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Mitigation and adaptation of local organization to achieve food security: Case of traditional irrigation system in Bali, Indonesia

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Abstract

Climate change has affected the agricultural sector, particularly the food crop cultivated on rice fields. *Subak* as a local farmers organization is always expected to have important role to to improve rice farming practices and increase its productivity. The changes of rainfall and rain patterns happened in Bali should be anticipated by the *subak* through the mitigation and adaptation efforts to prevent the failure of harvest, and ensure better production. The aims of this study were to describe *subak*s activities and its problem, and the adaptation and mitigation efforts for achieving food security. The study was purposively conducted in 14 *subak*s which obtained irrigation water from the Buleleng River, Bali Province. A total of 140 farmers were selected as samples by using non-proportional sampling technique. Primary data and secondary data were collected using survey, direct observation, and FGD. Data collected were analyzed by a qualitative descriptive method.

The results indicate that *subak*s have some problems, such as water availability, competition of water among the users, and rice field conversion. The efforts of adaptation and mitigation comprise the changes in cropping patterns and planting schedules, borrowing water between *subak* members, and forming a *subak*s federation to increase rice productivity and achieve food security programs. The government should provide useful weather information for farmers regarding water availability, make a digital map of forest, regulations, and law enforcement.

Keywords: Adaptation; Mitigation; Cropping pattern; Planting schedule; Food security

1. Introduction

In developing countries, including Indonesia the general objective of economic development is to increase the productivity of natural and human resources by using the new science and technology that is aimed to make a higher economic growth [1; 2]. Aside from this, economic development also has a significant role in providing more business and employment opportunities for economic actors from the producer to the consumer level. Agricultural development is an important sector and has a significant role in economic development to produce and provide food, employment, and community income in rural and urban areas [3; 4; 5; 6; 7; 8]

Agricultural issues have a close relationship with other sectors, industry, finance, cooperatives, irrigation (irrigation), trade. Therefore, the development of the agricultural sector also has an influence on rural development, and vice versa. Various sources of income for farmers in rural areas also have interrelationships between sectors because they have varied jobs. Such conditions require integrated efforts from both the government and non-governmental organizations in developing agriculture and rural areas to reduce rural poverty and improve income distribution. Gaps or income inequality need to be addressed to prevent social and economic problems from occurring in rural areas, including adjoining urban communities [9; 10]. Several studies also show that income inequality in rural communities have an

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influence on poverty, and in turn can hinder rural economic development. Increased agricultural development cannot be separated from industrial development, especially regarding agriculture, namely agro-industry.

Rural poverty in Indonesia, including in the province of Bali, is found in groups of farmers cultivating rice due to their landholding is very small. In fact, the dependence of the population on food, especially rice, is currently still very high, where the demand is increasing along with population growth. Some research results show that most of the food (rice) is produced by producers (farmers) who control limited paddy fields or are small farmers [11; 12; 13]. Limited land tenure (owned and leased or rented land) contributes to low productivity and production resulting in relatively low income received by farmers, and this might be a reason for farmers to leave their farming activities [14]. Therefore, the gap leading to poverty will be further opened if no efforts are made to improve the management of rice farming in paddy fields [15; 16; 17]. In addition, farmers also have limited technical skills (plant cultivation) regarding the management of their farming business [18]. Access to information, capital and markets are also other issues faced in the development of the agricultural sector [19].

The implementation of agricultural development, especially in rice farming, is increasing to increase the productivity of land and plants. The selection of new superior varieties has a significant effect on land and plant productivity. This is also enriched by the recommended use of fertilizers and irrigation water as well as the implementation of integrated pest and disease management. In the Province of Bali, Indonesia, the management of rice fields is fully run under a farmer organization called *subak* as an irrigation management institution for rice farming in Bali established since thousands of years [20; 21]. The existence of *subak*, therefore, plays a major role in supporting agricultural development. Besides that, the cultural aspects of *subak* have become a buffer for Balinese culture as one of the attractive factors to support tourism development.

