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Climate Change Vulnerability to Rice Paddy Production in Bali, Indonesia

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Abstract

This chapter presents the recent vulnerability assessment project on a rice paddy production and climate change in Indonesia and attempts to demonstrate a practical framework and methodology for a vulnerability and adaptation assessment in the agricultural sector. This chapter applies the outcome vulnerability framework, which is defined by the IPCC. The framework is applied into a practical methodology using multidisciplinary approaches such as statistical modeling, GIS and remote sensing, as well as participatory research, focus group discussion, and policy assessment. The chapter produces vulnerability maps illustrating how climate change affects rice paddy production in Indonesia especially Bali island. In Bali island, the suitability for rice paddy production has been decreased 20 % in the last 20 years because of changes in climate, and climate change will continue in the future. On the other hand, the chapter suggests that actual damages will be based on rice paddy location and the adaptive capacity of farmers. The chapter demonstrates the impacts of climate change on rice paddy production, which is a staple food for many developing countries including Indonesia. It is important to understand the impacts of climate change in agriculture sector that is the most vulnerable to adverse changes in climate. The chapter successfully demonstrates a multidisciplinary approach, which can be applied in other agricultural products in different countries.

Keywords

Vulnerability assessment; Climate change; Agriculture; Rice production; Multidisciplinary approach; Indonesia

Introduction

This chapter assesses the vulnerability of rice paddy production on Bali island, Indonesia, and creates a climate change vulnerability map. The present assessment includes the three subcomponents that are required for climate change vulnerability: exposure, sensitivity, and adaptive capacity. The assessments of exposure are based on climate data from BMKG, such as annual rainfall,

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temperature, and humidity. The data regarding paddy location are used as an element of sensitivity. Adaptive capacity assessment employs a normative approach to determine paddy production, such as mixed qualitative and quantitative techniques.

The devastating impact of climate change has already been evident in Indonesia. The country's combination of high population density, high levels of biodiversity, having more than 15,000 islands, and having a coastline that stretches over staggering tens of thousands of kilometers makes Indonesia one of the most vulnerable countries to the impact of climate change. Bali, a small island of Indonesia, is likely to suffer from rising sea levels, droughts, and floods, which will impact the island's rice production. In general, the production of paddy has decreased since year 2000. Decline in paddy's production is in line with the shrinking of harvested areas for paddy. In contrast, the production rate has been increased; therefore, it negates the reduction of total yield level. From years 2000 to 2008, the harvested area has been reduced 7.1 %, productivity rate increased 8 %, and production size increased 1.6 %. The paddy production may not be able to rise or may even shrink in the future if paddy areas, production rate, or production cycle is reduced by climate change (Takama et al. 2012). Rice is one of the most important agricultural crops in Indonesia, and it can be affected by climate change just as other agricultural products can be (Centennial Group International 2012).

This chapter demonstrates the approach and the results of a vulnerability assessment for climate change and rice paddy production. This approach uses qualitative and quantitative assessment methods and relevant maps of the assessment. It also helps researchers to make policy recommendations based on the assessment. The approach will be transferable to other regions of Indonesia as well as many developing countries.

Background

Vulnerability Assessment

The IPCC (Intergovernmental Panel on Climate Change) gives the most frequently quoted definition of vulnerability: "Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (2007, p 883). Extensive climatic and socioeconomic vulnerability may worsen the plight of poor farmers who comprise the majority of rural populations in developing countries such as Indonesia, and farmers will continue to be vulnerable to social and weather changes in the immediate future. It is believed that the earth is warming, and climate change on a global scale has already been observed. As a result, disasters, especially drought, hurricanes, and floods, occur more often and hinder agricultural activities. According to a report created by the Asian Development Bank, weather-related disasters in Southeast Asia will increase (Yusuf and Francisco 2009). However, "rise in disaster" does not mean "rise in vulnerability," because the concept of vulnerability is often defined based on exposure, sensitivity, and adaptive capacity. Exposure is the likelihood that climate-related disasters will happen to a target group (i.e., an exposure unit), including droughts and floods. Sensitivity can be defined as an exposure unit's susceptibility and is represented by rice paddy field density, population density, etc. Adaptive capacity is defined by the IPCC as "the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences" (IPCC 2007) and is usually estimated by social factors, financial resources, and climate-proof infrastructures.

The social factors that are included in assessments of adaptive capacity are not related to climate, but they are closely related to the climatic impacts on rice paddy production. For example,

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a meteorological drought can occur in a rice paddy location, but the rice paddy will not be damaged if the farmers know how to cope with the impact, if they understand how to apply seed variety choice, and if they enforce policies adequately (Liverman 1990; Meze-Hausken 2004; Ifejika Speranza et al. 2008). In other words, when farmers possess high adaptive capacity, they can minimize the impacts of droughts. Therefore, it is important to include adaptive capacity based on social factors in a vulnerability assessment.

This report assesses separately the three components of the vulnerability assessment, because the natures and the measures of these three components (i.e., exposure, sensitivity, and adaptive capacity) differ. For example, exposure is climate stresses or potential climate-related disasters, so exposure is difficult for humans to reduce and might even be impossible for them to eliminate. Some reports mention terms like "reducing exposure through building a dike in the case of sea level rise" (Know Climate Change 2004). However, building a dike is not reducing exposure, but is, instead, improving adaptive capacity, because it is not possible to stop the sea level from rising beyond mitigation measures, such as the reduction of greenhouse gasses. Although it is not possible to tackle exposure directly, information about exposure is important. Without exposure information, it is not possible to know where potential disasters will happen or at what magnitude. It would be a waste of resources to build an irrigation system in an area where drought is unlikely to occur or to construct a dam where there will be no flood. Exposure indicates the areas of potential disasters and thus helps policymakers and stakeholders to decide how to prepare for climate change.

Normative Index Development Process

Some analysts expect vulnerability assessments of climate change to be objective (Nagel 1989). However, it is neither possible nor desirable to be purely objective when each assessment includes social issues and the desires of a number of stakeholders (Schwandt 2000; Johnson and Onwuegbuzie 2004). Therefore, a vulnerability assessment needs a normative approach so that the researchers can work with the local stakeholders.

