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MORALITY BEFORE KNOWLEDGE

A system dynamics model for rice farmers' livelihood resilience in Indonesia coastal area

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ABSTRACT

Background: Climate change has become a major global challenge, particularly for vulnerable archipelagic and agrarian countries like Indonesia. Many rice fields in coastal areas—including Cirebon District—are highly exposed to extreme climate events such as prolonged droughts. These conditions disrupt rice farmers' livelihood systems and reduce their income, threatening their overall livelihood resilience. **Methods:** This study employed a mixed-methods approach by integrating qualitative and quantitative data to develop a system dynamics model. The model explored interactions between livelihood capital assets, self-organization, learning capacity, and climate conditions. Livelihood resilience was assessed through farmers' income as a key livelihood outcome. **Finding:** Model outcomes show that rice farmers' livelihood systems are not resilient to drought impacts, as their income consistently falls below the ideal threshold. Drought events disrupt livelihoods and lead to income losses, and current farmer-led adaptation efforts are insufficient to improve resilience. Without intervention from government or relevant stakeholders, the livelihood system is projected to remain non-resilient in the future. **Conclusion:** Rice farmers in Cirebon District lack adequate resilience to cope with drought impacts. Strengthening livelihood resilience requires targeted government interventions to improve critical subsystems, including irrigation governance, crop insurance mechanisms, adaptive farming capacity, and access to climate information. **Novelty/Originality of this article:** This study provides a system-level understanding of rice farmers' livelihood resilience by integrating system dynamics modeling with mixed-methods data. It offers a holistic analysis of how livelihood assets, learning capacity, self-organization, and climate stressors interact, and identifies leverage points for policy intervention in drought-prone coastal regions.

KEYWORDS: climate change; drought; livelihood resilience; rice farmers; system dynamics.

1. Introduction

Over recent decades, climate change has been widely recognized as a critical global challenge because of its profound effects on environmental systems. Climate change caused an increasing global surface temperature of 0.85°C in 1880-2012 (Intergovernmental Panel on Climate Change, 2014). The global surface temperature is projected to increase 0.4-1.1°C in 1990-2025, and 0.8-2.6°C in 1990-2050, and continue to increase by 1.4-5.8 C in 1990-

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2100 (Intergovernmental Panel on Climate Change, 2001). In Indonesia, the temperature increased around 0.5°C during the 20th century and is projected to increase by 0.8-1°C in 2020-2050 relative to the baseline period in 1961-1990 (BAPPENAS, 2010). Climate change influences the changes in the hydrological cycle and the rising frequency and severity of extreme weather events that can lead to hazards or natural disasters, and is further exacerbated by environmental degradation (Intergovernmental Panel On Climate Change, 2012). From 2005 to 2015, Indonesia experienced an increase in natural disasters with 98% of hydro-meteorological disasters including drought, and 2% of geological disasters (BNPB, 2016a). Zikra (2015) highlight that the effects of climate change increasingly compound and amplify longstanding issues affecting coastal areas. Coastal communities rely heavily on natural resources to be very vulnerable as their livelihoods are influenced by climate change (Cinner et al., 2018; Fischer 2018). Indonesia's circumstance as a climate-vulnerable archipelagic and agrarian country is reflected in its coastal rice-growing areas, which are highly exposed to extreme weather events. Cirebon District, located on Java's northern coast, represents a coastal rice-producing area with high vulnerability to climate change. The coastline in this area stretches for approximately 54 km and a coastal area of 50,720 ha with an agriculture area of 32,200 ha. The rice farmers in Cirebon coastal area are affected by extreme weather events, among others Pegagan Kidul Village in Kapetakan Subdistrict.

