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Analysis of Flood Identification and Mitigation for Disaster Preparedness: A System Thinking Approach

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Abstract

Floods are a major threat to agricultural production. Reducing the impact on agricultural production is a challenging task in mitigating flood. By understanding the causes of the flooding, we can use the information to make a comprehensive flood mitigation model. The approach of system dynamics can be used to look at the factors that influence the handling and prevention of flooding in the agricultural sector. This study aims to illustrate flood mitigation in agriculture using a system dynamics approach. We are using the information collected from interviews with key officials from the government office. We also use the information from existing research reports or another publication related to floods and disaster management. Both information source is used as a base in developing flood mitigation model. District governments can use flood mitigation models to reduce the risk of flooding on agriculture.

Keywords: flood mitigation; risk analysis; system dynamics; causal loop diagram

1. Introduction

Floods that hit various regions in Indonesia are a logical phenomenon because this country is in the tropics with extensive rainfall. According to disaster data from the Badan Nasional Penanggulangan Bencana in 2000-2009, flooding was the biggest disaster that caused damage to agriculture. Besides, various triggers that can promote land

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conversion in areas such as forest clearing and urban development are very fast. The opening of forests in the upstream area will cause rainwater not to be absorbed by the soil and directly into runoff water which directly flows into the river. The flow of river water will be higher and eventually cause flooding.

East Java Province has various regional conditions in the form of lowlands, rivers, mountains, and high rainfall at certain times. The condition of vulnerable areas that cause potential disasters with a significant impact from disasters is a concern for local governments and stakeholders for the preparation of disaster management planning in East Java Province.

Floods cause one of the factors of damage to agriculture land. The cumulative area of land affected by flooding in East Java from January to June 2017 was 10,567.73 ha in rice commodities and 11.63 ha in corn commodities (Central Java Statistics Agency). Floods that resulted in agriculture also happened to farmers in Madiun, East Java, losing up to Rp. 7 billion because floods submerged 497 hectares of rice fields. The amount of loss due to the disaster is quite large. The record is based on the Madiun Regency Government. In more detail, it is mentioned in Government Regulation Number 21 of 2008 concerning the Implementation of Disaster Management.

Armah et al. in a study entitled "Impact of Flood on Livelihoods and Vulnerability of Natural Dependent Communities in Northern Ghana" research is a study that aims to assess the coping and vulnerability strategies of two communities that depend on agriculture after the flood [1]. Causal loop diagram is used to conceptualize the flood mitigation caused by flooding in the study area. The results show that several socio-cultural environmental characteristics emerge to reduce risk and reduce vulnerability.

Research related to flood hazard carried out by Sintondji et al. concerning the assessment of flood hazard in the agricultural sector[2]. The impact of flooding on the loss of agricultural production and the level of a shift from the agricultural sector to other sectors was carried out by Rana and Islam [3]. Jose et al. also conducted a study concerning flood vulnerability using AHP (Analytic Hierarchy Process) method and linking the results of flood vulnerability assessment with geographic information systems[4]. Consequently, to develop long-term flood mitigation policies at several levels (the district, regional, and national), we need to assess the damages done by flood events. To achieve this goal, the implementation of a risk-based approach is carried out to give a basis for disaster management planning, land use area determination, policy making, especially related to the evaluation of the cost-effectiveness of alternative flood control measures and the possibility of agricultural insurance[5].

These phenomena happen in Indonesia, but different regions might have different causes. The study of the main causes of flooding in an area is critical. Knowledge of the causes of flooding can be used for information on making a comprehensive flood mitigation model. We can use system dynamics approach to look at the factors that influence the handling and prevention of flooding in the agricultural sector. System dynamics approach based on the consideration that system dynamics methods offer the power to combine expert knowledge, which in turn enable us to model nonlinear behavior.

This study will mainly address the identification and assessment of flood risk in the agriculture sector, which is an early and vital part of the mitigation and control process of those risks under conditions of limited resource availability. Since the agricultural sector is a strategic sector, which affects the national economy, then our focus in this study is to model flood risk that has an impact on the agricultural sector.