Climate change is about the future, so the vulnerability problems in question have not occurred in most cases. In addition, developing a vulnerability map requires quantitative information, because it compares factors and locations. Quantitative techniques are neither appropriate nor outperform qualitative methodologies in terms of exploring normative questions, such as "What kind of issues usually concern farmers and policymakers?" or "What are the key factors that might affect paddy production in a particular area?" Therefore, it is important to conduct further exploratory research to answer these normative "what" questions before working on quantitative assessments. Similarly, to calibrate the quantitative results so that they fit the needs of the users and to make the results transplantable, discussions with key stakeholders are necessary.

Moreover, the process is bound to be politically sensitive to policymakers and stakeholders. Fortunately, constructing the indicators through an objective and scientific process results in fewer arguments. A normative index development involves subjective judgments, because vulnerability assessment must include judgments, such as which weather conditions would be "good" or "bad" for paddy production (Takama et al. 2012; Adger et al. 2004; Harvey et al. 2009). In the normative process, stakeholders can discuss their thoughts and priorities to develop the index collaboratively. Another advantage of the normative index is that it is more likely to be accepted by its users because they have contributed to the process of indicator development (Giovannini 2008).

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Methods

Weighting Between Exposure, Sensitivity, and Adaptive Capacity

Many vulnerability assessments use three components to express vulnerability, and they are usually exposure, sensitivity, and adaptive capacity. Among16 recent vulnerability assessments conducted by the ADB, UN, World Bank, etc., almost all of them used equal weighting among the three major components, i.e., 1/3, 1/3, and 1/3 (e.g., Yusuf and Francisco 2009; Heltberg and Bonch-Osmolovskiy 2011; WHO 2011). The equal weighting may not produce the optimal end result, but assessing with equal weights is a reasonable starting point. Weighting factors within each component can be assessed with a scientific or a social scientific method. However, weighting among the three components can be too complicated or too political to be determined scientifically. The three components are organized in terms of similarities in their characteristics. Therefore, it is easier to apply the same domain of science and social science techniques to estimate weight within a component. For example, agriculture's exposure to potential disasters can be defined by the FAO's soil suitability assessment or other agricultural drought assessment techniques (FAO 1976; FAO and UNESCO 1990). In many cases, sensitivity can be defined as a statistical proportion, namely, the density of a target exposure unit, including human settlements, rice paddy density, and protected ecosystems (Yusuf and Francisco 2009). Social science assessment techniques are usually applied to estimate the weight within adaptive capacity (Ziervogel et al. 2006; Takama et al. 2012). In contrast, the characteristics of these three components are significantly different, so it is difficult to implement well-defined science or social science techniques. As a result, the weighting among the three components is evaluated in a less scientific way, such as with expert opinions and stakeholder meetings (Vincent 2004; Vincent 2007).

Equal weighting has significant biases. Heltberg and Bonch-Osmolovskiy (2011) and Eakin and Bojorquez-Tapia (2008) mentioned that equal weighting makes an implicit judgment about the degree of influence of each indicator and that it is normative and not as objective as other approaches. Therefore, the researchers of this report initialized the weighting of the three sub-components as equal and then calibrated the weighting while discussing the results with experts and stakeholders (Savonis et al. 2008).

An index within each component is composed of a unique number of factors and weights that are estimated with approaches that are more scientific and social scientific in nature. The three components use different units and scales. For example, when a paddy area density is used as sensitivity, the unit is a percentage between 0 and 1, and the adaptive capacity is the production gain in kg/acre. Therefore, it is necessary to normalize and standardize these subindexes into a common unit such as [0, 1] for the final integration. The project tested multiple scientific techniques such as z-score normalization and minimax standardization (see more in Giovannini (2008) and CARE International (2009)) ranking based that was used by WFP (2009) were implemented for the standardization and color categorization. Moreover, values for adaptive capacity should be inversed, because the vector/direction of adaptive capacity is the opposite of the other two components. High exposure and high sensitivity mean high vulnerability, whereas high adaptive capacity means low vulnerability.

A weighting factor development starts with a prototype that is developed through qualitative stakeholder meetings (Takama et al. 2012). After the appropriate stakeholders were identified for the present study, the prototype was updated to reflect the users' needs and the non-captured reality from the stakeholders' and experts' viewpoints. For example, a stakeholder workshop was conducted with provincial and district agriculture agencies, a cultural agency, a public work agency, Udayana University, Technology Research on Agriculture, head of subak (*pekaseh*), and Indonesian Met

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Office (BMKG) in Denpasar. This workshop helped to finalize the components and the weight of the vulnerability and to make the models more useful and more accessible to nonexperts and stakeholders.

Livelihood Zone Map

Before the social surveys were conducted, the livelihood zones were assessed to understand the characteristics of farmers and livelihoods in Bali and to determine the survey locations (Food Economy Group 2006; Selvaraju and A.D.P. Center 2006). A livelihood is a means of living through assets (e.g., livestock, land, forest, and ships), activities (e.g., grazing land, fishing, and wage labor), and capabilities, which is the product of assets and activities. Livelihoods vary by location due to the fact that the livelihoods of many Indonesian farmers are determined by geography, agricultural potential, and market access.

Geography affects production through climate, soil, and topography and dictates marketing/trade activities through roads and proximity to urban centers. The household production of food and other items may either be directly consumed or may be traded/exchanged for other items in the market. Market access determines the ability of people to trade their goods, such as crops, livestock, or other items, to sell their labor and to obtain the prices that they desire. Factors that do not determine livelihood zones are man-made factors, such as poverty, wealth, conflict, healthcare, education, and other governmental and nongovernmental services (USAID 2009). In this study, more weight was placed on geographical characteristics, including precipitation, topology, and types of agricultural production. A complete step-by-step guide was developed by the Food Economy Group (2006), and an assessment with climate variability has also been implemented by FAO (Selvaraju and A.D.P. Center 2006).