As an international tourist destination, the growth of economic development in the province of Bali has given rise to several problems in *subak*, such as competition for water use and land conversion (rice fields). Competition in water use has been felt by *subak* because irrigation water sources are also dug by other sectors for household and industrial water needs. The availability of water for irrigation is becoming scarce, so cropping intensity decreases. Consequently, rice production is getting lower and is a threat to the government's food security program. Land conversion is also difficult to control because of the high demand for land for housing, physical and industrial infrastructure in line with economic development.

In Indonesia, climate change is affecting the agricultural sector, particularly the food crop sub-sector which is cultivated in paddy fields. Climate change is generally interpreted as a change in climate patterns caused by high greenhouse gas emissions and the activities of people who do not pay attention to the environment which affect world life in various ways [22; 23]. This climate change is related to biophysical and genetic changes to food crop farming, such as rice. This is significantly predicted to result in instability in the agricultural sector and food security, in which the impact will vary according to the geographical conditions where the farm is located [24]. Besides, the other impacts that are happened by the climate change are reduction of water availability needed by farmers which influences the low productivity and agricultural production [25].

This condition is due to the management of rice farming needs the availability of irrigation water starting from land tillage to harvest. Rice plant varieties have a high level of vulnerability and are strongly influenced by irrigation water conditions, soil properties, cropping schedule arrangements, cropping patterns and cultivation technology. Several research results show that global climate change such as changes in rain patterns, prolonged droughts and floods, and changes in increasingly high temperatures have a negative impact on the agricultural sector and its sustainability, especially food crops in the relation to food security [26; 27; 28; 29; 30].

One of the most important factors in the management of rice farming in paddy fields is the availability of irrigation water. The availability of irrigation water has a very significant influence on the productivity of rice as a staple food for people in Asia, including in Indonesia. In relation to agricultural development, Indonesia is a country that is vulnerable to climate change related to the management of rice farming. This can affect rice production and food security in the country. Irrigation management requires technical and social skills to ensure the sustainability of rice farming. It was mentioned that the agricultural productivity could be increased by implementing the technological innovation as recommended to the agricultural development in the South and Southeast Asian Countries [31].

In the case of the Province of Bali, the management of irrigation water along the river and at the farm level is run by the government together with local farmer organizations called *subak* as a traditional irrigation system. *Subak* is always expected to be able to regulate the irrigation water available to its members in managing farming in their paddy fields. Changes in rainfall and rain patterns that occur in Bali require mitigation and adaptation by *subak* to prevent crop failure

and then ensure good rice production and food security program. The purposes of this research are to describe traditional irrigation systems in rice farming management and its problem and explain the adaptation and mitigation efforts made by *subak* and government for achieving food security.

2. Methods

This research was conducted on *subak*s which obtained irrigation water from the Buleleng River in Buleleng Regency, Bali Province, Indonesia which were purposively selected (see Figure 1). The considerations of selection are the condition of water on the river was very extreme, wherein flood often occurs during the rainy season and water availability was very scarce during the dry season, and there are drinking water enterprise belong to local government which got water from the river Buleleng, too. The number of *subak*s that obtain water from the Buleleng River are 14 *subak*s. Aside from this, all *subak*s have established the federation of *subak*s which is locally called *subak-gede*, namely *subak-gede* Ekatani.

In this study, the key respondents were deliberately selected for each *subak*, namely the chairperson, secretary, and treasurer of the *subak*, so that there were 42 respondents in total. Besides, sampling was also carried out using non-proportional sampling technique, where 10 farmers were taken as samples in each *subak*, so that the total sample was 140 farmers. Data collected were primary data and secondary data using survey, direct observation, and interview guideline interviews techniques. In the research, it was carried out the Focus Group Discussion (FGD) for having more data or information relating to the irrigation water management, rice farming activities, problems faced by *subak*s and farmers, mitigation, and adaptation. This was attended by the *subaks*' management boards, agricultural extension workers, officials of Public Works institution, and other stakeholders. Data collected was analyzed by employing a qualitative descriptive method.

