Plant Archives Volume 20 No. 2, 2020 pp. 7895-7904 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

ANALYSIS OF KEY VARIABLES FOR RICE FARMING SUSTAINABILITY IN THE DOWNSTREAM OF SEKAMPUNG WATERSHED : AN APPLICATION OF MICMAC METHOD

Robet Asnawi[1,2*], Bustanul Arifin[3], Wan Abbas Zakaria[3], Irwan Sukri Banuwa[4] and Zainal Abidin[3]

[1]Faculty of Agriculture, University of Lampung, Prof. Dr. Soemantri Brojonegoro Street No. 1, Bandar Lampung, 35145, Lampung, Indonesia.

[2*]Lampung Assessment for Agricultural Technology, ZA Pagar Alam Street No. 1 A. Bandar Lampung, 35145, Lampung, Indonesia.

[3]Department of Agribusiness, Faculty of Agriculture, University of Lampung, Prof. Dr. Soemantri Brojonegoro Street No. 1, Bandar Lampung, 35145, Lampung, Indonesia.

[4]Department of Forestry, Faculty of Agriculture, University of Lampung, Prof. Dr. Soemantri Brojonegoro Street No. 1, Bandar Lampung, 35145, Lampung, Indonesia.

Abstract

The sustainability of rice farming is essential in achieving rice production targets and realizing the food security of the Indonesian people. This study aimed to determine the strategic variables that defined the sustainability of rice farming in the downstream of Sekampung watershed, Lampung Province. This research was conducted in Central Lampung and East Lampung regencies from October until November 2019. This research used a prospective structural approach. The analysis method was Matrix of Crossed Impact Multiplications Applied to a Classification (MICMAC) to identify the most influential variables and their relationship with the sustainability of rice farming in the downstream of Sekampung watershed. The results of the analysis that embody the typology of strategic variables based on the strength of influence determined four classifications: 1). Influence variables (key drivers) consisted of erosion, water availability and soil fertility; 2). Key relay variables included farm cost, cropping index, productivity and land-use change; 3). Depending variable (output variable) consisted of income and exchange rate of farmers and 4) Excluded variable (autonomous variable) consisted of rice price incentives and farmers' culture in rice farming. The key variables that determined and had a strong influence on the sustainability of rice farming in the downstream of Sekampung watershed were erosion, water availability and soil fertility. The results of this study indicated important sources of information for policymakers to determine and develop sustainable rice farming.

Key words: key variables, rice farming, Sekampung, prospective structural, MICMAC.

Introduction

The upstream of Sekampung watershed is a source of irrigation water for the downstream of Sekampung watershed. However, its availability continues to decline from year to year due to high erosion and sedimentation rates caused by forest land conversion, population activities, non-conservation agriculture and others. On the other hand, the use of water for living needs, especially for drinking water and irrigation continues to increase along with population growth and food needs, especially rice where farmers will plant rice at least twice a year. In the most downstream areas of the Way Sekampung irrigation channel, crop failure always happens during the dry season due to lack of water.

Damages also occurred in the upstream (on-site) and downstream areas (off-site) of Sekampung watershed. In the on-site area, damage indicators that can be used include erosion and land productivity, while indicators in the off-site side are sedimentation and fluctuations in river discharge. The average erosion that occurred in the upstream of Sekampung watershed was 67.5 tons. $ha^{-1}.year^{-1}$ (Banuwa, 2009; Tama *et al.,* 2018) that exceeded tolerable erosion (Etol) of $38.7^{1}.year^{-1}$ (Banuwa, 2013). The high level of erosion is also triggered by land with a slope of more than 15%, which is 84.19%. From 1992 to 2000, in the Sekampung watershed area, there was a significant decrease in river discharge, *i.e.*, the minimum flow, maximum flow, average discharge and annual total discharge (Tusi, 2000). Ecological degradation includes sedimentation, water quality degradation, frequent flooding and the impact of climate change (Issaka and Ashraf, 2017; Ali *et al.,* 2017).

Sedimentation that occurred in the Sekampung watershed reached 9.1 million tons.year^{-1} while the tolerance limit was only 1.7 million tons.year^{-1} (Radar Lampung, 2006 in. The high rate of sedimentation causes many rivers and irrigation channels to be filled with sedimentation mud; thereby reducing the volume of water for irrigation. River discharge is also not evenly distributed. The ratio of maximum and minimum discharge is very high, which is 84.18 times, causing water shortages (drought) in the dry season and flooding in the rainy season. The impact of water shortages, especially during the dry season, affects the sustainability of rice farming in the downstream of Sekampung watershed. These conditions will further affect the ability of food production, especially rice and can threaten the food security of farm households.

Sustainable agriculture is an exciting topic and debate that lives in many segments of the world. The discussion mostly comes from a different perspective as to what sustainable agriculture is (Lowrance *et al.,* 1986). Sustainable agriculture is defined as a system that in the long term improves the quality of the environment and the resource base on which agriculture depends, provides basic human food needs, is economically viable and enhances the life quality of farmers and society as a whole (Crews *et al.,* 1991; Flora, 1992). Sustainability is a critical factor for ensuring long-term community livelihoods. Sustainability has many dimensions such as economic, social and environmental aspects. Maintaining the food security and sustainable ecological balance are critical challenges for intellectuals, researchers, conservationists and policymakers. Sustainable agriculture must be carried out through an ecosystem approach, where living things that live in the soil, water, plants and environment are in harmony and balance between the food chain and energy balance (Abubakar and Attanda, 2013). Innovative technologies are used to ensure agriculture sustainable and increased productivity through the use of modern irrigation systems, superior varieties, improving soil quality and preserving the environment with resource conservation technology (Delgado-Serrano *et al.,* 2015). Sustainable agriculture addresses not only many environmental and social issues but also offers innovative and economically feasible opportunities for farmers, consumers and policymakers. This study aimed to determine the strategic variables that defined the sustainability of rice farming in the downstream of Sekampung watershed, Lampung Province.