Exposure

Exposure was measured with FAO's soil-climate suitability index (FAO 1976; FAO and UNESCO 1990; FAO 2001). The suitability method indicates the potential damages related to climate factors; therefore, it is appropriate for measuring exposure factors. Simplicity is not necessarily inaccurate. Izumi et al. (2013) predicted the global rice yield from only estimated soil moisture and the temperature of cultivation areas. The verification revealed that the model predicted good results in 20 % of the rice growing regions in the world from 1982 to 2006. The categorization is based on a report from the Indonesia Ministry of Agriculture (Subagyono et al. 2003) and is summarized in Table 1. In short, lowland rice can be grown at an altitude of 0–2,500 m above sea level, and the physical and chemical properties of acceptable soil can vary greatly from a sandy to clay soil texture, a pH of 3–10,and an organic matter content of 1–50 %. The soils can also include different levels of available nutrients. Rice needs enough radiation intensity during the reproductive and ripening phases.

Sensitivity

In this case, sensitivity was defined as paddy field density. This approach is similar to what ADB did for their South East Asia vulnerability assessment project (Yusuf and Francisco 2009). ADB's report defined human sensitivity and ecological sensitivity as the population density and the percentage of protected ecological areas, respectively. Areas with more human settlements and more biodiversity are more vulnerable to the same level of exposure than areas with fewer humans and less biodiversity. Sensitivity indicates the general likelihood that an area will be affected. Climate change is often believed to impact areas with high exposure and high sensitivity. For example, if drought is expected in a large area, policymakers should focus on the places with more rice paddies or more people rather

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Table 1 Suitability of land for rice (Oryza sativa) commodity (Subagyono et al. 2003)

Land requirements/characteristics	Class of land suitability			
	S1: high suitability	S2: mild suitability	S3: low suitability	N: not suitable
Average temperature (°C)	24–29	22–24	18–22	<18
		29–32	32–35	>35
Rainfall (mm):				
First month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Second month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Third month	175–500	125–175	100–125	<100
		500–650	650–750	>750
Fourth month	50–300	30–50	<30	
		300–350	500–600	>600
Humidity (%)	33–90	30–33	<30 > 90	
Oldeman climate type	A1,A2,B1,B2	A1,A2,B1	C1,C2,C3	D1,D2,D3,D4,E
		B2,B3		
Altitude	<500 m	<750 m	<1,000 m	<1,000 m
Land physics:				
Slope (%)	<3	3–8	>8 up to 25	>25
Texture	Smooth, quite smooth, mild	Smooth, quite smooth, mild	Quite rough	Rough
	5.5–8.2	5.0–5.5	<5.0	
pH H2O		8.2–8.5	>8.5	
Peat:				
Thickness (cm)	<60	60–140	140–200	>200
Thickness (cm) if there is insertion of mineral material	<140	140–200	200–400	>400

than the places with few rice paddy fields or people. Therefore, sensitivity information is very valuable.

The paddy areas were defined with remote-sensing techniques that acquire information by utilizing devices that have no physical contact with observed objects, regions, or phenomena (Boschetti et al. 2009; Gumma et al. 2011; Wayan and Nishio 2007, Nuarsa et al. 2010, 2011, 2012; Sari et al. 2010; Shao et al. 2001; Uchida 2010; Xiao et al. 2005). The sensitivity as paddy field density was defined by dividing the rice paddy area by total land areas in each kecamatan (subdistrict). There are 39 kecamatan in the Bali province.

Adaptive Capacity

Adaptive capacities include the functions of socioeconomic factors, technology, and infrastructure. To obtain factors that can be used for adaptive capacity, the researchers conducted a stakeholder meeting, expert discussion, and a survey of rice farming in Bali. Issues, objectives, and potential impacts were explored beforehand, as explained by Takama et al. (2012). Based on these identified issues and the livelihood zone analysis, a survey was designed to model adaptive capacity. Secondary data were also collected after distinguishing significant factors. A model was developed with a normative approach, which is the combination of the statistical assessment, expert opinions, and stakeholder meetings. The purpose of the survey and statistical analysis is to quantify the

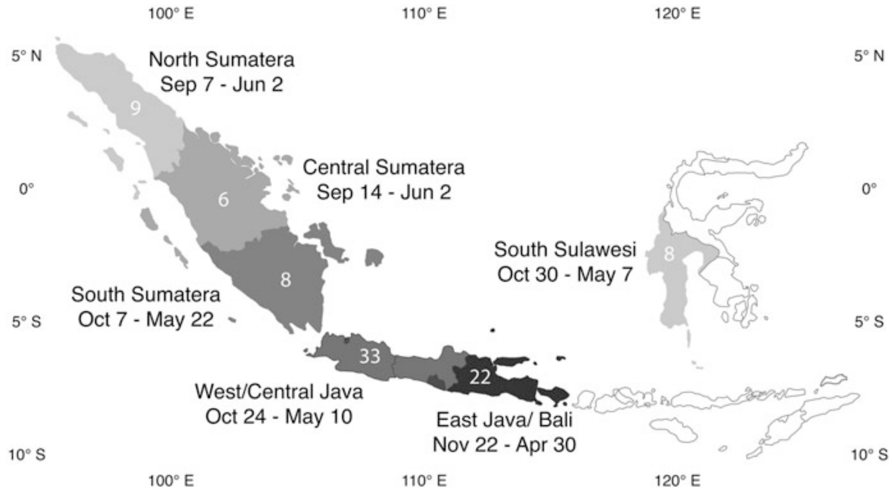

Fig. 1 Periods of a wet season and the proportion of paddy production in Indonesia. Numbers in the figure indicate the percentage of rice paddy production in Indonesia. The dates indicate the wet season periods. For example, East Java and Bali produce 22 percents of rice in Indonesia and a wet season starts from 22 November and ends 30 April on average

importance of the factors that influence the productivity of paddies. The factors are used as the elements of adaptive capacity. The potential factors identified by a statistical assessment were justified during stakeholder meetings and expert judgment.