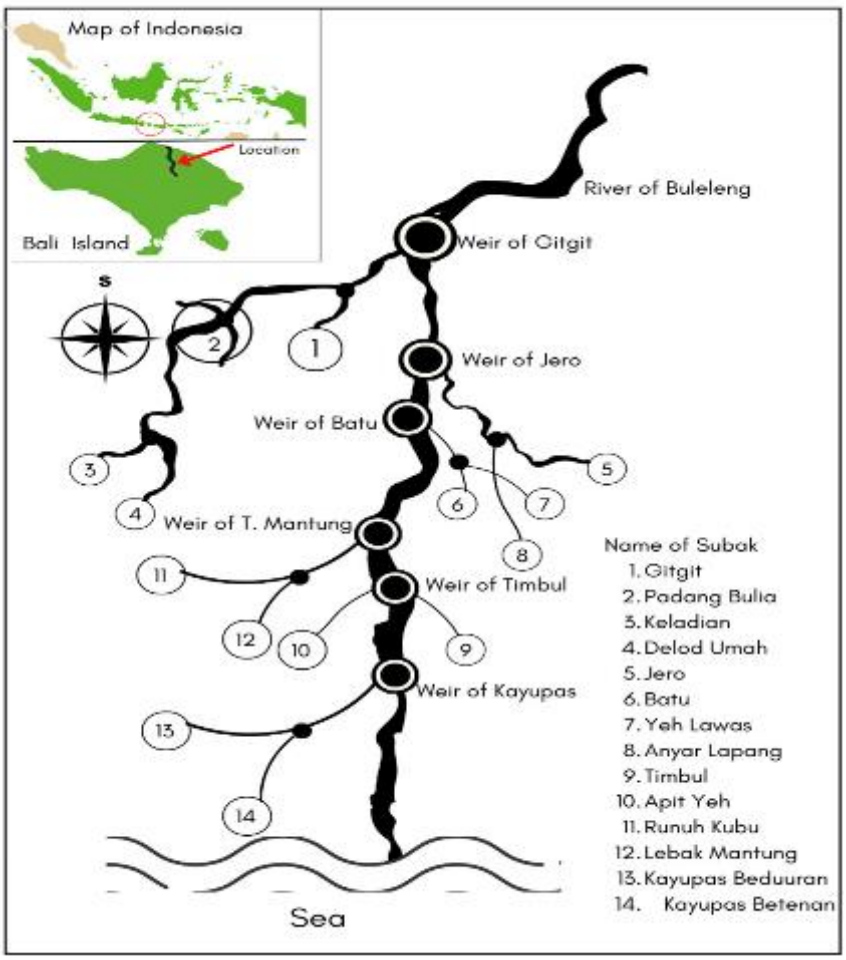

Figure 1 Research site

3. Results and discussion

3.1. Subak as a Traditional Irrigation System

Based on the research, *subak* is not only seen as an organization but must be seen as a system. This means that the *subak* system includes several subsystems, namely: (i) physical subsystem (rice fields and irrigation networks); (ii) irrigation subsystem; (iii) agricultural subsystem; (iv) social subsystem; and (v) cultural subsystem. The five subsystems are interrelated in the rice farming system on the rice field. *Subak* is a traditional irrigation system in Bali that has been managed by water user associations (farmers) since more than a thousand years ago. *Subak* has several specific characteristics related to irrigation management, agriculture, and socio-cultural aspects. The philosophy of subak is *tri hita karana* (three causes for happiness) consisting of the harmony between human and the God; between the human and environment, and harmony among the human. This is fully based on the harmonious relationship which has been implemented in daily activities within *subak* system [32].

Paddy fields in this *subak* have internal rules and regulations that must be obeyed by members. In terms of cultural aspects, *subak* is very closely related to socio-cultural activities in the life of the Balinese Hindu community. The main affiliation factors for *subak* members are irrigation water and temples. Ritual activities are carried out based on the stages of rice farming starting from taking water, preparing land, seeding, transferring to harvesting. The *subak* organization is very simple, chaired by a *subak* head called *pekaseh* who is democratically elected by all members. *Pekaseh* is assisted by a secretary and treasurer for administrative matters. In larger *subak* sizes, a sub-subak head must be elected to coordinate activities in each sub-*subak*. At the *subak*s federation level, the entire *subak*s (14 *subak*s) selected the head of federation which is also assisted by the secretary and treasurer. The head of federation coordinated the water management along the river, such as water distribution and allocation for each *subak*, and water borrowing among the *subak*s. He also coordinated the ritual activities at the mutual temple constructed at the village and near the weir. Besides, he was also as liaison between the government and *subak*s as members of federation. Based on the research, the existence of *subak*s federation was very effective for the farmers, particularly during dry season. The organizational structure of *subak* can be seen in Figure 2.