2. Background

2.1. General approach to flood risk management (FRM)

One of the issues of thickly populated urban dwelling is a flood disaster, which involves the occurrence of geomorphological triggered natural event. This issues significantly added the miseries of marginalized and vulnerable communities in the developing nations[6]. Rather than just pure prevention, managing the risk of the flood disaster is about incorporating mitigation, adaptation, and preparedness by choosing the most suitable solution with the least amount of risk/hazard[7].

A set of policy options which aim to reduce the flood risk is called flood risk management [8]. Flood Risk Management (FRM) activities can be considered by incorporating mitigation, preparedness, response, and recovery[9]. In spite of the hierarchical context, we can use the assessment of flood risk to represents the logical base for flood risk management. The key to effective flood risk management is the establishment of a strategy and corresponding measures in relation to flood risk assessment [8].

Dikes, channel improvement works, and barriers are the example of flood defense structures in which flood risk management focused on in the past. However, in the present, flood risk management does not rely only on engineered flood defense structures but also considers various steps that might be used to reduce the impact of the flood. The example of the said step is changing the use of the land in upstream catchments. Another one is by reducing flood vulnerability, which in turn would reduce the consequence of the occurred flooding. The criteria for assessing the available options of flood risk management rarely focus on economic value only but also considering the value of public safety, equity, and the environment[10].

The most important thing in FRM is that the strategy is well developed and implemented. From the strategies implemented, it can add positive value to the system. In carrying out this strategy, effective communication is needed, effective time management, and the system implemented clearly describes the process[11]. Good collaboration between authorities, agents, and people who are experts in handling risk, exposure, and vulnerability can support the achievement of FRM. This is because good collaboration can be utilized for evaluation, mitigation, and responsive response[11].

A person actively engaged in flood risk assessment (e.g., engineers) and stakeholders comprehend flood risk with identifying ‘sources’ of flood hazards (e.g., rainfall), water flow path that may cause broke(e.g., floodplain, agriculture) and ‘receptors’ (people and ecosystems) that are at risk[12]. Flood damage assessment is an essential part of flood risk management, yet it has not received much scientific attention.

One of the crucial parts of flood risk management is flood damage assessment, but only a few scientists are interested in researching this part. This assumption is especially correct for the agricultural sector, where flood damage causes crop failure, wreck agricultural buildings and machinery, and instance of livestock losses[13]. The emphasis in our study is on the deliberative decision-making on flood risk management plans, strategies, and designs. To be more exact, we focused on decision making, which associated with the political process that formulates policies related to the flood risk management.

2.2. System dynamic

System Dynamic (SD) combines mathematics and computer simulations to explore real-world system behavior, relationships, and processes over time[14]. The most important feature of system dynamic is to explain the endogenous structure of the system under investigation, to identify how the different elements of the system relate to each other, and to experiment with changes in relationships in the system when different decisions are entered [15]. The core process of the SD modeling process is identifying how structure and decision policies can help to generate the observable patterns of behavior of a system[16]. Then we can implement the identified structures and decision policies.

As the popular saying goes, there is no formula for successful modeling. Which means, there is no exact procedure we can follow that guarantee a useful model. Modeling is inseparable from creativity, and there are always viable alternatives to model something. Modelers have their styles and approaches. Yet as Sterman claimed[17], Most modelers follow the following approach in using system dynamics, namely identifying problems to be solved, formulating hypotheses related to the root of the problem, formulating a simulation model to test previously formulated hypotheses, testing simulation models until the results of testing are the same as actual systems, and formulating appropriate policies related to the issues raised.

In this study, we focused on system dynamics as a system thinking to analyze the flood identification and mitigation for disaster preparedness. Hence, the steps of analysis are as follows:

- Problem articulation

The problem articulation is that it involves defining the problem. According to Sterman [17], a problem should never be a system model which is the boundary of the hypothesized behavior of the problem and the time period of interest problems must be determined in this step.