A household survey was conducted to learn the farmers' adaptive capacities and perceptions of climate change. The questionnaire is mainly based on WFP's household questionnaire, which they used in their pilot food security and nutrition monitoring system project in Indonesia as well as in other similar studies (WFP, Ministry of Agriculture (Kemtan) 2009). A field survey was conducted in July and August 2012 by visiting 490 farmers at 70 subaks that are located at 81 villages in seven livelihood zones. The survey locations were chosen based on a clustered stratified random sampling method. Ten subaks in each livelihood zone were selected to represent upper, middle, and downstream areas. An ordinal least square regression model was implemented for the preliminary parameter identification, and other statistical tests were conducted on the survey data. The regression model for adaptive capacity, which is used to estimate the weighting factor, was finalized with the preferences approach, including expert interviews and a stakeholder discussion (Hinkel 2011; Harvey et al. 2009, p 17).

Results

Exposure

Bali is one of the leading rice-producing areas in Indonesia. With East Java, Bali produces 22 % of the rice produced in Indonesia (Naylor et al. 2007). Compared with other regions of rice cultivation, Bali is characterized by a short rainy season. For example, a typical rainy season in North Sumatra starts in early September and lasts until early June, but Bali's rainy season begins in late November and ends in late April. Thus, Bali is more likely to face water shortages, which is unfortunate, because it is an important region for rice production in Indonesia. It is said that the northern and eastern parts of Bali are particularly susceptible to drought (Fig. 1).

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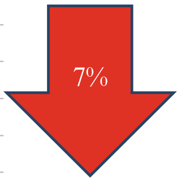
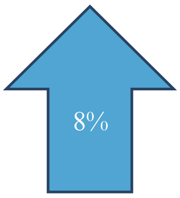
Table 2 Paddy harvested area, production rate, and production in Bali. In the past 10 years, paddy areas have decreased by 7 %, but because the production rate has increased 8 %, so rice production in Bali is reserved

Year	Paddy harvested area (ha)	Production rate (quintal/ha)	Production (ton)
2000	155,049	53.33	826,838
2001	147,942	53.35	789,232
2002	148,025	54.70	809,688
2003	145,294	54.60	793,260
2004	142,663	55.00	788,361
2005	141,577	55.00	785,481
2006	150,557	56.00	840,891
2007	145,030	58.00	839,775
2008	143,999	58.37	840,465





Impact of Climate Change on Rice Production

Based on a policy assessment with 10 governmental reports, including the National Action Plan and the Medium-Term Development Plan, there are 23 sets of adaptation policies in relation to agriculture (Takama et al. 2012). This is the largest number in the five major sectors, which also include water resources, coastal, ecosystems, and health. For example, the National Action Plan (2007) mentions the importance of developing an early warning system for drought. The fifth Presidential Decree in 2011 is also about climate change impacts on paddy production. As a result, examining the vulnerability of climate change on rice production is a priority in Indonesia.

Because of the warm climate, two or three cropping cycles in a year is possible in Indonesia. From the beginning of the rainy season until the beginning of the dry season, Balinese farmers usually cultivate rice twice. Then, they harvest vegetables once before the rainy season begins. If there is not enough water, then farmers cannot do double cropping in the paddy. Rice production must be ensured in order to sustain food supplies, because rice is a staple food, and Indonesia's current population of 240 million is expected to rise to 300 million by the year 2045. Bali is expected to undergo similar growth. In the past 10 years, paddy areas have decreased by 7 %, but because the production rate has increased by 8 %, rice production in Bali has not changed much (Table 2). In other words, the increase in the rate of production due to technological innovation must keep up with the decline in paddy areas; otherwise, the production volume would fall.

Nevertheless, a sign of production decline has already been seen. A spatial analysis revealed rain pattern changes of 46 % and 54 % in Bali during wet and dry seasons, respectively, between the 1970s and the 2000s (Fig. 2). A soil and climate suitability assessment for paddy production on the basis of a method from FAO shows that the land's suitability for rice production has decreased by 20 % in the past 20 years because of a decrease in precipitation (Prasetya and Novianti 2011). In other words, there is a possibility that rice production will decrease eventually as the productivity lowers. In fact, when the project team interviewed farmers in Bali, some responded that "as there is not enough water, paddy production forced to cut."

The research outcomes reconfirmed the likelihood of climate change in Bali as well as the strong possibility of paddy insecurity following the climate change. The reduction of suitability is mainly due to the decline in precipitation. The north and northeast regions of Bali have been getting drier. Therefore, drought is potentially the number one concern among the weather-related disasters that could harm paddy production.

In detail, 1.3 % of Bali's land is highly suitable (S1) for rice production (72,110 ha). Land with middle suitability (S2) covers 31.9 % of Bali (175,650 ha), and land with low suitability (S3) covers 56.9 % of Bali (313,226 ha), while land that is not suitable for paddies (N) covers as much as 9.9 %