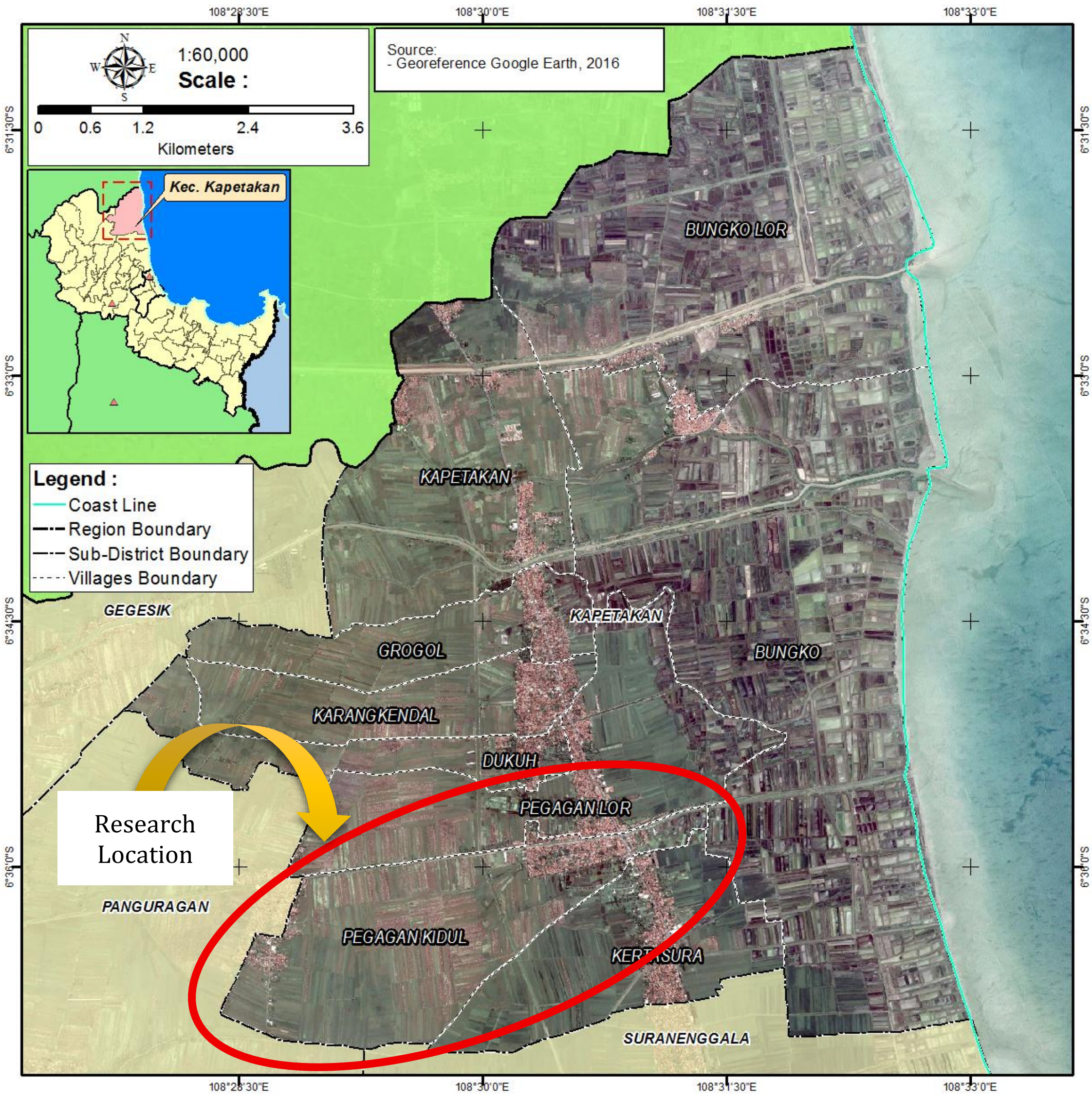

Fig. 1. Research location

Agricultural production has declined in recent years due to climate variability caused by droughts that limit water supplies (Williams, 2016; Rahut & Alli, 2017; Karimi et al., 2018; Makuvaro et al., 2018). Pratiwi et al. (2018a) argue that Kapetakan experienced a decline in rice production of around 48% in 2015 compared to 2014, because drought conditions disrupted the flow of upstream water to irrigated coastal rice fields. The vulnerability of the agricultural sector caused by climate change ultimately results in a decrease in farmers' income, while household living costs and costs for further cultivation remain (Abid et al., 2016a; Rahut & Ali, 2017; Pratiwi et al., 2018a). Accordingly, this study investigates the resilience of livelihood systems among rice farmers in addressing the impacts of drought in coastal areas by using system dynamics modeling. The study further elaborates on the interrelationships and problems that occur in the natural environment (extreme weather events), artificial environments (agricultural areas), and social environment (socio-economic characteristics of people who work in agriculture). The results can be used to find out adaptation options that need to be taken in dealing with the effects of drought to reach livelihood resilience.

1.1 Climate change and drought

The Intergovernmental Panel on Climate Change (2014) states that climate change refers to long-term changes in the climate system caused directly or indirectly by human activities that modify the composition of the global atmosphere, beyond the natural climate variability observed over comparable time scales. Future climate will depend on global warming caused by past and future anthropogenic emissions and natural climate variability (Intergovernmental Panel On Climate Change, 2014). Climate variability encompasses variations in mean climate conditions and other statistical measures—such as variability and extreme events—across spatial and temporal scales beyond individual weather events (Intergovernmental Panel On Climate Change, 2014). Variations in climate conditions can intensify wet and dry extremes, leading to significant environmental, economic, and social consequences. El Nino/Southern Oscillation (ENSO) causes climate variability and seasonal shifts, primarily through reduced rainfall and increased air temperatures (Irawan, 2006; Bhuvaneswari et al., 2013). El Nino reflects deviations in oceanic conditions, manifested by increased sea surface temperatures along the equatorial Pacific (Irawan, 2006; Bhuvaneswari et al., 2013; Capa-Morocho et al., 2014). El Nino events lead the dry season to become longer, the rainy season shorter and the monthly rainfall lower. El Nino also affects agricultural production, especially food plants that are relatively short-lived, because of changes in rainfall, air temperature, and humidity. Climate change and variability are projected to significantly impact water resources, food security, infrastructure, and agricultural incomes in rural areas, with implications for global food crop production (Intergovernmental Panel On Climate Change, 2014). In the context of hazards, drought is one of the impacts of extreme weather conditions that indicates the ecosystem and human-system vulnerability and exposure to current climate variability. Drought is widely recognized as a highly destructive natural disaster, which is projected to increase and expand in scope as a result of climate change (Chang et al., 2018).

1.2 Livelihood resilience

Current challenges for livelihoods are increasingly high due to climate uncertainty that affects human livelihoods to be vulnerable. Addressing livelihood vulnerability can be done if there is a resilience of each system at the level of individuals, households, communities, and also institutions. Curtin & Parker (2014) argue that resilience is the capacity of a system to recover and reorganize from various disturbances or to switch from a condition that causes change without changes to the system's structure or function. Livelihood approach is basically used to understand the resources a person has and the strategies adopted to make a living in order to meet the needs of life (Speranza et al., 2014). Livelihood resilience is the livelihood capacity to absorb stress and shock with strategies that can sustain or enhance important assets and functions (Speranza et al., 2014). A livelihood can be resilient if it can maintain its main function as a source of fulfillment of life's needs, and is able to absorb the effects of stress and shock without causing a large reduction in productivity and welfare. The livelihoods concept must be in accordance with social-ecological perspectives as its agreed approach is relations of human and environment (Tanner et al., 2015). According to the social–ecological resilience framework, resilience encompasses the abilities to withstand disturbance, self-organize after disruption, and adapt through learning (Carpenter et al., 2001; Milestad, 2003; Folke, 2006; Speranza et al., 2014). Regarding that, Speranza et al. (2014) state that the livelihood resilience is structured around buffering capacity derived from livelihood assets, self-organization and the capacity to learn. Milestad (2003) argues that self-organization, the capacity to learn and the ability to adapt are prerequisites for increasing buffer capacity. Therefore, resilience is sustained when buffering capacity is maintained, self-organization is present and supported, and learning processes are actively taking place.

