosion weight to obtain the total area of erosion. Secondary data were obtained from the Meteorology, Climatology and Geophysics Agency (Ind. Badan Meteorologi, Klimatologi, dan Geofisika, BMKG), the Central Statistics Agency (Ind. Badan Pusat Statistik, BPS) and related articles. Model simulation designed using Powersim Studio Express Software ver. 10.

This study uses a dynamic system approach based on a causal philosophy through a deep understanding of the workings of a system. The parameters used are based on sustainable agriculture in terms of physical sustainability aspects/critical land from erosion factor indicators. The economic sustainability aspect of the farming component and the economic value obtained, while the social sustainability aspect is based on public perception [MOLAJOU *et al.* 2021; POULADI *et al.* 2020]. A comprehensive model picture is presented in a causal loop. The approach used is by compiling a causal loop diagram and an input–output diagram (black box diagram). Model validation is done by comparing the behaviour of the model to the natural system, namely the mean absolute percentage error (*MAPE*) middle-value test (Eq. 1).

$$MAPE = \frac{1}{n}\,\frac{|X_m - X_d|}{X_d}\,100\% \tag{1}$$

where: X_m, X_d, n = simulated value, actual value and period, respectively.

The criteria for the accuracy of the model with the *MAPE* test are: *MAPE* < 5% (very precise); 5% < *MAPE* < 10% (precise); *MAPE* ≥ 10% (not precise).

RESULTS AND DISCUSSION

The success of coffee cultivation on critical land is limited by the factors that cause land degradation. Therefore, it is necessary to think in a systems way, namely efforts to overcome it by issuing externality costs in the form of erosion prevention funds in line with the suitability of community aspirations while reducing costs, technology, and institutional barriers perceived by the community. Systems thinking is a logical step to resolve the complexities of critical land management problems in the Welang watershed. A systemic approach is required to successfully study commodity farming within the framework of its zoning [CALLEROS-ISLAS 2019; KANTER *et al.* 2018].

The simulated policies in the model are expected to answer the goal-setting on the issues raised so that in making the dynamic system model, several scenarios are applied. The scenario model based on the conditions in the field is shown in Table 1.

Table 1. Scenario modelling

Proposed sub-model	Scenario formation	Information
Physical/ critical land	actual condition	All parameter values used are the same as the current conditions, reflected in the coffee production area of 489 ha, the annual erosion weight of 410,557.37 Mg. Therefore, the managed land 0 ha and the annual erosion of 842.63 Mg·ha^{-1} is classified as erosion - hazard class V. Using the magnitude P (soil conservation measures) = 0.35 (unfavourable construction). In addition, it is identified that there is no effective erosion control, both measures and funds for erosion control of 0.0001 ha·IDR^{-1} (USD1 ≈ IDR14.27 thous. in average in 2021), and the percentage of proposed funds set aside for erosion is 0%.
	model simulation	Using the magnitude of P (soil conservation measures) = 0.15 (medium construction). Annual erosion of 361.13 Mg·ha^{-1} belongs to erosion hazard class IV, and annual erosion weight is –241,448.46 Mg, managed land is 541.64, and the percentage of proposed funds set aside for erosion is 25%.
Economy	actual condition	Using real data from the distribution of questionnaires (primary data), the average value of production is 384.91 kg, and productivity is 0.79 kg·ha^{-1}, the average selling price of coffee is IDR16,900·kg^{-1} so that the revenue is IDR6,505,007 and an income of IDR4,672,538.
	model simulation	They were using data on the productivity of coffee plantations at the end of the projected year (2037) of 3.67 kg·ha^{-1}. The revenue was IDR63,591,396, and the income was IDR59,735,447.

Source: own study.

The impact of erosion is the reduction of the top layer of the soil surface, which will cause a decrease in the ability of the land, in addition to the decreased ability of the soil to absorb water (infiltration) so that land productivity decreases. The potential of productive land and its land-use practices for coffee plantations in the watershed of Welang River varies with altitude and slope. This parameter determines the main constraints to improving productivity and land-resource degradation [KOVALENKO *et al.* 2021]. Due to the increasing population pressure on land for coffee cultivation, the highly sloping highland and medium lands have to be cultivated with a very high risk of soil erosion [YAVITT *et al.* 2021]. The physical/critical land sub-model simulation results in the actual model scenario are shown in Table 2.