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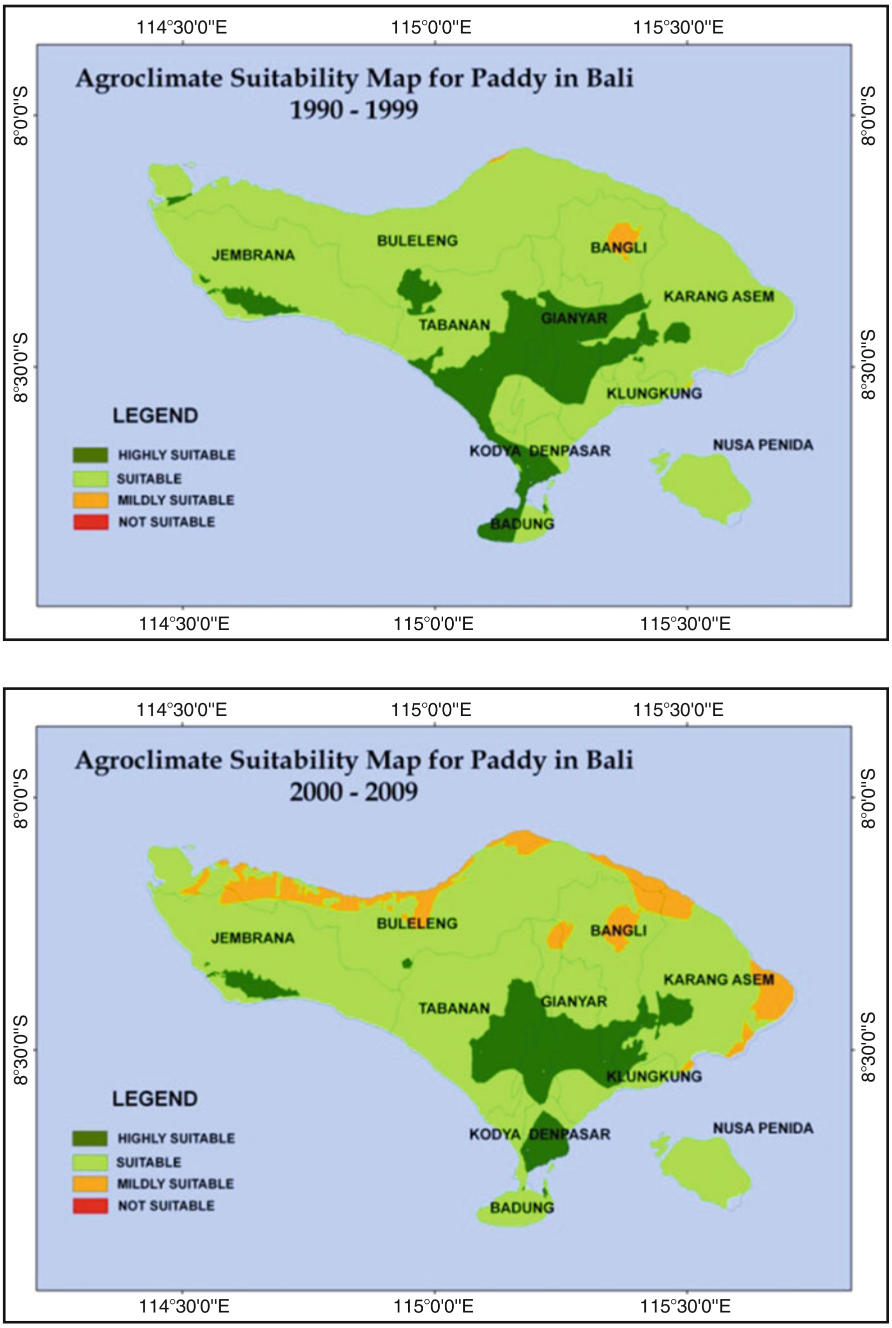

Fig. 2 Reduction of crop suitability: the dark green indicates the suitable areas and orange color indicates the less suitable areas for for rice production in Bali. The areas of dark green has decreased and the area of orange has increased in 20 years

(54,235 ha). Areas and percentages of land suitability for paddies in each regency are presented in Table 3. For example, "high suitability" areas (S1) cover parts of eastern Tabanan and parts of western Karangasem, and "not suitability" areas (N) cover parts of western Buleleng, parts of northern Tabanan, parts of northern Bangli, parts of northern and eastern Karangasem, and parts of Nusa Penida Island. The soil-climate suitability map in Fig. 2 is used as an exposure map in this vulnerability assessment.

Table 3 Total area and percentage of land suitability for paddy in Bali province

		S1: high suitability		S2: moderate suitability		S3: low suitability		N: not suitable	
	Regency	Total area (Ha)	%	(Ha)	%	(Ha)	%	(Ha)	%
1	Badung	392.6	1.1	10,346.2	27.9	26,046.6	70.4	234.9	0.6
2	Bangli	6.4	0.0	17,853.4	33.6	34,733.5	65.4	505.8	1.0
3	Buleleng			28,768.5	21.9	73,310.2	55.9	29,179.6	22.2
4	Gianyar	40.4	0.1	26,321.4	72.8	9,813.7	27.1		
5	Jembrana			18,675.2	22.7	58,355.0	70.9	5,308.7	6.4
6	Karangasem	1,431.4	1.7	20,943.4	25.5	50,891.2	61.8	9,023.8	11.0
7	Klungkung			726.7	2.5	20,161.2	69.8	7,988.4	27.7
8	Kodya Denpasar			2,767.3	22.9	9,318.9	77.1		
9	Tabanan	5,239.5	6.0	49,248.5	56.6	30,595.5	35.1	1,994.3	2.3

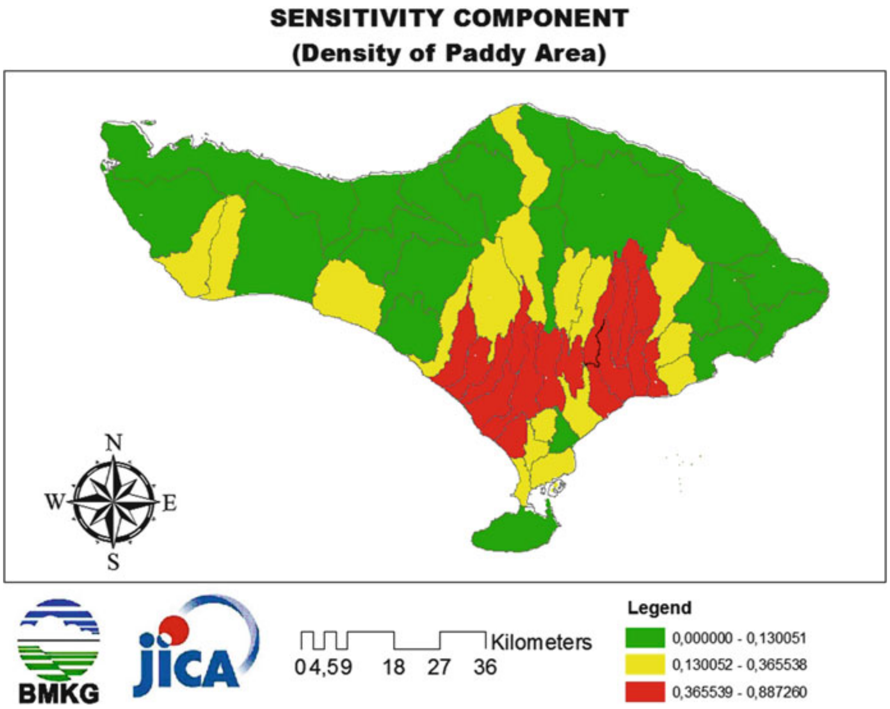

Fig. 3 Proportion paddy areas based on data from BPS-Statistics Indonesia. The red indicates the top 33 percent and green indicates the bottom 33 percent of sensitive areas for rice paddy production in Bali