Buffer capacity in the context of livelihood resilience can be defined as the capacity of livelihood capital assets, including natural, human, economic, social and physical capital, which can be utilized to obtain livelihoods and to respond the opportunities and risks and thereby minimize vulnerability or improve welfare (Speranza et al., 2014; Tanner et al., 2015). Table 1 outlines several indicators that can be used to assess livelihood capital assets. Livelihood resilience places more emphasis on strengthening adaptive capacity by utilizing access to capital assets to deal with impacts, both before and after stress and shock occur. However, the capacity of livelihood capital assets depends on livelihood strategies that have implications for reducing or increasing the capacity. Self-organization can be formed through communities, collective networks or external institutions that have adaptive capacity, empowerment and social interaction (Obrist et al., 2010; Nyamwanza, 2012). According to Milestad (2003), self-organization in agricultural systems refers to the ability of farming groups to build adaptable networks and engage with social, economic, and environmental institutions beyond the local scale. According to Tripathi & Mishra (2017), social networks and collective activities can be a support system for improving adaptation strategies in agriculture as response to the impacts of climate change impacts. On the other hand, Euler & Heldt (2018) argue that self-organization can enhance individuals' knowledge, skills, and competencies, thereby enabling improvements in their living conditions. Thus, livelihood resilience requires strengthening the interaction of each individual in order to network with communities and institutions that have more resilience when compared to individual resilience.

Table 1. Livelihood capital asset indicator

Capital	Definition	Indicator	Source
Natural	Natural resources that can provide environmental services to support production activities.	Terrestrial ecosystems (forests, rice fields, grasslands, savannahs, etc.), aquatic ecosystems (rivers, lakes, swamps, coral reefs, estuaries, etc.), biological resources (flora and fauna).	DFID (1999), Brocklesby & Fisher (2003), Elasha et al. (2005), Reed et al. (2013), Keshavarz et al. (2017).
Human	An asset based on the quantity and quality of available human or labor resources.	Educational achievements, skills, productive age, reading and writing abilities, health.	
Financial	Stock of money or savings that can be used at any time.	Income, savings, access to loans.	
Social	An asset in the form of participation from certain group memberships.	Vertical and horizontal social networking and interaction, membership in an organization, mutual trust in community relations.	
Physical	Resources created by economic production and utilized to support other economic activities.	Road networks, transportation equipment, machinery, irrigation networks, electricity, communication equipment, warehouses (storage areas).	

Capacity for learning, connotes adaptive management, is acquiring knowledge or skills that combine previous experience to determine current actions (Speranza et al., 2014). In addition, Nyamwanza (2012) argues that livelihood resilience requires learning to cope with change and uncertainty, that are having the ability to look for issues related to livelihood diversification (in a broader conceptualization), learning from crises and building quick feedback mechanisms to livelihood challenges, correcting the failure of past experience, and improving decent livelihood strategies during a crisis period. Therefore, learning ability at the individual and community level in the livelihood system is very important to build resilience. Resilience can be interpreted as opposed to vulnerability, and is used to understand the ability to adapt to and withstand stresses and shocks (Adger, 2000; Tanner et al., 2015). Adaptation options to strengthen farmers' resilience in the context of facing the climate change impacts can include adopting agricultural extensification, agricultural intensification, diversification of livelihoods, and migration (Paavola, 2008). Table 2 shows the various adaptation options that need to be made in addressing the effects of drought. Abid et al. (2016b) revealed that efforts to mitigate climate risk to reduce the vulnerability of farmer households should be able to reduce poverty, increase yields and income.

Table 2. Adaptation options for farmers' livelihoods resilience

Adaptation Option	Potential Impact	Source
Change planting practices		
Change plant varieties	The use of heat and drought tolerant varieties to protect plants from extreme increased temperatures and decreased rainfall, and also water shortages.	Bryan et al. (2013), Shiferaw et al. (2014), Jianjun et al. (2015), Abid et al. (2016a), Abid et al. (2016b), Khanal et al. (2018).
Change planting date	Modification of planting date can be earlier or delayed to respond to daily weather variability.	Bryan et al. (2013), Abid et al. (2016a), Abid et al. (2016b), Hochman et al. (2017), Khanal et al. (2018).
Change plant type	Selection of plant types that require a little water to respond to water shortages caused by low rainfall.	Bryan et al. (2013), Gentle & Maraseni (2012), Abid et al. (2016b).
Change agricultural management practices		
Use of fertilizer	Use of different micronutrients or fertilizers to maintain soil fertility during high rainfall.	Abid et al. (2016a), Abid et al. (2016b), Khanal et al. (2018).
Use of pesticides	Increased use of pesticides to protect plants from pest attacks due to climate anomalies.	Abid et al. (2016b), Khanal et al. (2018).
Irrigation development	Irrigation development is needed for irrigating rice fields because of the increasing number of dry days.	Calzadilla et al. (2014), Jianjun et al. (2015), Abid et al. (2016b), Hochman et al. (2017), Khanal et al. (2018).
Agricultural technique	Change agricultural techniques to protect plants from various pests and soil problems such as salinity.	Jianjun et al. (2015), Abid et al. (2016b).
Sustainable land management		
Soil conservation	Soil conservation is carried out to maintain soil fertility and crop productivity due to increased rainfall. The method used is for example the use of higher organic fertilizer.	Abid et al. (2016b), Khanal et al. (2018), Partey et al. (2018).
Tree planting	The method of planting trees is carried out to maintain the micro-climate of agriculture so that it can protect food plants from extreme temperature rises.	Abid et al. (2016a), Abid et al. (2016b).

Agricultural diversification		
Change the monoculture planting system into multiculture	This method is carried out to reduce the effects of drought by utilizing climatic conditions, such as intercropping various types of plants with strip cropping or double cropping patterns.	Gentle & Maraseni (2012), Shiferaw et al. (2014).
Agroforestry	Increase commodities and income, as carbon sinks, and increase food security.	Bryan et al. (2013), Partey et al. (2018).
Livestock development	Increase the number of livestock to reduce the economic risk of agriculture due to extreme weather events.	Jianjun et al. (2015), Abid et al. (2016b).
Migration	Migration enables agricultural households to transform a set of opportunities and associated risks to reduce poverty and enhance socio-economic development.	Paavola (2008), Hugo (2011).
Change livelihood options	Changing livelihood choices contribute to improving livelihood security, for example creating handicrafts, herbal plants, and construction.	Osbahr et al. (2008), Martin & Lorenzen (2016).
Climate information development and dissemination	Climate information provides evidence of the risk of climate shocks which can further help to anticipate the costs and scale of actions needed, for example adjusting agricultural management options at the local scale.	Shiferaw et al. (2014), Abid et al. (2016a), Khanal et al. (2018), Partey et al. (2018).
Early warning system development	Early warning systems contribute to the determination of initial actions that can reduce or mitigate risk.	Shiferaw et al. (2014).
Loan access	Provides financial strengthening opportunities against climate risks.	Shiferaw et al. (2014), Khanal et al. (2018).
Access to agricultural insurance or climate indexed insurance	This type of insurance can protect the risk of agricultural production and stabilize farmers' income due to climate variability and extreme weather events.	Dick & Wang (2010), Shiferaw et al. (2014), Jianjun et al. (2015), Mârza et al. (2015), Farzaneh et al. (2017).