Materials and Methods

Research time and locations

This research was conducted in Central Lampung and East Lampung regencies from October until November, 2019.

Data collection

This study was designed based on a prospective structural analysis paradigm in the future thinking context. Data collection was carried out using the focus group discussion (FGD) method required in the prospective structural analysis. The FGD method encouraged knowledge sharing and transfers between participants. The FGD aimed to identify and determine strategic variables (key variables) in assessing the sustainability of rice farming in the downstream of Sekampung watershed. The scope of strategic variables for evaluating the sustainability of rice farming was the link between the upstream sector of Sekampung watershed as a source of water availability and the downstream sector as a user of water for rice farming. In this study, there were three dimensions that determined sustainability, *i.e.*, the economic aspect of rice farming such as income, farming costs, productivity and cropping index; the social dimension consists of labor scarcity, the culture of farmers rice planting, farmer institutions and policies on grain price incentives; and environmental aspects including erosion, soil fertility, water availability and land-use change.

Participants involved in the FGD represented stakeholders in agriculture, food crops, irrigation and forestry, *i.e.*, operational officers of the River Basin Research Center (Region II Lampung), officials from the Regional Development Planning Agency of Central Lampung and East Lampung Regency, officials from the Agriculture Office of Central Lampung and East Lampung, officials from Forestry of Central Lampung and East Lampung, researchers, farmers association (Gapoktan), field extension officers (PPL), irrigation managers in Trimurjo and Sekampung districts and the management of Water User Farmers' group.

In the first stage, each FGD participant provided input to define problems, identify internal and external variables that affect the sustainability of the farming. The second stage was analyzing the relationships between sustainability variables agreed upon with the scale: 0 = no relationship, 1 = weak, 2 = moderate, 3 = strong and P = potential. The final stage was entering the assessment results into the MICMAC program. This study used an FGD technique involving 25 respondents who were deliberately chosen to identify the main sustainability variables. The defined variables were grouped into three categories, *i.e.*, economic, social and environmental. The MICMAC (Matrix of Crossed Impact Multiplications Applied to a Classification) developed by (Godet and Roubelat, 1996). was used to assess variables that affected sustainability. MICMAC is part of structural analysis in which variables are mapped into components of influence and dependence in a system. MICMAC has been used for continuous analysis in various cases (Ahmed *et al.*, 2009; Arozamena and Ibarbia, 2012; Fauzi, 2019). MICMAC has the power to capture interactions between variables and identify critical variables that can be used as drivers for the system to work sustainably (Veltmeyer. and Sahin, 2014). MICMAC analysis works on the principle of matrix multiplication properties (Kannan, Pokharel and Kumar, 2009); (Diabat and Govindan, 2011); (Dewangan, Agrawal and Sharma, 2015). In this study, MICMAC was applied to identify critical variables that determined the sustainability of rice farming in the downstream of Sekampung watershed. Therefore, the results of the MICMAC analysis can be used to design better and more effective policies for a sustainability process.

MICMAC employed three basic steps that must be carried out as described in (Godet and Roubelat, 1996), *i.e.*, (1) Identifying elements (variables); (2) Describing the relationship between variables and (3) Identifying key variables. Step 1 of the MICMAC analysis in this study was identifying key variables that determined the sustainability of rice farming in the downstream of Sekampung watershed. Step 2 and step 3 were conducted automatically after the data was entered into the MICMAC computer program developed by Lipsor.

Data analysis

Data analysis was performed based on the prospective concept of structural analysis using the MICMAC method. MICMAC is software designed to improve prospective structural analysis, such as AHP (Analytical Hierarchy Process) and ISM (Interpretive Structural Modeling). The MICMAC method was developed by the Institute d'Innovation Informatique pour I'Etreprise in 1986, under the supervision of the Investigation Laboratory in Prospective Start and Organization (LIPSOR) (Godet and Roubelat, 1996); (Omran, Khorish, & Saleh, 2014). This software changed the future strategic analysis through various quantitative methods, in which almost all previous future analyzes were qualitative (Gómez-Limón, Gómez-Ramos and Sanchez Fernandez, 2009). According to (Manjunatheshwara and Vinodh, 2018). MICMAC makes it possible to analyze qualitative variables and explore diverse and uncertain future.

MICMAC aimed to identify and analyze the main variables of a system and relationships and hierarchies based on stakeholder perceptions. The MICMAC method application consisted of three stages, *i.e.*, defining the problem, identifying internal and external variables and analyzing the relationships between system variables. The first and second stages were performed through focus group discussions (FGD), while the third stage was carried out using the MICMAC software. The relationship level of mobility variables was assessed on a scale of 0 = no relationship, 1 = weak, 2 = moderate, 3 = strong and P = potential.

The results of this assessment identified the relationship of variables into three classifications of direct effect, indirect effect and potential effect. The direct effect occurs if variable A influences variable B. The indirect effect occurs if variable A influences variable B and variable B influences variable C. With the transitivity process, C is indirectly affected by A. The potential effect occurs if the effect of variable A conflicts with B. If there is no direct effect of one variable on another, it is called no effect (Hernandez and Gonzalez, 2004). This comparison between direct and indirect effect classifications confirmed the importance of specific variables and revealed that these variables may have long-term effects. Mobility and dependency between variables determined the location of the indicator variable in the input-output quadrant (Fig. 1).

Results and Discussion

Focus group discussions (FGD) identified factors considered as strategic variables that determined the sustainability of rice farming in the downstream of

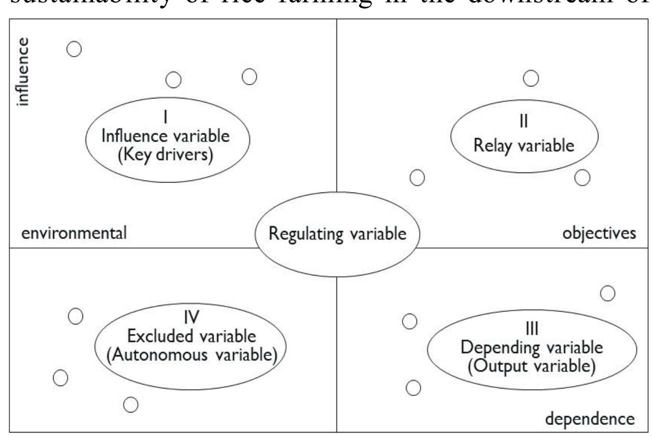

Fig. 1: Classification of variables in MICMAC a (Fauzi, 2019; Dubey and Ali, 2014; Majumdar *et al.,* 2016).