Sensitivity

If no paddies exist in a location where severe drought is expected, then a drought in this location would cause no damage to paddy production, although the drought might cause other problems due to the climatic disaster. Paddy locations as sensitivity are not directly connected to the exposure of climate change; however, in paddy production, these factors cannot be ignored. Sensitivity is spatially determined by the proportion of rice paddy areas in each kecamatan. For example, the paddy fields in the south and central regions, including Gianyar, Tabanan, Badung, and Denpasar, cover more than 20 % of the total area (Fig. 3). Experts on rice paddy production in Bali mentioned that the impact of agriculture on climate needs to be considered seriously for areas with more than

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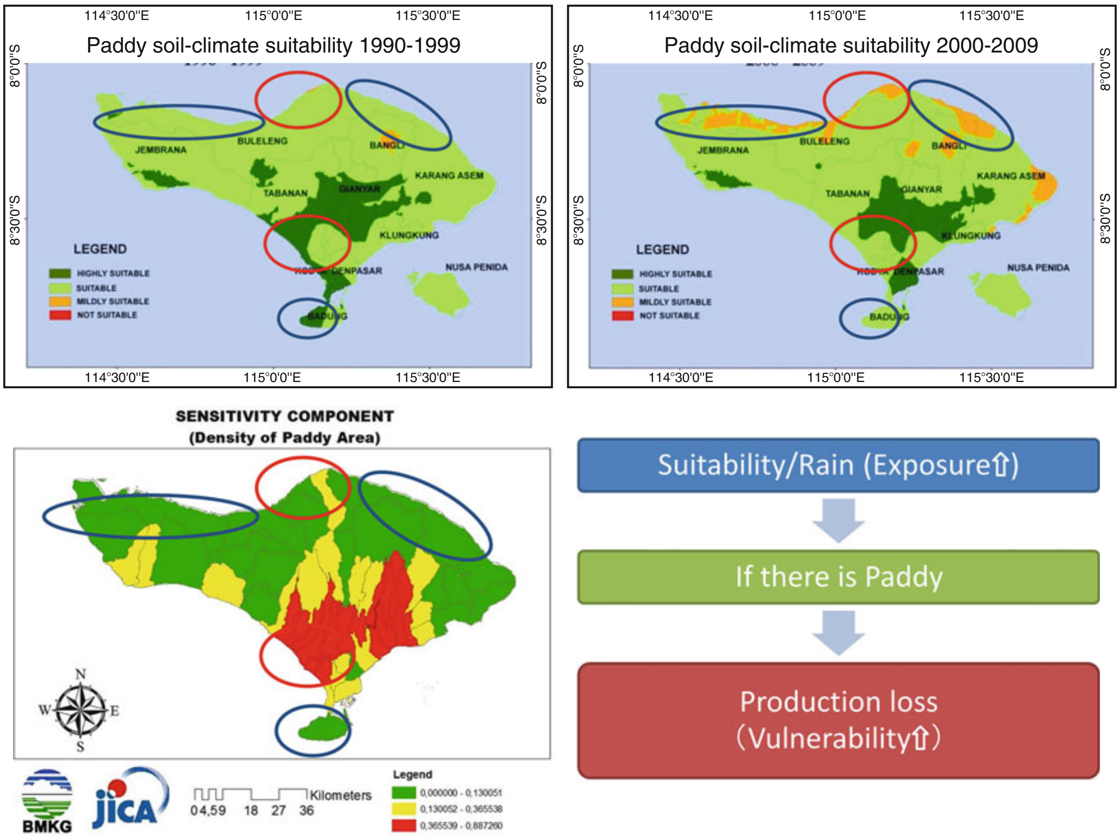

Fig. 4 Demonstration of spatial sensitivity on paddy production. Red circles indicate the areas the suitability has decreased and sensitivity (existing of rice paddy) is high. Blue circles indicate the areas suitability has decreased, but sensitivity is low

20 % of their land dedicated to agriculture (per com 2012). Therefore, these regions are perceived as areas that will be sensitive to climate impacts on rice production.

As a simple demonstration of the relationship between exposure and sensitivity, the top two maps in Fig. 4 show the change in the soil-climate suitability of paddy production. Areas circled with blue experienced reduced suitability when the precipitation has decreased. The map on the bottom shows the location of the paddy fields. In the areas enclosed by blue circles, there are very few paddies, so the sensitivity in these areas is not high. Therefore, the "vulnerability" of rice production may not necessarily be high. However, the areas with red circles have experienced decreased suitability, and they have many paddy fields. Therefore, vulnerability is higher in these areas.

Adaptive Capacity

To determine adaptive capacity, livelihood zones were first estimated as shown in Fig. 5 after a development workshop and discussion during a stakeholder meeting. The zones explain the overall characteristics of the social activities and geographical features in Bali. The central part is the highland, and the south and southwestern regions are the lowlands. The northeastern region is drier. Typically, the northern and southern regions are more tourism-oriented, and agricultural activities are more important to the rest of the regions.

The survey showed that Zone 1 has the highest rice paddy productivity (74.72 kg/acre) followed by Zones 5, 6, 3, 4, and 2. Zone 7 has the lowest productivity (36.85 kg/acre). The high productivity