- Formulating a dynamic hypothesis

After modelers have successfully determined problems in a period of time, the next step is developing a dynamic hypothesis to explain the existing problematic behaviors. The purpose of this step is integrate feedback loops into a generic causal loop diagram. System archetype is used to describe causality, positive and negative loops, reinforcing and balancing cycles. As a diagnostic tool, provide systemic insights into dealing with the dynamic complexity[18]. System archetype can be used to understand the system in its entirety[19]. A dynamic hypothesis is the step where the problem is specifically determined[17]. This theory leads to the process of modeling by focusing on a specific pathway. The rest of the modeling process would help the modeler to test the validity of the constructed dynamic hypothesis. The test would be administered by comparing data generated by the simulation model to the actual data collected from the real world.

3. Model development

3.1. Problem articulation

In this study, the problem identified is "illustrate risk and mitigation on agriculture production of a flood-threatened and to establish a relationship between the factors and the behavioral pattern". At this stage, the modeler constructs the specification of the problem by way of discussions with the customer partner, equipped with literature, data acquisition, and discussion. Data collection includes rainfall, rice damage caused by floods, flood prevention, and other data related to flood mitigation in agricultural production obtained from BPS East Java and the Agriculture Service of East Java Province. Some of the literature that supports this research is taken from related sources such as those contained in books, articles in relevant journals, or previous studies. Interviews with stakeholders and collected data are analyzed to develop and discuss the dynamics hypothesis and it is expected that the system built can model actual system behavior.

3.2. Formulating a dynamic hypothesis

In this step, discuss problems and theories related to the problem solving with the client team. The variables that are modeled must be endogenous and the model boundaries must be extended as the actual system being modeled. Model boundary and sub-model diagrams do not indicate how between the variables included in the actual system but only indicate the boundaries and architectural models of the actual system. In this study, system archetype is described using causal loop diagram. System archetype represent an effort to identify and categorize behavior pattern that recur in flood mitigation. Causal loop diagram (CLD) is a map that shows a causal relationship between variables discovered in the modeled system. Data or literature related to research and interviews with several stakeholders was collected and analyzed to develop the CLD model.

- *Physical sub-model*

One of the regions of Indonesia that suffered severe flooding was East Java. Floods were found on the river level, which broke down due to the brunt of water and then inundated the agricultural area[20]. Rainfall is the main variable that results in flooding and the risk of damage to agricultural production. Table 1 contains information on endogenous variables and exogenous variables on the physical sub-model. In Table 1, structural validity is carried out on each variable at the physical sub-model. The structural validity process is carried out by including references from each variable.

Table 1. Model Boundary Physical Sub-model.

Sub-model	Endogenous Variable	Exogenous Variable
Physical sub-model	Rainfall[21][22][23]	Effectiveness of runoff[21], [24]
	Predicted Rainfall[21]	
	Water table level[21]	
	Water level risk to paddy land[21]	
	Upstream runoff[21], [24]	

- *Economic agriculture sub-model*

The effect of rainfall on sub-model physical is damage to agricultural production. Damage to agricultural production can reduce the availability of seeds, increase the risk of starvation, and reduce household income. In addition, flooding also causes damage to irrigation infrastructure. Model boundary charts for economic agriculture sub-model show in Table 2.

Table 2. Model Boundary Economic Agriculture Sub-model.

Sub-model	Endogenous Variable	Exogenous Variable
Economic Agriculture sub-model	Potential damage to agriculture production[21], [23]	Starvation[1]
	paddy production disruption[20,21,22]	Household income[1]
	Damage to irrigation infrastructure[25]	
	Availability of seed[1]	

- *Policy sub-model*

Damage to agriculture can be reduced by carrying out flood mitigation actions. Some flood mitigation policies that can be carried out are land management, water governance and IT governance. Model boundary for policy sub-model show in Table 3.

Table 3. Model Boundary Policy Sub-model.