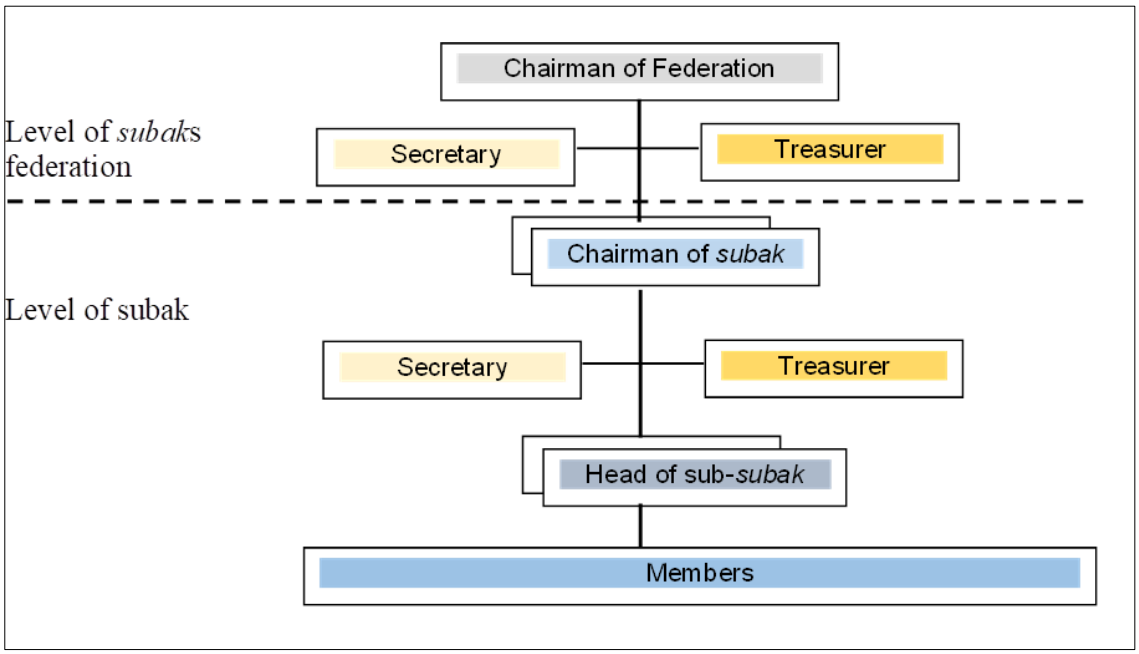

Figure 2 *Subak* organizational structure

In implementing agricultural development programs, government officers always coordinate with *pekaseh* for making it easier and faster to socialize and disseminate innovations for the individual farmers. The respondents mentioned that the implementation of new rice farming practices at the farmer level was very effective through the *subak* system. *Subak*s made decisions through the monthly meetings related to the selection of varieties, cropping patterns, planting schedules and others. The introduction of commercial farming has been developed by extension agents so that farmers have a higher income from rice farming. This higher income could be a driving force for farmers to work more intensively in their fields. Thus, land conversion can be controlled or minimized.

3.2. Irrigation Water Problem, Its Adaptation and Mitigation

Indonesia has two seasons along the year, namely the rainy and dry seasons. Because of climate change, the rainy and dry seasons have shifted and are unpredictable, where originally the rainy season always occurred from October to March, and the dry season from April to September. The availability of irrigation water is also affected by changes in rainfall, and then has an impact on agricultural management in paddy fields, particularly rice planting, thus the food security program. Like the other counties, sustainable development has the objectives for increasing agricultural productivity and quality, achieving food security, eradicating poverty, and preserving natural resources by using economic principles that provide social benefits for society and the natural environment is guaranteed sustainability [33]. In Tabalong District, South Borneo, the strategies recommended for the adaptation in the farming consists of superior seeds application, pests and diseases control, and use of agricultural machines [34].