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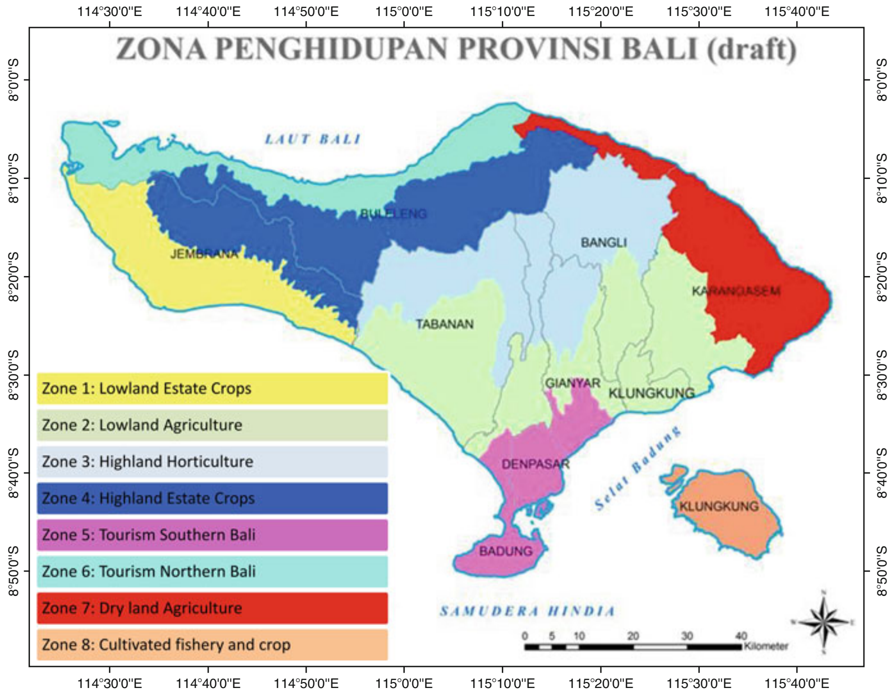

Fig. 5 Livelihood zone map in Bali: Livelihoods are categorized into eight zones based on a means of living through assets, activities, and capabilities

in Zone 1 may come from the lowland farming. However, Zone 1 and Zone 5 are not paddy-intensive areas. That is, less productive farmers may have already quit rice farming, and only the highly productive farmers may have remained in the two zones. The type of farmers can explain why the survey showed such high productivity in Zones 1 and 5, although rice production is not as popular in these two zones as it is in some other zones. The correlation between farmers' formal education and the productivity of their paddies indicated that formal education does not affect rice paddy productivity. However, farmers with agricultural training produce 54.70 kg/acre, which is 2.65 kg/acre higher than that of farmers who have not had the training. Farmers who use only inorganic fertilizers have higher productivity (60.09 kg/acre) than farmers who use only organic fertilizers (55.21 kg/acre) or farmers who use both organic and nonorganic fertilizers (59.33 kg/acre). In any case, the use of fertilizer seems to affect the productivity of a paddy.

Regression Analysis and Normative Approach for Weighting Value Estimation

The project team is expecting to develop the vulnerability assessment to cover the whole of Indonesia in the future; therefore, scalability was an important consideration during the model construction. The microlevel quantitative data are difficult to access or are likely to be inaccurate in Indonesia. Therefore, the project focused on a model with only mesoscale and macroscale qualitative/categorical data. Regression analyses were carried out with ordinary least square, and the best fitted model is as follows:

$$\begin{aligned}\text{normhvst} = \alpha &+ \beta_1\text{two.cycle} + \beta_2\text{lowland} + \beta_3\text{infari} + \beta_4\text{only.inorganic} + \beta_5\text{cooperative}\\ &+ \beta_6\text{agritrain} + \beta_7\text{owner}\end{aligned}$$

Where:

Table 4 Coefficients of a paddy production OLS model

	Estimate	Std. error	t value	Pr(>|t|)
(Intercept)	35.15	1.79	19.69	0.00
two.cycle	9.35	1.38	6.75	0.00
lowland	9.27	1.33	6.98	0.00
infari	6.84	2.40	2.85	0.00
only.inorganic	6.11	2.00	3.06	0.00
cooperative	5.11	1.36	3.75	0.00
agritrain	4.14	1.42	2.91	0.00
owner	3.30	1.36	2.43	0.02

Table 5 Marginal willingness to pay for intercept

(Intercept)	two.cycle	lowland	infari	only.inorganic	cooperative	agritrain	owner
1	0.27	0.26	0.19	0.17	0.15	0.12	0.09

- normhvst: KGs of unfilled grains per acre under normal conditions
- two.cycle: Dummy variable for cropping two cycles
- lowland: Dummy variable for a lowland paddy field
- infari: Dummy variable for a good variety, i.e., infari 13
- only.inorganic: Dummy variable for using only inorganic fertilizer
- cooperative: Dummy variable for a cooperative in their village
- agritrain: Dummy variable for agricultural training
- owner: Dummy variable for ownership

The coefficients for these variables are shown in Table 4. All coefficients are statistically significant at least to the 99.8 % level. All independent variables are dummy variables; therefore, the results are the same as those of the ANOVA model. Estimates indicate that all seven variables contribute to paddy production. It can also be explained logically the role of each variable in supporting paddy production. Farmers who grow paddy only once a year if their farmlands are not suitable for paddy farming due to lacking water have low productivity, while farmers who grow paddy three times a year also have low productivity due to decreasing soil nutrient. According to lapse rate, the temperature usually decreases with increasing altitude, and Luh (1991) mentions that the temperature greatly affects grain filling. Low temperature and high humidity during flowering will interfere with a fertilization process resulting in grains becoming empty and causing decreased paddy production, so paddy cultivation in lowland is likely to produce better than that in highland. Inpari13 is a superior variety with potential yield around 8.0 tons/ha; it is resistant to brown plant hopper and some diseases such as blass and “virus kerdil rumput”; grain of inpari 13 does not easily fall off so it can prevent yield loss at harvesting process by 1.34 % and 0.73 % at threshing process (BPTP Indonesia 2010). The advantage of inorganic fertilizers is that nutrients can be tailored to the needs of the plant. Most required nutrients for the growth and yield of the rice crop are N (nitrogen), P (phosphorus), and K (potassium), and these three nutrients are found in inorganic fertilizers. Within a cooperative, farmers share resources and it is easy to access the resources including fertilizer, seed, capital, and insecticide. Through agricultural training, farmers can improve their farming knowledge such as determining the appropriate planting time and choosing the appropriate variety. It is also proved by Suprapto (2010) that a farmer who has been taught by an extension