Table 1: Identification of key variables of rice farming sustainability.

Dimension	Variable	Short Label
Economic	1. Farmer income	1. INCOME
	2. Farming cost	2. COST
	3. Productivity	3. PROD
	4. Farmers exchange rate	4. FER
	5. Cropping index	5. CROP
Social	6. Labor scarcity	6. LABOR
	7. Farmer's rice planting culture	7. CULTURES
	8. Farmer institution	8. INST
	9. Price incentive	9. PRICE
Environmental	10. Erosion	10. EROSION
	11. Soil fertility	11. SOIL
	12. Water availability	12. WATER
	13. Land conversion	13. LAND

Sekampung watershed. These variables were grouped into three dimensions of sustainability, *i.e.*, economic, social and environmental (Table 1). The next step was to identify the type of each variable as observed from the intensity of its power in influencing other variables or depending on different variables through visualization of interrelation graphs (Fig. 1).

According to, the variables in MICMAC were grouped into four quadrants based on the categories of dependence and influence. Influence variables or often called determinant variables/key drivers in quadrant I describe variables that are very influential with little dependence. This variable is a crucial element in the system because it can act as a critical factor. Relay variables in quadrant II are instrumental but highly dependent variables. This variable is often categorized as factors that describe the instability of a system. Every change in this variable has severe consequences for other variables. The dependent variables in quadrant III are also called the output variables, which are characterized by high dependence but have a small influence. This variable is quite sensitive to changes in influence variables and relay variables. Quadrant IV describes excluded variables or known as autonomous variables, which are characterized by small influences and small dependent ones (Saxena *et al.,* 1990). This variable is excluded because it will not stop the operation of a system or utilize the system itself.

The driving factors and the dependent forces based on variables can be classified into four forms, i.e., driving factors, dependent factors, linkage factors and autonomous factors (Singh *et al.,* 2015; Majumdar *et al.,* 2016). Based on the results of FGD, it was agreed that 13 key variables determined the sustainability of rice farming from three dimensions (economic, social and environmental), with a short label code of each variable (Table 1). Economic, environmental and social (community) links are essential aspects that need to be considered for overall sustainability (Carter and Rogers, 2008). It is necessary to describe interactions in understanding their overall impact on future generations (Carter and Easton, 2011).

After evaluating the relationships between variables, all of these variables were assessed through the Matrix of Direct Influence (MDI) using MICMAC tools (Delgado-Serrano *et al*., 2015). The MDI matrix is shown in fig. 2. Identification was made by considering data from previous changes, characterizing the current situation and identifying upcoming trends. At this stage, all FGD participants agreed to fill in the data in the Matrix Direct Influence (MDI), with the following scale: 0 = no influence, 1 = weak influence, 2 = moderate effect, 3 = strong effect and P = potential effect. MDI provided a general description of the position of group variables related to the intensity of the influence of variables on other variables. From this mapping, we found several variables that have a strong direct influence on other variables and other variables that have a weak influence. This mapping also showed the influence of variables that have an impact on other variables and also as feedback on these variables. MDI analysis results obtained typology map of the variables that were directly affected in fig. 2.

Influences range from 0 to 3, with the possibility to identify potential influences: 0: No influence, 1: Weak, 2: Moderate influence, 3: Strong influence, P: Potential influence.

	1 : INCOME	2 : COST	3 : PROD	4 : FER	5 : CROP	6 : LABOR	7 : CULTURE	8 : INST	9 : PRICE	10 : EROSION	11 : SOIL	12 : WATER	13 : LAND
1 : INCOME	0	2	1	3	1	2	0	0	0	P	0	0	1
2 : COST	3	0	3	3	0	0	2	2	0	P	2	2	2
3 : PROD	3	0	0	3	3	2	1	0	1	0	0	0	3
4 : FER	1	1	1	0	1	0	0	1	0	0	0	0	1
5 : CROP	3	2	3	1	0	0	3	0	0	0	3	0	2
6 : LABOR	2	2	3	0	2	0	0	2	0	0	0	0	3
7 : CULTURE	1	1	3	0	3	0	0	0	0	0	0	3	2
8 : INST	0	1	2	0	2	3	2	0	2	0	0	0	2
9 : PRICE	3	1	1	3	0	0	0	0	0	0	0	0	2
10 : EROSION	2	3	3	2	2	0	1	0	0	0	3	3	2
11 : SOIL	2	3	3	0	3	2	0	0	0	0	0	3	3
12 : WATER	3	3	3	2	3	2	0	0	0	0	3	0	3
13 : LAND	0	0	2	0	2	3	2	0	0	3	2	3	0

Fig. 2: Matrixs of Direct Influence (MDI) (*Focus Group Discussion*, 2019).