2. Methods

This study employed a quantitative approach with mixed-methods. A quantitative method was used to measure each variable that became information for farmers' livelihood resilience modeling. A qualitative method was utilized to describe the interpretation of quantitative data hence it can be explained systematically to describe the facts of study results.

2.1 Conceptual framework

The concept of livelihood resilience is related to sustainable livelihoods. Sustainable livelihood is defined as an individual's ability to access capital assets which include natural capital, human capital, financial capital, social capital and physical capital (DFID, 1999; Elasha et al., 2005; Keshavarz et al., 2017). However, the capital assets can be affected by vulnerabilities, both stress and shock. The vulnerability context of this study is drought as a natural shock. Drought is influenced by a decrease in extreme rainfall at a certain time and results that water needs for rice farming activities are not fulfilled. In addition, an increased temperature affects the micro-climate of rice plants which lead to decrease in soil water content due to evaporation thus it can have a negative impact on plant growth.

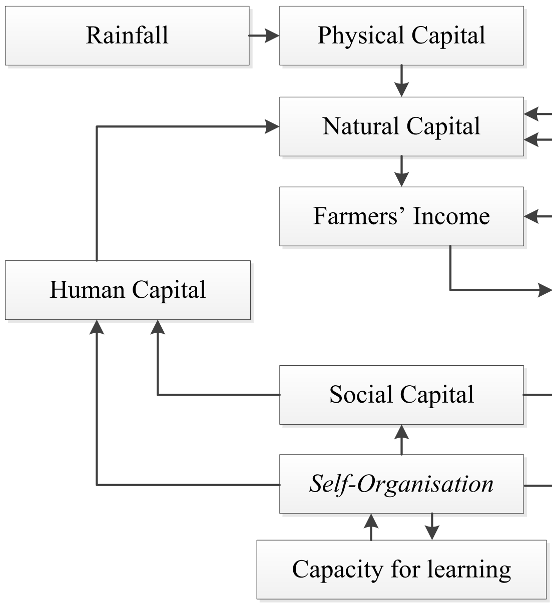

Fig. 2. Conceptual framework

Livelihood resilience is achieved if farmers have capacity to address the effects of drought by maintaining or increasing livelihood capital assets. The livelihood capital assets can be strengthened if there are interconnections between capital assets, and the existence of self-organization that is supported by capacity for learning. Meanwhile, in this study, livelihood resilience status is measured by the income of rice farmers as the outcome of livelihood resilience. Elasha et al. (2005) argue that stable income is a reflection of assessing community resilience. Figure 2 shows the relationship between variables as a research conceptual framework.

2.2 Research variable

We used ten research variables for this study, namely air temperature, rainfall, natural capital, human capital, financial capital, social capital, physical capital, self-organization, learning capacity, and rice farmers' income (see table 3).

Table 3. Operational definitions of research variables

Variable	Sub-variable	Operational definitions
Air temperature	N/A	The state of the air at a particular time and place.
Rainfall	N/A	The amount of rain that falls in a place during a particular period
Natural capital	N/A	Availability and condition of agricultural natural resources used by rice farmers to earn income.
	Rice field area	Extent of land cultivated and irrigated for planting rice.
	Rice production	Amount of dried unhulled rice harvested from rice fields.
	Rice productivity	Dried unhulled rice harvest per harvest area on rice fields that used to grow rice.
Human capital	N/A	The quality of human resources for rice farmers who support income generation.
	Farming experience	The expertise and the length of time that rice farmers carry out rice farming activities as a proxy for knowledge and skills.
	Health	Rice farmers do not have endemic diseases (such as malaria and tuberculosis), anemia, malnutrition, pesticide poisoning, skin diseases due to ultraviolet rays, or work accidents.

Financial capital	N/A	Inventories or financial reserves owned by rice farmers to support income generation.
	Farming capital	Availability of economic goods that used to support agricultural activities (calculated in rupiah).
	Non-farming business	Non-farm business activities that generate income.
	Access to loans	Agreement between rice farmers and lenders that used for agricultural activities or other economic activities.
	Agricultural insurance	An agreement between a rice farmer and an insurance company to commit themselves to the farm risk cover.
Social capital	N/A	Rice farmers' resources come from institutionalized social networks that still continue and there is mutual interaction.
	The activeness of the farmer group	Interaction between farmers in farmer groups, between farmer groups, and farmer groups with agricultural extension workers.
Physical capital	N/A	Man-made physical infrastructure that can support agricultural activities. In this study, the physical capital variable used is agricultural irrigation.
	Agricultural irrigation water discharge	Much water flows in agricultural irrigation per unit time, including primary, secondary and tertiary irrigation.
Self-organisation	N/A	The ability of the farming community to be able to determine efforts to deal with the effects of drought as a result of networking with stakeholders.
	Agricultural extension	An attempt to change the behavior of farmers so that they know and have the will and are able to solve agricultural problems.
	Participation in agricultural extension	The presence of rice farmers in agricultural extension to discuss agricultural activities.
Capacity for learning	N/A	Acquisition of knowledge and skills to be able to produce an action to deal with drought at the individual and social-community level.
	Understanding of production risk	Knowledge of farmer group members about the threat of extreme weather events that have an impact on crop failure and have implications for lost income.
	Adaptive planting practices	Farming trials to anticipate drought, such as changing plant varieties, planting date and/or plant type, etc.
Rice farmers' income	N/A	The amount of farmers’ money that is produced by utilizing the assets of livelihood capital, both agricultural and non-agricultural activities.