Sub-model	Endogenous Variable	Exogenous Variable
Policy sub-model	Cropping pattern[26]	Policy for mitigation[27]
	Adjustment of planting time[26]	Knowledge of vulnerable paddy land[27]
	Resistant varieties[26]	Perceived risk of damage[27]
		Willingness to mitigate[27]
		Vulnerable paddy land in hazard-prone area[27]
		Land management[28]
		Water governance[28]
		IT governance[28]

3.3. Causal loop diagram (CLD)

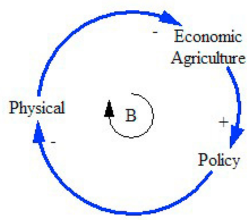

Fig. 1. System Archetype.

Fig. 1 illustrates the system archetype of flood mitigation in agriculture sector. System archetype can be used as tool to facilitate a systemic analysis of flood mitigation in agriculture sector. Physical sub-models contain physical variable variables that are the cause of flooding in the agricultural sector. The economic agriculture sub-model consists of the effects of floods, which have an impact on the agricultural economy. The policy sub-model is a sub-model that consists of policy policies related to flood mitigation on agriculture.

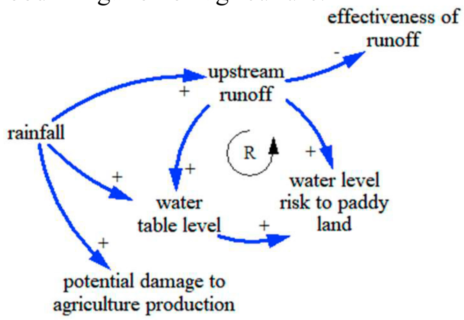

Fig. 2. Physical sub-model.

From Fig. 1, it can be divided down into three sub-models, namely physical sub-model, economic agriculture sub-model, and policy sub-model. Fig. 2 shows the CLD from the physical sub-model. Several climate-related variables are the main causes of flooding. Hence, there is variable potential damage to agriculture production, which is a connecting variable between the physical sub-model and another sub-model.

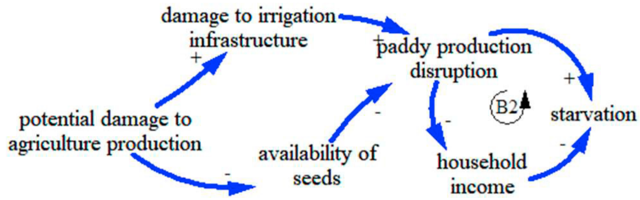

Fig. 3. Economic Agriculture sub-model.

Fig. 3 illustrates CLD from the economic agriculture sub-model. In this CLD, there are several variables related to economic agriculture sub-model. In this CLD, the variable drawn is the effect of a flood variable in the physical sub-model in Fig. 2.

Fig. 4 illustrates the policy sub-model. Sub-model policy is an effect caused by physical sub-model. This policy sub-model consists of several variables related to flood mitigation policy policies in the agricultural sector. Flood mitigation is carried out to prevent and deal with the effects of flooding on the agricultural sector. Fig. 5 illustrates the overall causal loop diagram of risk analysis of flood mitigation in production agriculture.

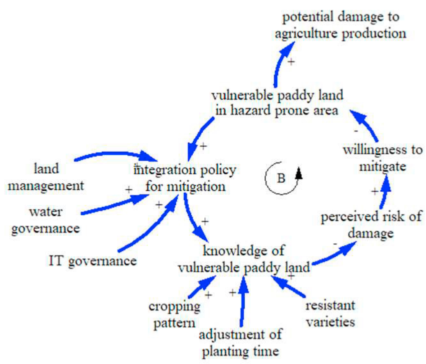

Fig. 4. Policy sub-model.