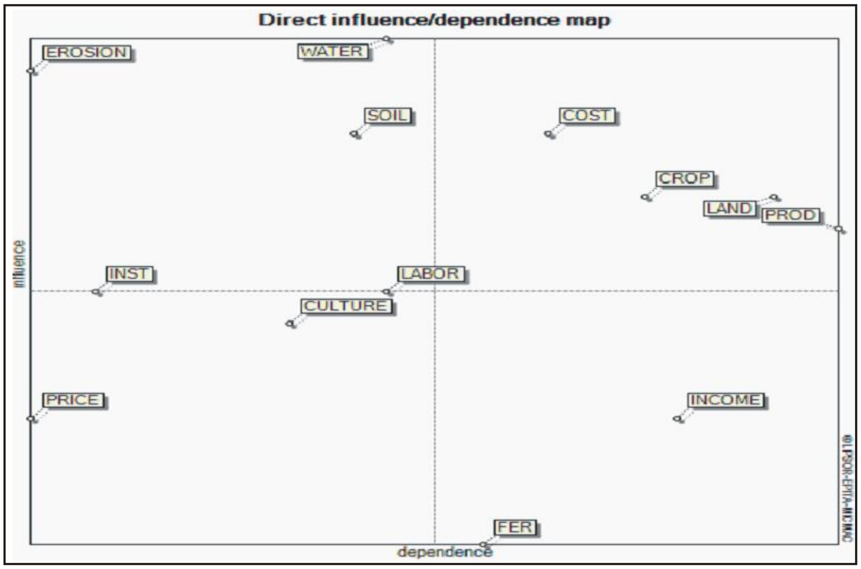

Fig. 3: Map of direct influence (MDI).

The influence of variables from the strongest to the weakest can be identified from the colors connecting the lines between variables: 1) the red line indicates that the influence is powerful; 2) the thick blue line indicates that the effect is relatively stable; 3) the thin blue line indicates that the effect is moderate; 4) the black lines indicate that the effect is weak and 5) dotted lines show that the influence is weak. The results of this analysis can be a direction for decision-makers to focus on the variables that have the most substantial impact because these variables will determine the direct effect on other variables.

The variables of erosion (EROSION), water availability (WATER) and soil fertility (SOIL) were the most influential variables affecting the sustainability of rice farming. Erosion had a strong influence on water availability, soil fertility, farming cost and productivity. Water availability had a strong influence on soil fertility, farming cost and rice productivity, while soil fertility had a strong influential on cropping index, water availability and rice productivity. The intensity of its effect on other variables as a whole is shown in the graph of direct influence with a percentage of 75% in MICMAC software (Fig. 4).

The results of the analysis of indirect effects indicated that stability was more satisfying in qualifying variables. The output from the indirect classification model will confirm system stability. If there are many changes in the variable position of the direct influence map, the system has low stability and vice versa. The results of the analysis of indirect effects in fig. 5 showed that there was no change in the position of variables, especially input and output variables, except farmer's culture (CULTURE) that moved from autonomous variables to influence variables and productivity (PROD) from relay variables to dependent variables. This result showed that the system and typology of variables that were classified in the indirect effect were stable.

When viewed from the intensity of the effect, the classification of variables based on indirect effects experienced a significant change, as observed from the difference in the color of the line connected to the variable (Fig. 6). Compared to direct effects, the analysis of indirect impacts obtained variables that have powerful effects such as erosion (EROSION) and water availability (WATER). Erosion and water availability had a powerful effect (thick red line) on increasing rice productivity. In contrast, soil fertility had a relatively stable impact (blue line) on rice productivity and several other variables.

The dashed line shows the variable change from the initial to the final position after calculating the indirect effect. The shifting of these variables still occurs in the same quadrant but only changes in magnitude (Fig. 7). For example, the erosion variable (EROSION), water availability (WATER) and soil fertility (SOIL) are still in the quadrant I (influence variable) and the farmer income variable (INCOME) and the farmer exchange

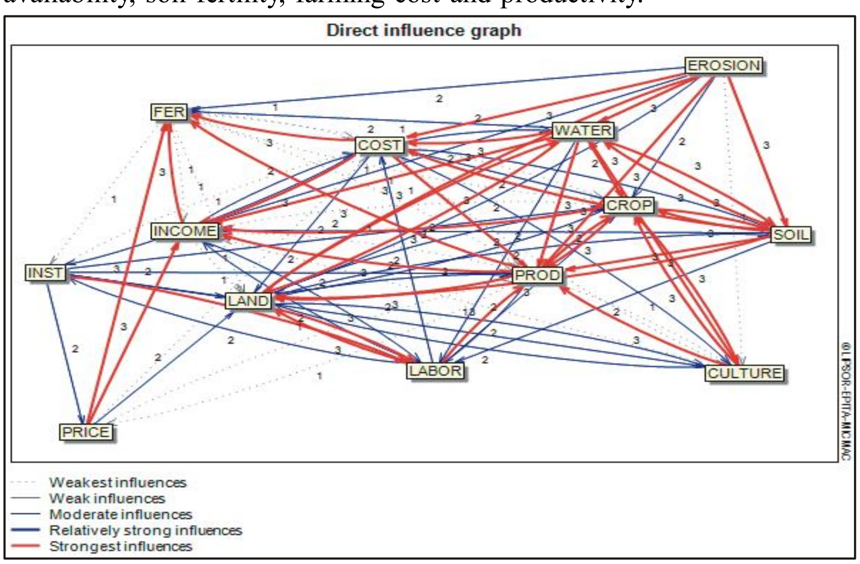

Fig. 4: Intensity of direct influence variable.

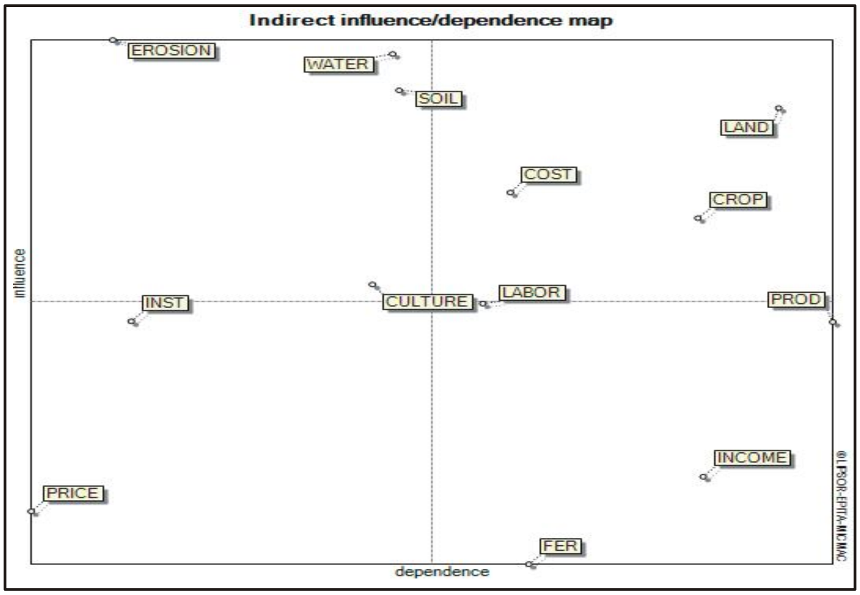

Fig. 5: Map of indirect influence (MII).