This situation could be seen from the uncertainty of rainfall within three years in Bali (2020-2022) as shown in Table 1. In August, for example, rainfall was usually very low, but in 2022 a very significant change occurred, where there was increased rainfall compared to 2021 and 2020. Unlike the case in January, there was a decrease in rainfall in 2021 when compared to the previous years, namely 2021 and 2020. *Subak*s located in research site took anticipative effort to adapt to the rainfall and water availability at the source or river level.

Table 1 Rainfall condition in Bali within 2020-2022 (mm)

No	Month	2020	2021	2022
1	January	327.1	369.4	156.0
2	February	408.2	299.7	357.3
3	March	252.0	346.7	325.7
4	April	128.6	138.0	75.7
5	May	11.3	106.0	147.6
6	June	14.1	6.5	21.1
7	July	4.8	5.0	11.6
8	August	107.2	7.9	14.5
9	September	8.7	6.7	14.4
10	October	1.5	0.0	97.6
11	November	90.6	54.5	57.9
12	December	284.4	131.8	397.1

Source: Bureau of Bali Province Statistic, 2023

Considering data presented in Table 1, it is shown that the rainfall in the same months within 2020-2022 are significantly different, such as in April, May, August. This change in rainfall caused a decrease in the availability of irrigation water for *subak*s and subsequently had impacts on cropping intensity, cropping patterns, planting schedule of rice crops, including the productivity of crops grown on paddy fields. This condition might also contribute to a decrease in farmers' income from their farming land if it is not handled wisely.

Due to a high dependence on water, *subak*s located in the research site often faced various problems to ensure good farming management. In the dry season, the availability of water at the source (river) level was getting smaller, and even scarce. This condition resulted in disturbed rice plant growth, pest and disease attacks and decreased production. Some of the problems caused by the dry season for *subak*s in Bali are presented in Table 2.

Table 2 Problems encountered by *subak*s during dry season

No	Problems	Level	Impacts
1	Low water availability	River and on-farm	Lower crops intensity and disrupted cropping patterns and planting schedule.
2	Disrupted plant growth.	On-farm	Decreased production.
3	Pest and diseases attacks	On-farm	Decreased production

Source: Primary data, 2023

The smaller availability of water at the river level has significantly contributed to the lower irrigation water flowing to the *subak*s' area consisting of the rice field plots belong to farmers as members of *subak*s. It has changed the cropping patterns which already applied since a long time, that is rice-rice-*palawija* (secondary crops). The cropping pattern commonly applied by the *subak*s in the study area is rice-paddy/*palawija* (secondary crops)-palawija (secondary crops). The secondary planted by farmers in the research sites are corn, ground nuts, pie nut, soybeans. The application of cropping patterns at the *subak* level has several functions, including breaking the chain of the spread of pests or diseases, restoring soil fertility, adjusting to environmental conditions, especially water availability and the intensity of sunlight due to seasonal changes. Thus, these could secure rice productivity and bring about the achievement of food security.

Meanwhile during the rainy season, respondents revealed that there was often excess water in the river and in irrigation canals at the farm level which had a negative impact on *subak*s members. *Subak*s often experienced problems both at the river level and at the farm level due to higher water discharge on the river and irrigation canals, such as damage to canals. In addition, rainwater that flowed directly to paddy fields also sometimes had an impact on the growth of rice crops which was disrupted due to excess stagnant water. The problems that usually occurred in the rainy season can be seen in Table 3.

Tabel 3 Problems encountered by *subak*s during rainy season

No	Problems	Level	Impacts
1	Flood	River	Damages of dam
2	Sediment and garbage	River and on-farm	Poor water quality
3	excess water	On-farm	Irrigation facilities damage and decreased production.
4	Pest and diseases attacks	On-farm	Decreased production

Source: Primary data, 2023

Observing Table 2 and Table 3 shows that the main problems and challenges faced by *subak*s due to climate change are

- damage to irrigation facilities;
- scarcity of irrigation water,
- more complex competition for water use among the users,
- pest and disease attacks, and
- conversion of paddy fields. These could be directly affected by the rice production and food security program planned by the government. Water scarcity was caused by poor management in the upstream or hilly areas. Deforestation and changes in land use in hilly areas by communities have caused degradation of forest and soil functions. The forest may not function as a water storage area that can become a source of water.