2.3 Data sources and collection

Primary and secondary data were employed in this study. The primary data obtained through questionnaires and interviews. The population in this study is rice farmers with a total sample of 84 people. We used a purposive sampling technique to obtain respondents. Interviews were conducted with farmers' communities namely Joint Farmer Group and also Water User Farmers Association, as well as with local government agencies of Cirebon District including Regional Development Planning and Research Board, Agriculture Agency, Public Works and Spatial Planning Agency, and Village Government of Pegagan Kidul. The secondary data including climate data, irrigation water discharge and demographic statistics obtained from certain agencies that have authority to issue the data. The climate data (rainfall and temperature) were obtained from Jatiwangi Meteorological Station for baseline data (2012-2017), and Global Circulation Model (GCM) simulation under the Representative Concentration Pathways (RCP) 4.5 scenario for projection data (2020-2045). Interpretation of those climate data could be seen in another study by Pratiwi et al.

(2018b) that identifies rainfall historical and projection in Cirebon District. Furthermore, the irrigation water discharge data were obtained from River Basin Organizations of Cimanuk-Cisanggarung, and demographic statistics from Central Bureau of Statistics.

2.4 System dynamics modeling

System Dynamics is a method for studying complex systems based on the theory of nonlinear dynamics and feedback control (Sterman, 2000). System Dynamics uses a Systems Thinking approach that has a focus on understanding interactions with other parts of the system. In this study, System Dynamics was used to assess the variables of livelihood due to the interconnection and interdependence of variables, dynamic feedback processes between variables, and behaviors that arise to study systemic interactions on variables that affect resilience. Forrester (1987) states that the discovery of endogenous variables from behavior is seen in the appearance of the model and is often found in other models. However, the system can also be influenced by possible external environmental factors, and external changes are considered as exogenous variables. The dynamics that arise from intervariable interactions produce two types of loops, namely self-reinforcing which tends to strengthen whatever happens in the system, and self-correcting or balancing that tends to fight and oppose change (Sterman, 2000). System Dynamics produces a qualitative system model or Causal Loop Diagram (CLD), and a quantitative system model or Stock-Flow Diagram (SFD). Walters et al. (2016) argue that CLD describes the interaction of dynamic variables, while SFD is used to simulate dynamic effects of variables and interactions produced. The structural interaction of variables in CLD can be used as a reference for building SFD by employing the same structure and combined with variables that have parameters then simulated using real data (Walters et al., 2016). The resulting model behavior is then used to analyze the livelihood status of rice farmers hence the problems that exist in the rice farmers' livelihood systems can be found. Powersim Studio 10 was employed in this study as a tool for System Dynamics modeling.

3. Results and Discussion

3.1 Rice farmers' livelihood resilience model development

In the following section, we describe model development of qualitative and quantitative models. The qualitative model was built through compilation of information that was interpreted systematically and generalized into a diagram of causal relationship model between the constituent variables of the system to form the dynamics of problem structure and the performance of rice farmers' livelihood resilience system in CLD. Hereafter, the concept of rice farmers' livelihoods resilience system in CLD was developed into SFD. In addition, we also define the rice farmers' livelihood resilience status from simulation of stock-flow diagrams which are limited to Business as Usual (BAU) scenarios that are measured through rice farmers' income as a livelihood outcome.

3.1.1 Qualitative system model

The concept of this model is based on the existing conditions of the study area which have been identified with primary and secondary data. The concept is a picture of researchers to interpret and simplify the complexity of rice farmers' livelihood resilience system into the structure of relationships between variables. This stage is called from story to structure. Hence, the characteristic of each variable is described in this section.Temperature and rainfall are exogenous variables or external environmental factors that affect rice farmers' livelihoods. Cirebon's average temperature baseline in 1971-2010 reached 26.0-26.9°C. Based on GCM simulation results, the temperature in Cirebon increased by 0.44°C over the next 25 years, which is still very suitable for rice plants. Rainfall trends in Cirebon during the baseline period 1986-2017 tended to decline and in a certain year the decline was extremely dry. According to GCM simulation results, the average annual rainfall projection tends to decrease in the period 2020-2045, which is 55 mm/year relative to the baseline period 1986-2017. In other study, Pratiwi et al. (2018b) has investigated the drought projection in Cirebon District by using rainfall data with Standardized Precipitation Index (SPI) as method and found that indication of drought is projected to occur in Cirebon District among others in 2023 and 2025.

Irrigation networks as physical capital become one of rice production determinants. Jatigede Reservoir is primary irrigation that has been operating since 2016 with annual average inflow discharge of 90 m^3/sec and average annual outflow discharge of 155 m^3/sec in 2017. The reservoir functions to drain water (outflow discharge) covering 85% for hydropower with a water requirement of 68 m^3/sec, 5% for raw water with a water requirement of 3.5 m^3/sec, and 10% for agricultural irrigation through Rentang Weir. Rentang Weir is secondary irrigation which flows the water to among others Gegesik Main Channel about 9.8% of Rentang Weir water discharge. Furthermore, water flowing to Pegagan Weir as a tertiary irrigation about 6% of Gegesik Main Channel water discharge that used to irrigate the rice fields of Pegagan Kidul with water needs of 0.0012 m^3/sec/ha. According to the National Agency for Disaster Countermeasure/*Badan Nasional Penanggulangan Bencana* (BNPB) (2016b), during the 2012-2017 period, Cirebon District experienced drought in 2012 and 2015 and caused water discharge to decrease. Consequently, the soils of rice fields in Pegagan Kidul became extremely dry and resulted in crop failure. This condition affected the decline in rice production as natural capital by around 40% in one year. If extreme weather does not occur, rice production in this village can reach more than 7 thousand tons with twice the planting period. Meanwhile, drought occurs during the second planting period. The area of rice fields is also a natural capital that affects rice production. In Pegagan Kidul, the area of rice fields was 548.28 ha in 2012 and decreased to 532.44 ha in 2017 because of land conversion. Accordingly, the rice fields conversion in this village is around 0.6% per year.