rate (FER) are still in quadrant II (output variable). In general, there is no change in the position of the influence of the direct variable (MDI direct effect matrix) or the MII indirect influence matrix. Based on the results of the analysis, the grouping of variables based on direct and indirect effects is stable.

Fig. 8 explains the comparison of ratings between variables according to their influence and the transfer of several variables after indirect effects were calculated. For example, the availability of water (WATER) which was initially in the first rank shifted to the second rank. It was replaced with erosion (EROSION) which was changed from the second rank to the first rank of the MDI matrix. Other variables such as farming cost (COST) was changed from the third to the fifth, while soil fertility (SOIL) was increased from the fourth to the third after accounting for indirect effects. These results showed that the erosion and water availability variables were still the most influential variables on the sustainability of rice farming in the downstream of Sekampung watershed. The significant erosion rate that occurred in the upstream of Sekampung watershed (on-site) as a source of water caused a high percentage of sedimentation which in turn had an impact on the low river flow and availability of water in the downstream of Sekampung watershed. Water is a significant factor in the sustainability of rice farming in the downstream of Sekampung watershed because lack of water causes crop failure and decreases farmers' income. According to Fuadi *et al.,* (2016) inadequate water supply causes rice growth to be disrupted even can cause rice plants to die due to drought.

Comparison of ranking, according to the dependence, is shown in fig. 9. When viewed from the aspect of dependence, several main variables, *i.e.*, productivity (PROD), land-use change (LAND), farmer income (INCOME) and crop index (IP) were consistent in the four significant sequences of the dependent variable. The farming cost variable (COST) exchanged positions with the farmer exchange rate (FER) from the fifth to the sixth. Farmer exchange variable (FER) had a high dependency on farming sustainability. The last variable from the dependency aspect was the price incentive (PRICE) which exchanged positions with erosion (EROSION) from the twelfth to the thirteenth. In contrast, the erosion (EROSION) was changed from the level thirteen to the twelve, after indirect effect was calculated. Based on the calculation results, the consistency of the system built of the INCOME and FER variables were still included in the five highest rankings from the dependency aspects as well as the output variables. In contrast, erosion (EROSION) and water availability (WATER) were included in the five lowest rankings of the dependency aspects. These results indicated that these variables had a weak dependency effect, but had high influence effect on the farm sustainability.

The results of this study are beneficial to policymakers for the sustainability of rice farming in the downstream of Sekampung watershed

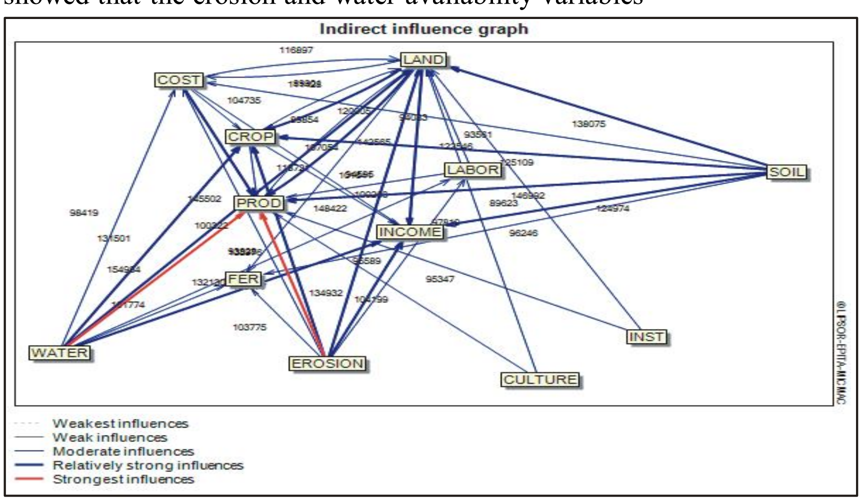

Fig. 6: Intensity of indirect influence variable.

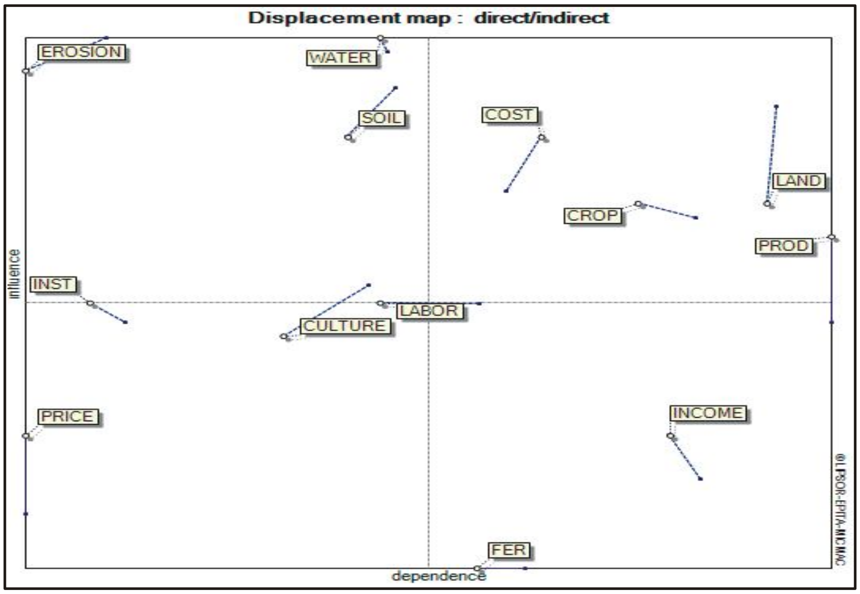

Fig. 7: Displacement map between variables from direct to indirect effects.