Changes in land use from tree cultivation to horticultural cultivation in the hilly areas have an impact on changes in the physical and chemical structures of the soil. Farmers prefer to cultivate the land for the cultivation of cash crops to earn more money than perennial crops. As a result of this situation, the availability of water at the river level decreases during the dry season. Instead, farmers always have a plan to plant rice which requires more water.

Competition for water use between *subak*s and non-*subak*, such as industry and domestic water users was increasingly complex. The demand for water for household and industrial purposes was increasing every year in line with the population growth and economic development in the regency. They used water from a similar source, namely the River of Buleleng. Usually, *subak* got into big trouble if the industry also took water for their clients' needs. The solution to

this problem was negotiation between the *subak*s federation and the industries. The government was requested to have facilitation and mediation between the water users pertaining to the allocation of water based on the updated data or information about water balance or annual plan of water uses for irrigation, household water, industry, and other sectors.

Pest and disease attacks on crops grown by farmers were usually caused by an erratic climate (rain and drought). In the research site, pests and diseases always threaten farmers in farming activities even though the farmers already implemented the technical recommendations from agricultural extension workers. They even conducted intensive extension and training for farmers on pest and disease control. Integrated sustainable pest and disease management was introduced and applied by farmers.

Land conversion (rice fields) was increasing due to infrastructure development such as buildings, roads, housing, and others, particularly in the downstream area. The flow of irrigation water in residential areas or other buildings was disrupted resulting in difficulties for planting. Regarding the need for water for irrigation, this conversion creates excess water for farmers because the rice fields have been converted. The problem, however, is the ecological aspect. Flooding in the city is threatened after the conversion of rice fields in the city area. The air environment is also affected because there are no plants after the rice fields are converted into buildings.

3.3. Adaptation and Mitigation

Climate change threatens Indonesia's efforts to fight poverty. The impact can exacerbate the various risks and vulnerabilities faced by the poor, as well as add to the burden of problems that are already beyond their capacity to deal with. Thus, climate change hinders the efforts of the poor to build a better life for themselves and their families. In the research site, mitigation and adaptation activities carried out by *subak*s along the Buleleng River are social-technical engineering both at the *subak* level and outside the *subak*s to ensure the availability of water throughout the year for achieving the food security program. To overcome the threat of climate change, *Subak*s in the research site took an internal solution by changing cropping patterns and planting schedules, such as paddy-rice-plants or rice-plants-rice, or rice-plants-plants. Secondary crops that are usually planted by *subak*s are corn, green beans, soybeans, and the like. The management of water irrigation under the *subak*s system is carried out in staggering and rotation system. Staggeringly, the *subak*s arranged the members to take turns cultivating rice crops. Some farmers were firstly provided to use irrigation water to prepare the land by using tractors or cows until the process of transplanting rice. Other members then switched to using the water to grow crops. Thus, the rice planting schedule in *subak*s can be longer due to water scarcity. Taking turns, *subak*s can make decisions to determine cropping patterns among *subak*s members as mentioned above.

The cropping patterns in the research site were based on the *subak* area. Within one sub-*subak*, for instance, some members were allowed to plant rice again as a second planting after the harvest in the year, while the other members planted secondary crops. However, in the following year, members who plant rice must take turns to plant secondary crops. On the other hand, those who planted secondary crops in the previous year can plant rice crops. This condition is applied every year and depends on the availability of water throughout the year and is always decided at a *subak* meeting. In some cases, *subak*s allow farmers to borrow water whenever they need it. It must be agreed upon among the farmers. It means that after planting and harvesting the first rice, the *subak*s still allow farmers to plant a second rice if the availability of irrigation water is sufficient. Due to the unpredictable condition, some members of *subak* planted secondary crops to avoid the risk if they planted rice.

The increase of rainfall in the research site was anticipated by having the rehabilitation and upgrading of irrigation facilities, such as the main and tertiary canals. The main canal was responsible by the government, and the *subak*s had responsibility in the tertiary canal. The main purpose of this rehabilitation and upgrading is to make the canal become stronger to hold large amounts of water during the rain. In other side, this activity also serves to prevent leakage and loss of water in the canals during dry season or drought situation.