The natural capital is influenced by human and financial capital. Human capital describes the ability or capacity of farmers' resources in farming. Increased farming capacity can increase rice production. Farming capacity is influenced by several factors, including farming experience, health condition, and adaptive farming cultivation. Around 77% of farmers in this village have more than 10 years of farming experience and have learned to farm from families, farmer groups, and training from agricultural extension workers. The farmers have a good health history, and most farmers already have health insurance. Farming experience and health conditions certainly have a positive influence on farming capacity, whilst adaptive farming cultivation is determined by other variables which are self-organization and capacity for learning. Meanwhile, financial capital is one of the factors that determine rice production. Farming activities are influenced by farming capital to meet production costs. The farming capital in this village was around IDR 10.8 million in 2012 and 12.3 million in 2017. Thus, the farming capital is always increasing around 2.64% per year. The availability of farming capital affects the increase in rice production. In this model, we did not include loan access variables because farmers in this village who obtained loan access were less than 6%. Rice farmers' income varies greatly as it depends on rice productivity and also price of dried unhulled rice harvest. The price of dried unhulled rice harvest is different for the first and second planting periods, respectively IDR 3.6 million per ton and IDR 4.3 million per ton in 2012 with price increase of 4.68% per year. If rice productivity is high, then the farmers' income will increase. Part of farmers' income is then used as farming capital for rice production in the next planting period.

Drought affects the loss of rice farmers’ income, even though farming capital has been used for rice production. The response of rice farmers to deal with these impacts is looking for alternative jobs in order to obtain additional income, yet the alternative jobs are limited to the informal sector. This response shows the presence of rice farmers’ reactive capacity in addressing the impact of unpredictable natural shocks. The income earned is only around

IDR 6 million for one planting period when crop failure. However, this additional income can increase the total income of rice farmers in one year. The total income of rice farmers is reduced by agricultural capital, then becomes net income for family living costs which increases by around 5% per year. Discrepancy of income from net income minus the cost of living is the determinant of ownership of crop insurance that can become new financial capital for rice farmers. The current crop insurance premium is IDR 36 thousand per hectare per planting period or IDR 72 thousand per hectare per year. If the income discrepancy can meet the insurance premium, then rice farmers can take the decision to own crop insurance. The next action that needs to be done is to register crop insurance through PT JASINDO so that rice farmers are able to have a crop insurance policy. As financial capital, crop insurance contributes to increase the income from insurance claims about IDR 6 million per hectare per planting period if there is a crop failure. Thus, ownership of crop insurance indicates anticipatory and planned steps that are part of proactive capacity in addressing the impacts of drought.

Social capital is also found in rice farmers' livelihood resilience of Pegagan Kidul that are membership of farmer groups and the activeness of farmer groups. The higher farmer group membership, it can increase the activeness of farmer groups because of social interaction. Active farmer groups can increase the participation of rice farmers to be present in every extension activity which is also due to social interaction. In addition, active farmer groups can also encourage rice farmers to have crop insurance because rice farmers will obtain information on the benefits of crop insurance from farmer groups. Other variables that also affect the livelihood resilience system are self-organization and capacity for learning. Both of these variables become determinants as supporting factors for assets of livelihood capital. Self-organization can improve human, social and financial capital, as well as capacity for learning. Furthermore, self-organization can be enhanced by capacity for learning. In this model, self-organization is determined by agricultural extension, participation in agricultural extension, and adaptive farming cultivation. The capacity for learning that influences and is affected by self-organization in this system is an understanding of agricultural production risks and adaptive farming practices.

Agricultural extension that is carried out routinely can increase farmer group activeness and encourage rice farmers to participate in the extension. Increased extension participation will further improve understanding of agricultural production risks and adaptive farming practices since the information obtained from agricultural extension workers is able to improve the knowledge and skills of rice farmers. Increased understanding of agricultural production risks, especially extreme weather events such as drought, can increase the motivation of crop insurance ownership, as well as affect self-organization that is adaptive farming cultivation. Moreover, the adaptive farming practices are able to improve the learning of rice farmers in addressing the impacts of drought. Regarding that, rice farmers can increase their initiative to determine and carry out appropriate adaptive farming cultivation. Furthermore, the adaptive farming cultivation influences the improvement of adaptive farming practices as well as human capital which is farming capacity. The adaptive farming cultivation is a form of anticipatory and planned measures that show proactive capacity in addressing the impacts of drought. Based on those descriptions, the rice farmers' livelihoods resilience system in Pegagan Kidul consists of five subsystems that are irrigation subsystem, rice production subsystem, farming capital subsystem, crop insurance subsystem, and adaptive capacity subsystem. These subsystems influence each other to form a system and this structure is called CLD (see Figure 3).

3.1.2 Quantitative system model

In this stage, the quantitative system model in the form of SFD was built based on the rice farmers' livelihoods resilience concept in the CLD. The transformation process from CLD to SFD functions to quantitatively analyze the model of the rice farmers' livelihood resilience system. Numerical data entered into each variable of SFD in accordance with the data obtained. Nevertheless, the model is abstractions or simplifications of real conditions thus it has certain limitations. Regarding that, the model requires assumptions to bridge the limitations. In this study, the rice farmers' livelihood resilience system modeling in Pegagan Kidul employed the following assumptions as follows. First, the aspect of land suitability in rice fields is assumed to be in the good category. Second, the event of crop failure is assumed to be only due to drought and there is one planting period in one year, while crop failure due to other influences is ignored. Third, the quality of dry grain harvest for sale is assumed to be entirely in good condition. Fourth, irrigation system governance is assumed to have no water conflict. The model of rice farmers' livelihood resilience systems can be seen in figure 4.