in determining the priority scales of the key variables that should be added in their development compared to other variables. The key variable that obtained the highest rankings must be prioritized before the low ranking variables. Prospective structural analysis is a method built upon the development of future scenarios based on the historical trends of a system. Prospective structural analysis is a powerful method for identifying key variables (domain drivers) and studying the relationship between the dependent and independent variables of a system (Delgado-Serrano *et al.,* 2015). The primary purpose of this method is to reduce future uncertainties, create possible or desirable scenarios and encourage the actions needed to achieve them. Prospective analysis can identify the existence of complex strategic factors and their independent relationships that are required to realize long-term quality.

The prospective structural analysis assumes that the future is different from the past and is not forced, but can be constructed. Prospective structural techniques of analysis will analyze the complexity of the elements, factors and their relationships and understand the system of critical variables in the current and future situations. The relationship between these variables is a rich source of information. It will determine a thought about some problems in the future context (Majumdar *et al.,* 2016). Through structural analysis, many variable functions will be identified, making it easier for decision-makers to determine the correct policy.

Prospective structural analysis is carried out by a working committee consisting of expert actors from the field studied without excluding external advisors (Omran *et al.,* 2014). Prospective structural analysis has different advantages from other analyzes in these factors, such as allowing group experts to find methods and provide ideas for group members, allowing group members to explain their views and thoughts about a particular problem (Sundawa, 2016). Structural analysis was initially philosophical and qualitative, but later, it was changed and operationalized into various quantitative methods (Gómez-Limón *et al.,* 2009). Structural analysis methods are beneficial for policymaking, operational planning, impact determination strategies and evaluation of future alternatives operated in the form of a matrix.

The variables of erosion, water availability and soil fertility were the key variables that determined of rice farming sustainability in the downstream of Sekampung watershed. Erosion in the upstream of Sekampung watershed has an indirect impact on farming in the downstream of Sekampung watershed, especially in terms of water availability due to high sedimentation rates. Land management activities in watersheds that do not pay attention to the principle of conservation have the potential to increase land use change and soil erosion. Eroded land will be carried to the river and cause river siltation due to sediment deposition (Sutrisno *et al.,* 2011; Sarminingsih, 2011). Damage to land resources, especially in the upper watershed, will reduce land productivity and affect production, ecological and hydrological functions of watersheds (Ilyas, 2002).

The higher rate of erosion causes high sedimentation rates and decreases river discharge or reduces water

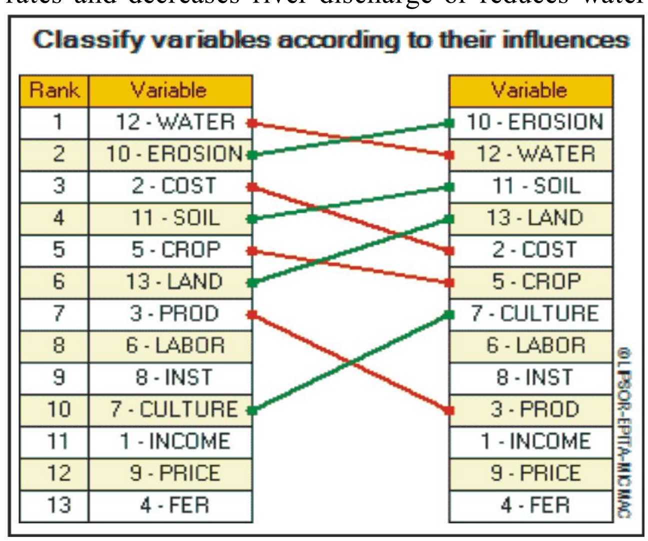

Fig. 8: Ranking comparison according to the dependence.

quantity and quality (Issaka and Ashraf, 2017). Lack of water will decrease productivity, increase farming costs, reduce crop index and soil fertility and decrease income of farmers. Lack of water irrigation causes the high additional farming costs used for watering. Fertile soils generally have a high water retention capacity that can be used during the dry season. Additionally, fertile soils can also increase cropping indexes, reduce farming costs and reduce land-use change because fertile soils will cause farmers to continuously grow rice without thinking of switching to non-rice or non-agricultural functions.

These results showed that the erosion and water availability variables were still the most influential variables on the sustainability of rice farming in the downstream of Sekampung watershed. The significant erosion rate that occurred in the upstream of Sekampung watershed (on-site) as a source of water caused a high percentage of sedimentation which in turn had an impact on the low river flow and availability of water in the downstream of Sekampung watershed. Water is a significant factor in the sustainability of rice farming in the downstream of Sekampung watershed because lack of water causes crop failure and decreases farmers' income. According to Fuadi *et al.,* (2016) inadequate water supply causes rice growth to be disrupted even can cause rice plants to die due to drought.