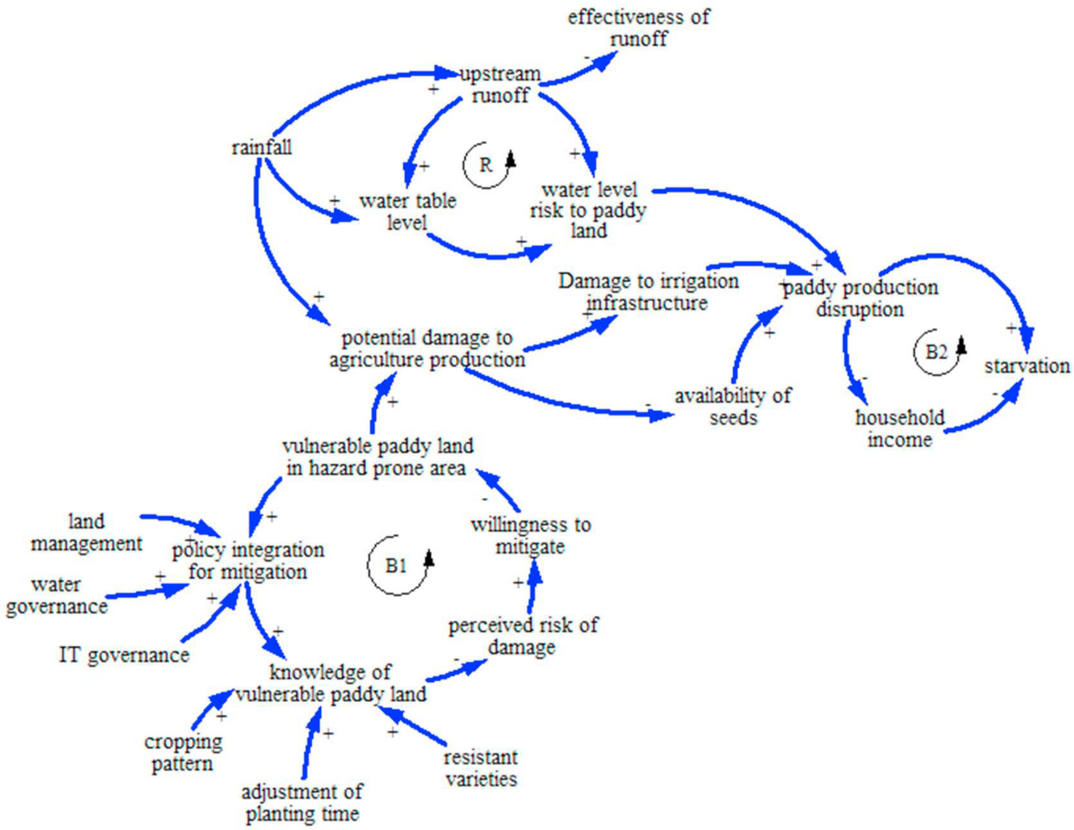

Fig. 5. shows the full CLD of risk analysis of flood mitigation in production agriculture.

4. Conclusion

In this study, we identified two main problems. One of them is illustrating the risk and mitigation of flood-threatened agriculture production. The other one is establishing the relationship between the factors and the behavioral pattern. To solve the problems, we did several steps. First, we discuss with the client team to develop the initial characterization of the problem. The initial characterization would also be supplemented with information gained from data collection, literature, and discussion. Then, we have collect information from literature and related research to analyze possible theories, which caused the problem and other potential difficulties, which might arise from the said problem. That session is done to expand the boundary and endogenously model the variable. After that, the structural validity is carried out on each variable at each sub-model. The structural validity process is carried out by including references from each variable. After structural validity, the development of causal loop diagrams is carried out in three sub-models, namely physical, agricultural economics, and policy sub-model. Each sub-model is interrelated so that it describes the cause and effect of the risk of flooding in the agricultural sector. Sub-model physical as a whole describes causal models. Whereas the economic agriculture model and policy sub-model describe the effect model. In addition, in the sub-model policy, there are several variables related to flood mitigation policies in the agricultural sector. From the causal loop diagram generated, further research can be carried out in several scenarios and policies to simulate flood mitigation systems in agricultural production.

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