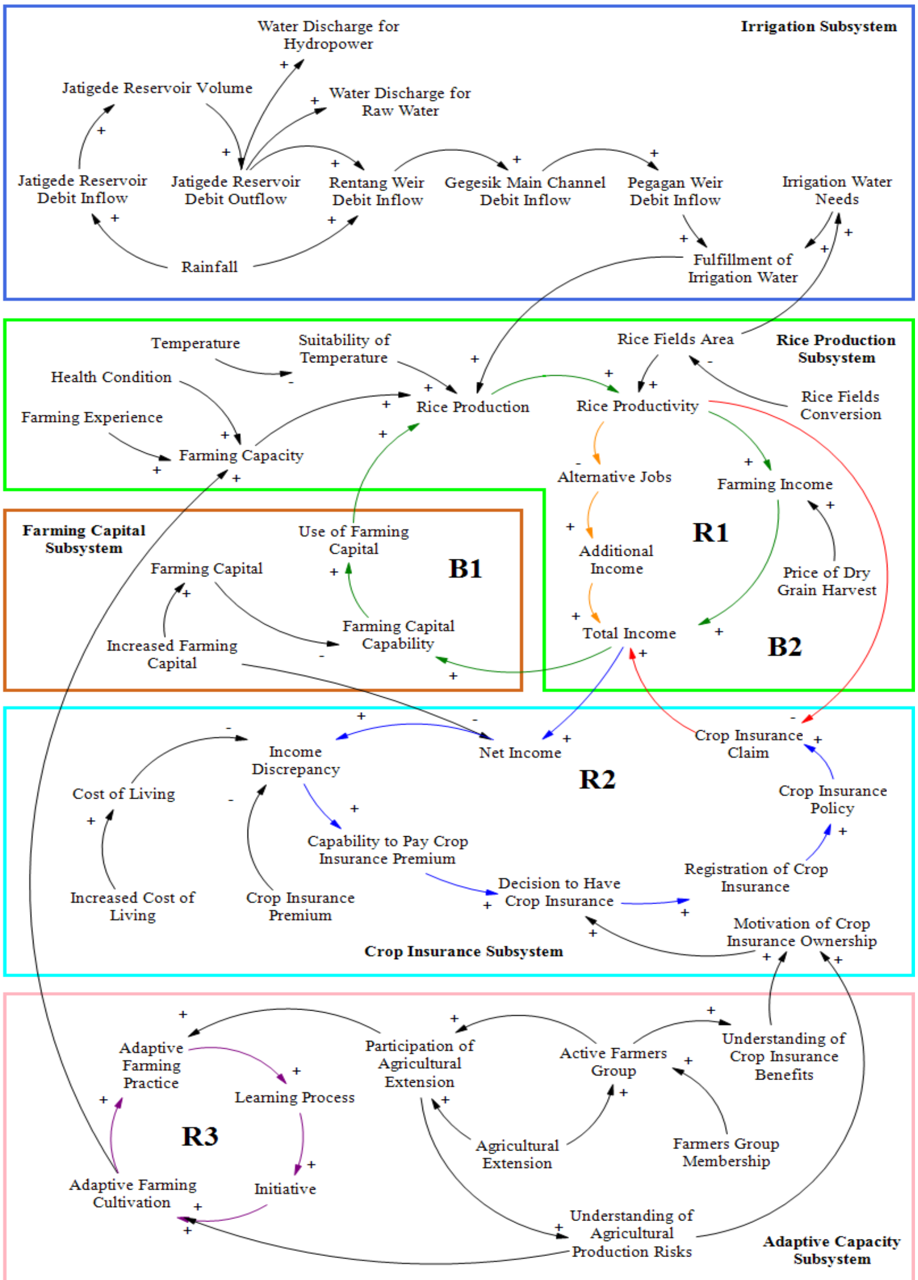

Fig. 3. Diagram of rice farmers' livelihood resilience system casual loop diagram.