This finding has implications to policymakers for rice farming sustainability in the downstream of Sekampung watershed that they must seriously monitor the relay variables and direct all managerial efforts towards these variables in the planning and policy interventions. At the same time, policymakers must also be aware of the relative shortcomings of the current relay variable, which is one of the problems that must be resolved to achieve the

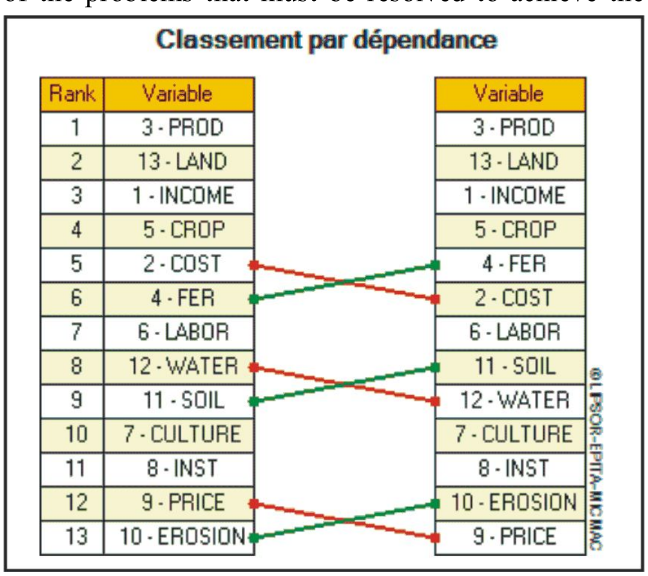

Fig. 9: Ranking comparison according to the influence.

desired results. Based on the results of the assessment of the variables found in this study, relay variables such as farming cost, cropping index, productivity and land-use change can still be optimized.

This finding is a firm basis for all parties involved in policy-making for the sustainability of rice farming in the downstream of Sekampung watershed. By understanding the results of this study, stakeholders can be included in the decision-making in the sustainability of rice farming in the downstream of Sekampung watershed. Reducing erosion rates in the upstream of Sekampung watershed, increasing the availability of water irrigation and maintaining soil fertility were key variables that determined the sustainability of rice farming in the downstream of Sekampung watershed.

Ensuring of rice farming sustainability in the downstream of Sekampung watershed, policymakers must seriously control the dominant variables and relay variables and also direct all managerial efforts towards the desired results. Policies of rice farming sustainability in the downstream of Sekampung watershed based on the findings of this study will produce benefits in conserving natural resources, maintaining soil fertility and supporting food security. All stakeholders to support the sustainability of rice farming in the downstream of Sekampung watershed can be involved in the appropriate decision-making process that promotes economic, social and environmental policies.

Conclusion

This research identified 13 variables that were considered as the essential variables for rice farming sustainability in the downstream of Sekampung watershed. The result of MICMAC analysis based on the strength of influence found four classification of variables, *i.e.*, 1). Input variables (dominant variables) consisted of erosion, water availability, soil fertility and farmer institutions; 2). The key variables (relay variables) included farming cost, productivity, cropping index and land-use change; 3). Autonomous variables consisted of farmers' culture of rice planting and price incentive policies; 4). Output variables included the farmer's income and farmer exchange rate. Finally, we revealed that the method used in this study is a new way of constructing systematic analysis as well as the role of variables to determine system stability. The application of prospective structural analysis with the MICMAC method in the decision-making process considers the position and intensity of the influence of variables in the form of a direct or indirect impact (and no causal relationship). This research clarified the validity and strength of the approach in determining the variables that were most influential for the sustainability of rice farming in the downstream of Sekampung watershed as expected in the future.

Acknowledgement

The author would like to thank Prof. Ahmad Fauzi, M.Sc, PhD, the chair of the Study Program for Planning and Development in Rural Areas, IPB University, for critical comments on the manuscript and providing inputs in this sustainability analysis. This research was a part of a dissertation which was submitted as a partial fulfillment to meet requirements for the degree of Doctor of Philosophy at University of Lampung, Indonesia.

References

Abubakar, M.S. and M.L. Attanda (2013). The concept of sustainable agriculture: Challenges and prospects. *IOP Conference Series: Materials Science and Engineering.*, **53(012001):** 1-5. https://doi.org/10.1088/1757-899X/53/1/012001.

Ahmed, M.T., M. Saleh, A.F. Abdelkadir and A. Abdelrehim (2009). El-Maghara scenario a search for sustainability and equity: An Egyptian case study. *Journal of Futures Studies.*, **14(2):** 55-90.

Arozamena, E.R. and A.D. Ibarbia (2012). Influential Aspects Modeling For The Development Of Sustainable Strategies In Industrial Areas. *Proceedings from the 16th International Congress on Project Engineering*, 85-93.

Awang Ali, A.N., J. Ariffin, M.A. Mohd Razi and A. Jazuri (2017). Environmental Degradation: A Review on the Potential Impact of River Morphology. *MATEC Web of Conferences.*, **103:** 1-8. https://doi.org/10.1051/matecconf/201710304001

Banuwa, I. (2013). *Erosi*. Pranandamedia Group.

Banuwa, I.S. (2009). Prediksi erosi pada berbagai penggunaan lahan di das sekampung hulu provinsi lampung. *Prosiding Semirata BKS PTN Wilayah Barat Bidang Ilmu Pertanian*, 1-14.

Carter, C.R. and P.L. Easton (2011). Sustainable supply chain management: Evolution and future directions. In *International Journal of Physical Distribution and Logistics Management.*, **41(1):** 46-62. https://doi.org/10.1108/09600031111101420.

Carter, C.R. and D.S. Rogers (2008). A framework of sustainable supply chain management: Moving toward new theory. *International Journal of Physical Distribution and Logistics Management.*, **38(5):** 360-387. https://doi.org/10.1108/09600030810882816.

Crews, T.E., C.L. Mohler and A.G. Power (1991). Energetics and ecosystem integrity: The defining principles of sustainable agriculture. *American Journal of Alternative Agriculture.*, **6(3):** 146-149. https://doi.org/10.1017/S0889189300004124.

Delgado-Serrano, M. del M., M. Ambrosio-Albalá and F. Amador (2015). Exploration de l'analyse structurale prospective pour évaluer l'importance du développement rural territorial en Espagne et Nicaragua. *Cuadernos de Desarrollo Rural.*, **12(76):** 35-56. https://doi.org/10.11144/Javeriana.cdr12-76.epsa.

Dewangan, D.K., R. Agrawal and V. Sharma (2015). Enablers for Competitiveness of Indian Manufacturing Sector: An ISM-Fuzzy MICMAC Analysis. *Procedia - Social and Behavioral Sciences.*, **189:** 416-432. https://doi.org/10.1016/j.sbspro.2015.03.200.