Another adaptation strategy conducted by farmers in the research site was application of System of Rice Intensification (SRI) technique. The farmers gained benefits from this technique are water-saving on the rice field, and cost efficiency, only need 5 kg/ha of seeds. Aside from this, the benefits of SRI are the technique does not require the cost of removing seeds, does not require the cost of moving seeds, and increase the production (from 5 tons to 9 tons/ha). This technique is environmentally friendly which does not use chemicals and is replaced by using organic fertilizers, as well as the use of pesticides. The increase of rice productivity could ensure the sustainability of food security at the national level. This technique could overcome degradation of soil because of too much chemical fertilizers used during the application of modern agricultural innovation. The SRI techniques applied by farmers have been introduced to use a few inputs from

the external in the rice farming practices [35]. Aside from this, application of SRI techniques could also achieve the sustainable agricultural development in line with the Sustainable Development Goals (SDGs) implemented in various countries to develop better agroecosystem health without using synthetic chemicals to produce healthy, nutritious, and safe products for public consumption. This might realize social goals such as reducing hunger or poverty through reducing the adverse effects of climate change, ecological degradation, and loss of biodiversity [36].

Integrated pest management was conducted by the farmers within each *subak* to control the pest and diseases. They were trained by the agricultural extension worker every six months. The main purpose of this training is to create a sustainable agricultural system by suppressing pollution to the environment by pesticides and environmental damage in general by utilizing various appropriate control techniques (cultural, mechanical, physical, and biological). In the research site, however, it was still seen that the farmers applied chemical pesticide to control the pest. This condition occurs because they do not want pest attacks to become more widespread.

Each *subak* within the research site applied a system of water borrowing among the members during the dry season or drought. Due to the scarcity of water, the farmers who planted rice could borrow irrigation water from the other farmers based on their agreement relating to the duration of borrowing. The simple technique of water borrowing is closing the inlet on canal, so the water will flow to the canal goes to the borrower's land. Concerning the distribution and allocation of irrigation water, all *subak*s had established a coordination body which is locally called *subak-gede*, and its name is *Subak-gede* Ekatani. The main function of this *subak-gede* is to manage the water distribution and allocation along the river.

Another solution that will be carried out is to make a digitalization map of the forest area which is a water catchment area as a source of *subak* water. This map might serve to identify the condition of forest areas in relation to tree populations, deforestation, changes in trees or plants, etc. The government can use this map to take alternative and anticipatory efforts in controlling forest use and the availability of water for *subak*. Information on the digital water balance throughout the year is also important for the government to provide to *subak* for supporting the food security program. Calculation of the water balance must pay attention to several aspects such as water volume, infiltration, evaporation, water requirements for rice and other crops in paddy fields, and other components.

In addition to the adaptation carried out by *subak*s at the research location, mitigation activities are also carried out together with the government and community members in the upstream area. Some of the activities are conservation at the hilly area, agroforestry or social forestry, and spatial planning in mountainous areas. The government has issued spatial regulations and law enforcement against these regulations. Spatial maps must be disseminated by the government to the community so that they know and understand what they should and should not do with the rice that is proposed in relation to land conversion.

Mitigation was carried out before a disaster occurs, such as flood, land slide and scarcity of water. Planting trees or reforesting forests, as well as providing counseling and raising awareness of people living in disaster-prone areas were done by the government and *subak*s within the research site. Conservation in upstream areas, such as mountains and forests, guarantees the availability of irrigation water for farmers to increase their rice productivity and at the same time ensure food security.

4. Conclusion

The adaptation and mitigation efforts undertaken are rehabilitation and upgrading weir and irrigation facilities, cropping patterns and planting schedules, technology of rice cultivation (SRI), integrated pest and disease management, water borrowing among members of *subak*, and establishment of *subak*s federation. These activities guarantee the availability of irrigation water which supports the increase in rice productivity and realizes food security programs.

It can be suggested to the government to provide useful climate or weather information for farmers, especially regarding water availability, water balance and water allocation plans for irrigation and non-irrigation. Besides, the government must also make a digital map of forest to improve the environment of the upstream areas.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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