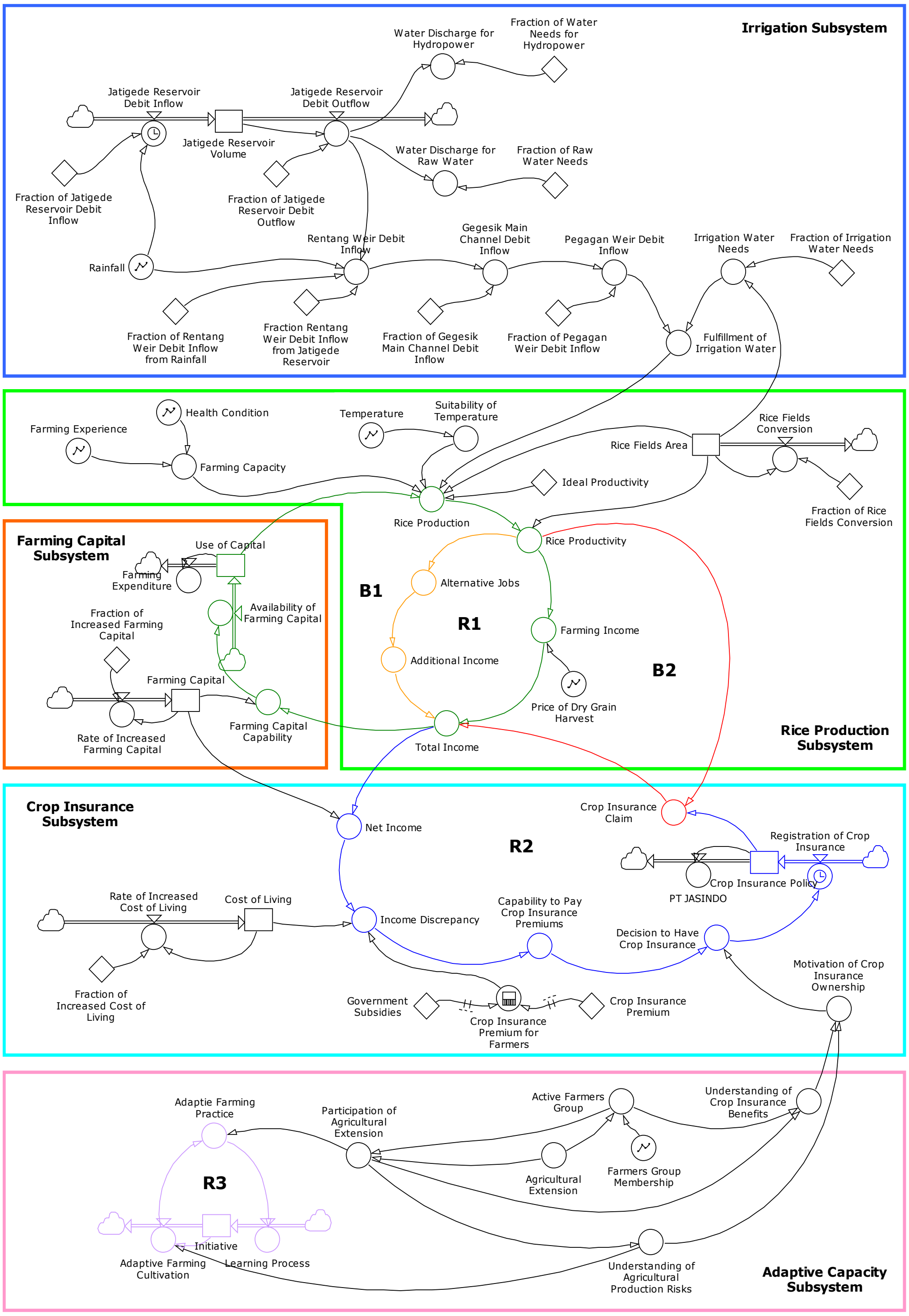

Fig. 4. Diagram of rice farmers' livelihood resilience system stock flow diagram.

3.2 Model simulation and assessment of resilience

Model simulation is carried out based on reference data from 2012 to 2017. Furthermore, modeling time is extended by using a BAU scenario that is without changing the value of existing variables or constants. This model simulation is carried out with projections to 2030. The consideration of projected year selection is to follow the Government of Indonesia's commitment to the Paris Agreement to address climate change listed in the Nationally Determined Contribution (NDC). The simulation results can be seen in Figure 5. The study area has experienced drought in 2012 and 2015. The drought in 2015 was triggered by the El Nino phenomenon which had an impact on extreme dry rainfall. This condition is in accordance with Bhuvaneswari et al. (2013) and Capa-Morocho et al. (2014)

that argue El Nino events, when accompanied by reductions in extreme rainfall, can prolong dry seasons and lead to drought conditions. Drought causes the water from Rentang Weir not to flow to Pegagan Kidul. The similar effect was also found in previous studies. Karimi et al. (2018) reveal that reduced water resources due to climate change and variability are projected to reduce crop yields. Nam et al. (2015) also reveal that changes in rainfall and hydrological patterns associated with climate change and variability are likely to increase reservoir water scarcity and reduce agricultural water availability in the future.

Pratiwi et al. (2018b) found that climate variability influencing future droughts will continue to occur over uncertain monthly periods with increasing severity. Based on model simulation with the BAU scenario, drought projection in 2023 and 2025 resulting in decreased farmers' income to below ideal income, it means that there will be no significant changes from baseline conditions. Meanwhile, various study found that Agricultural productivity and rural livelihoods are negatively impacted by extreme weather events (Gentle & Maraseni, 2012; Shah et al., 2013; Abid et al., 2016a; Khayyati & Aazami, 2016; Khanal et al., 2018). As a further impact, the study results from Abid et al. (2016a) and Rahut & Ali (2017) found that the vulnerability of climate change to agriculture ultimately results in farmers losing income. Therefore, rice farmers pursue temporary jobs to obtain additional income as happened with rice farmers in Pegagan Kidul. Abid et al. (2016a) reveal that the high dependence of households on agriculture could limit the farmers' capacity to adapt to climate change. In addition, Shah et al. (2013) also argue that extreme weather events directly affect the sustainability of livelihoods and reduce livelihood diversification opportunities for rural communities.

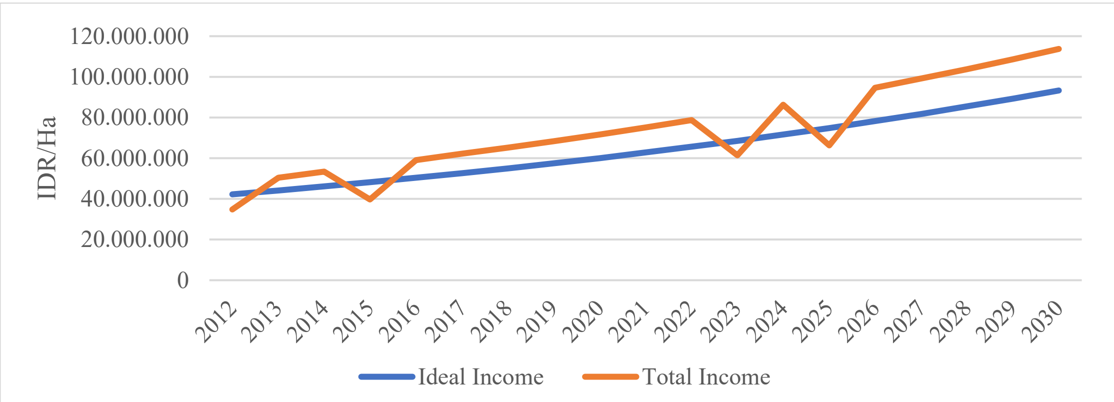

Fig. 5. Rice farmers' income simulation in business as usual scenario

Figure 5 shows that rice farmers still do not have livelihood resilience because when drought affected by climate variability occurs, rice production as natural capital experiences crop failure hence rice farmers lose their income. In addition, crop insurance and alternative livelihoods as financial capital have also not been able to make rice farmers' income stable or reach an ideal. Thus, intervention scenarios are needed to improve the rice farmers' livelihood resilience systems in addressing the impacts of drought. Paavola (2008) explains that there is no single solution that will increase adaptive capacity in vulnerable areas. Therefore, intervention scenarios need to be carried out on several subsystems simultaneously.

4. Conclusions

Climate change and variability affect the increased rice production risks and uncertainty of rice farmers' income. This study also found that drought events cause rice farmers to experience disturbance in their livelihoods and loss of their income. If the rice farmers' livelihood resilience system continues without any intervention scenarios from the government or other stakeholders, then the rice farmers' livelihood system may not be resilient in the future. Adaptation efforts that have been done by rice farmers are also not able to increase their income. In order to strengthen the rice farmers' livelihood resilience system, policy interventions from local governments are needed to improve the subsystem conditions in the livelihood resilience system. Several possible policy interventions to be carried out include irrigation network governance, value of crop insurance claims, adaptive farming capacity, and understanding of agricultural production risks through the provision of climate information.

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