Table 2. Simulation results of sub-model physical/critical land based on time table

Year	Production area (ha)	Controlled land (ha)	Annual erosion weight (Mg)
2017	487.23	483.61	171,591.12
2018	501.47	915.65	679,657.60
2019	543.64	1,373.02	1,194,685.03
2020	586.39	1,825.45	1,703,280.17
2021	628.60	2,266.89	2,199,100.80
2022	669.76	2,692.64	2,676,923.11
2023	709.41	3,098.73	3,132,333.44
2024	747.21	3,481.95	3,561,785.14
2025	782.86	3,839.91	3,962,648.10
2026	816.13	4,171.04	4,333,209.97
2027	846.89	4,474.54	4,672,629.61
2028	875.06	4,750.31	4,980,851.96
2029	900.64	4,998.86	5258,496.43
2030	923.69	5,221.21	5,506,730.81
2031	944.29	5,418.74	5,727,141.63
2032	962.58	5,593.10	5,921,609.92
2033	978.72	5,746.11	6,092,198.63
2034	992.88	5,879.68	6,241,055.73
2035	1.005.24	5,995.73	6,370,334.84
2036	1.015.97	6,096.11	6,482,133.46
2037	1.025.25	6,182.62	6,578,447.68

The model simulation scenario using the proposed erosion control fund is set aside by 25%, and the slope of the land is 0.15. Table 2 shows that graphically there is a trend of increasing the area of managed land and production land for 20 years. This scenario is inversely proportional to the scenario that the production area is known graphically to decrease. Simulations in the early year (2017) revealed that the area of remedied land was 483.61 ha from the annual erosion weight value of −171,591.12 Mg, so that the production area was 487.23 ha for coffee plants from SPL Plantation and Mixed Gardens. The scenario offered in principle refers to the proportion of agricultural support specifically for Payments for Environmental Services in Australia and New Zealand around 21–25%. The comparison step refers to the data in 2037, the annual erosion weight is known to be only −6,578,447 Mg so that the managed land reaches 6,182.62 ha, and the production area increases by 1,025.25 ha. The condition of decreasing annual erosion weight is an expectation that more land will be planted with only coffee commodities, in line with increasing conservative thinking through the high value of erosion control carried out [Singh et al. 2021]. Erosion reduction is used by the effectiveness of erosion control, verification methods, and visual indicators to assess erosion intensity through qualitative classification [Blanco-Sepúlveda 2018]. Water erosion control is one of the essential ecosystem services used to change the soil and water processes and improve ecosystems [Pichura *et al.* 2021; Xiong *et al.* 2018]. The productivity, revenue and income in the actual model scenario are shown in Table 3.

Source: own study.

Table 3. Simulation results of sub-economic models based on time table

Year	Productivity ($kg \cdot ha^{-1}$)	Revenue	Income
		IDR	
2017	0.79	6,505.007.73	4,672,538.43
2018	1.27	10,732,852.10	8,846,818.47
2019	1.67	15,310,484.41	13,265,851.46
2020	2.00	19,842,568.85	17,637.163.63
2021	2.28	24,266,501.02	21,902,331.46
2022	2.52	28,534,812.26	26,015,866.07
2023	2.72	32,607,513.65	29,939,409.24
2024	2.89	36,452,282.93	33,642,016,48
2025	3.03	40.004.911.57	37,100,586.38
2026	3.14	43,369,358.10	40,299,898.52
2027	3.24	46,417,375.37	43,232,240,26
2028	3.33	49,187,786.86	45,896.697.62
2029	3.40	51,685,516.01	48,298,211.32
2030	3.45	53,920,477.00	50,446,502.12
2031	3.50	55,906,244.16	52,354,959.80
2032	3.54	57,659,841.29	54,039.572.93
2033	3.58	59,198,929.60	55,517,955.52
2034	3.61	60,542,731.63	56,808,506.15
2035	3.63	61,710,409.52	57,929,716.43
2036	3.65	62,720,679.86	58,899,630.68
2037	3.67	63,591,396.40	59,735,447.88

Table 3 shows an increasing trend, meaning that revenues from potential land use for coffee cultivation can increase production per year, in line with this reduced soil erosion, which causes an increase in the ability and fertility of the land, along with a higher understanding of the community towards the conservation of land resources. The use of chemical fertilisers and pesticides contributes greatly to grain production but hurts soil quality and the rural environment in China. Pesticides and chemical fertilisers decrease drastically because the land can provide optimum coffee plant productivity to manage critical land.

CONCLUSIONS

The dynamic model of critical land management to realise sustainable agriculture is divided into three sub-models. The sub-model of physical sustainability/critical land concludes that using a model simulation scenario (25% erosion control fund) shows a trend of increasing the area of production land and the area of remedied land followed by a decrease in the weight of annual erosion. The sub-model of economic sustainability obtained results at the end of the projection year showing coffee farming revenues of IDR63,591,396, meaning that the higher the value of acceptance, the farmers can provide economic welfare. The conceptual model simulation can answer the implementation of critical land management policies through efforts to realize sustainable agriculture. In the future, the generalisation of the concept in this study can be a reference for researchers with different levels of land criticality and, at the same time, think systematically, namely optimising the land's carrying capacity without ignoring the principles of sustainable natural resource conservation.

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