Diabat, A. and K. Govindan (2011). An analysis of the drivers affecting the implementation of green supply chain management. *Resources, Conservation and Recycling*, **55(6):** 659-667. https://doi.org/10.1016/j.resconrec.2010.12.002

Dubey, R. and S.S. Ali (2014). Identification of flexible manufacturing system dimensions and their interrelationship using total interpretive structural modelling and fuzzy MICMAC analysis. *Global Journal of Flexible Systems Management.*, **15(2):** 131-143. https://doi.org/10.1007/s40171-014-0058-9.

Fauzi, A. (2019). *Teknik Analisis Keberlanjutan*. PT. Gramedia Pustaka Utama, Jakarta. Kompas Gramedia.

Flora, C. (1992). Journal of Sustainable Landscape Ecology. *Journal of Sustainable Agriculture.,* **2(3):** 37-49. https://doi.org/10.1300/J064v02n03.

Fuadi, N.A., M.Y.J. Purwanto and S.D. Tarigan (2016). Kajian Kebutuhan Air dan Produktivitas Air Padi Sawah dengan Sistem Pemberian Air Secara SRI dan Konvensional Menggunakan Irigasi Pipa. *Jurnal Irigasi.*, **11(1):** 23. https://doi.org/10.31028/ji.v11.i1.23-32.

Godet, M. and F. Roubelat (1996). Creating the Future: The Use and Misuse of Scenarios. *Long Range Planning.*, **29:**164-171. https://doi.org/10.1016/0024-6301(96)00004-0.

Gómez-Limón, J.A., A. Gómez-Ramos and G. Sanchez Fernandez (2009). Foresight analysis of agricultural sector at regional level. *Futures.*, **41(5):** 313-324. https://doi.org/10.1016/j.futures.2008.11.007.

Hernandez and Gonzalez (2004). Análisis prospectivo de la Gestión de la Información y el Conocimiento. *Quorum Academica.*, **1(2):** 3-33.

Ilyas, M.A. (2002). Sedimentasi dan dampaknya pada DAS Citarum Hulu. *Jurnal Teknologi Lingkungan.*, **3(2):** 159-164. Retrieved from http://www.kelair.bppt.go.id/Jtl/2002/vol3-2/11sedim.pdf.

Issaka, S. and M.A. Ashraf (2017). Impact of soil erosion and degradation on water quality: a review. *Geology, Ecology and Landscapes.*, **1(1):** 1-11. https://doi.org/10.1080/24749508.2017.1301053.

Kannan, G., S. Pokharel and P.S. Kumar (2009). A hybrid approach using ISM and fuzzy TOPSIS for the selection of reverse logistics provider. *Resources, Conservation and Recycling.*, **54(1):** 28-36. https://doi.org/10.1016/j.resconrec.2009.06.004.

Lowrance, R., P.F. Hendrix and E.P. Odum (1986). A hierarchical approach to sustainable agriculture. *American Journal of Alternative Agriculture.*, **1(4):** 169-173. https://doi.org/10.1017/S0889189300001260.

Majumdar, R., P.K. Kapur and S.K. Khatri (2016). Assessment of environmental factors affecting software development process using ISM & MICMAC analysis. *International Journal of Systems Assurance Engineering and Management.*, **7(4):** 435-441. https://doi.org/10.1007/s13198-016-0477-4.

Manjunatheshwara, K.J. and S. Vinodh (2018). Application of TISM and MICMAC for analysis of influential factors of sustainable development of tablet devices: a case study. *International Journal of Sustainable Engineering.*, **11(5):** 353-364. https://doi.org/10.1080/19397038.2017.1387186.

Omran, A., M. Khorish and M. Saleh (2014). Structural Analysis with Knowledge-based MICMAC Approach. *International Journal of Computer Applications.*, **86(5):** 39-43. https://doi.org/10.5120/14985-3290.

Sarminingsih, A. (2011). Study of change in land tataguna on the level of erosion hazards in dengkeng watershed. *Jurnal Presipitasi/ : Media Komunikasi Dan Pengembangan Teknik Lingkungan.*, **15(2):** 158-164.

Saxena, J.P., Sushil and P. Vrat (1990). Impact of indirect relationships in classification of variables-a micmac analysis for energy conservation. *Systems Research.*, **7(4):** 245-253. https://doi.org/10.1002/sres.3850070404.

Singh, S., R. Kumar and U. Kumar (2015). Modelling factors affecting human operator failure probability in railway maintenance tasks: an ISM-based analysis. *International Journal of Systems Assurance Engineering and Management.*, **6(2):** 129-138. https://doi.org/10.1007/s13198-014-0255-0.

Sundawa, T.T. (2016). *Pendugaan Erosi Pada Area dan Pemanfaatan Tanaman Bambu di Desa Waturejo Kecamatan Ngantang Kabupaten Malang* (Universitas Muhammadiyah Malang)., **2(2):** https://doi.org/10.1016/j.cya.2015.11.011.

Sutrisno, J., B. Sanim, A. Saefuddin and S.R.P. Sitorus (2011). The Policy Direction for Controlling of Erosion and Sedimentation at Keduang Sub-Watershed in Wonogiri Regency. *Jurnal Ilmiah Ilmu Tanah Dan Agroklimatologi.*, **8(2):** 105-118.

Tama, A., I. Kustiani and A. Siregar (2018). Analisis Ekonomi Teknik Investasi Proyek Regulating Dam Way Sekampung. *J.R.S.D.D.*, **6(4):** 569-576.

Tusi, A. (2000). *Analisa Trend Perubahan Iklim*. Lampung.

Veltmeyer, J. and O. Sahin (2014). Modelling Climate Change Adaptation using cross-impact analysis: An approach for integrating qualitative and quantitative data. *Proceeding of International Environmental Modelling and Software Society (IEMSs). San Diego, CA. USA.*, **4:** 1945-1952.