Table 6 Literature review for inorganic and organic fertilizers

		Inorganic and organic fertilizer = 4.45 tons/ha	Inorganic and organic fertilizer = 5.28 tons/ha	Grain productivity was enhanced by 21 % and 24 % under CFM and CFS compared to CF, respectively
		Inorganic fertilizer = 2.51 tons/ha (increasing 77.3 %)	Inorganic fertilizer = 3.52 tons/ha (increasing 50 %)	
1.	Resource	IPB (magister course)/ seminar paper	BPTP Maluku and South Sulawesi/Journal Agrivigor	Nanjing Agricultural University, China
2.	Year of research	2008–2009	2004	1987–2005
3.	Place of research	Bogor	Buru Island (Maluku)	Tai Lake Region, China
4.	Organic fertilizer used	Animal manure (10 tons/ha)	Chicken dung (1.5 tons/ ha)	Pig manure
				Paddy straw
5.	Inorganic fertilizer used	200 kg urea + 100 kg SP 36 + 100 kg KCl	300 kg urea + 150 SP 36 + 100 kg KCl	Chemical fertilizer
6.	Variety of paddy	Mentik wangi	Gilirang	

Table 7 Weighting factor for adaptive capacity before normalization

(Intercept)	two.cycle	lowland	inorganic.organic	infari	only.inorganic	cooperative	agritrain	owner
1	0.27	0.26	2.6	0.19	0.17	0.15	0.12	0.09

worker has higher production than other farmers who has not been taught. According to Suprapto (2010), there is a correlation between a land ownership and the principal occupation as a farmer, so that those who have the ownership will focus more on running the farm and produce more than other farmers who rent a land.

If none of the variables are available, a farmer produces an average of 35.15 KGs/acre per paddy. The effect is largest with the usage of a two-cycle cropping pattern and is the smallest with the ownership. For example, if a farmer cultivates rice twice per year or owns the paddy field, the farmer can produce an extra 9.35 KGs/acre or 3.30 KGs/acre, respectively. In other words, two-cycle cropping and land ownership, respectively, improve production by 27 % and 9 % (Table 5). The set of percentage improvement was used as the starting point to determine the index for the adaptive capacity for paddy production.

Based on the regression analysis, an index for adaptive capacity was developed normatively via stakeholder meetings and a discussion with experts. In addition to the factors already included in the regression model, other factors might affect production, including fertilizer types, excess water levels, dams, and land size. These factors are outside of the 10 % significant range; however, they are close enough to be significant to the level and are therefore logical to include.

Using inorganic fertilizer in a limited period can improve the productivity of paddy due to the composition of nutrient contained in the fertilizer. However, Syam'un (2001) states that the continual use of inorganic fertilizers can damage soil's physical properties, resulting a decrease in land productivity. Organic fertilizers provide a low impact on the growth and yield components. This can be overcome by a combination of organic and inorganic fertilizers (Syam and Sariubang 2001). Organic fertilizer can increase the paddy production when combined with a low dose of inorganic fertilizer. The area with an excess water level would ensure the water need of paddy so the plants will grow optimally and have better production. Similarly, the existence of dam will also

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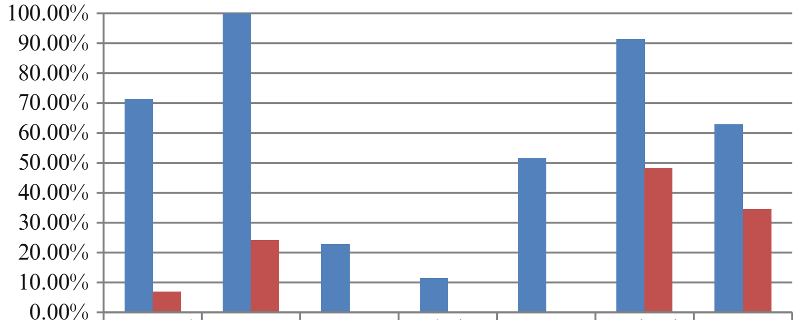

	two.cycle	lowland	infari	only.inorganic	cooperative	agritrain	owner
Most productive	71.43%	100.00%	22.86%	11.43%	51.43%	91.43%	62.86%
Least productive	6.90%	24.14%	0.00%	0.00%	0.00%	48.28%	34.48%

Fig. 6 Comparison between the most and least productive subaks based on seven factors used by the adaptive capacity model

Table 8 Adaptive capacity index for livelihood zones

Livelihood Zones	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	Sample no.
Zone 5	9.529	19.28	24.72	24.91	28.86	37.27	70
Zone 1	3.559	17.05	22.08	21.53	26.32	39.97	68
Zone 6	4.401	13.67	16.97	20.34	29.85	38.26	70
Zone 2	0.2606	13.91	18.78	19.99	27.29	33.13	74
Zone 3	3.559	12.81	18.02	17.54	22.16	31.43	71
Zone 4	0	12.55	16.97	16.74	20.9	28.99	71
Zone 7	0.2606	4.401	9.529	10.76	15.05	26.32	67

guarantee the sufficient water for paddy, and water from dam is more stable. All four factors will help the rice production.

Therefore, the project team discussed key stakeholders the possibility of adding these factors. As a result, the project decided to include inorganic and organic mixed fertilizer in the model. The level was decided based on literature reviews and expert opinions (Table 6). Three studies estimating the advantage of the mixed fertilizer compared with inorganic fertilizer were used for the source of the discussion. The productivities rose between 77.3 % and 21 % in these studies, and the stakeholder meeting decided to take the middle value of 50 %. With the additional inorganic and organic mixed fertilizer effect (inorganic.organic), the weighting factor for adaptive capacity was settled as Table 7.

Characteristics of the Most and the Least Productive Subaks

The characteristics of the five most productive and the five least productive subaks were compared to understand the magnitude of the given impacts in extreme situations. Subaks in which less than four farmers were sampled were omitted from this assessment. The five most productive subaks are Baluk, Lanyahan, Berawan Tangi, Pangkung Jajang, and Pangkung Liplip. A total of 29 farmers were sampled from these five subaks, and, on average, they produce rice at 84.97 kg/acre. The five least productive subaks are Datah, Lebah, Penaban, Tegakin, and Pajegan. A total of 35 farmers were sampled from these five subaks, and they produce rice at an average of 30.86 kg/acre.

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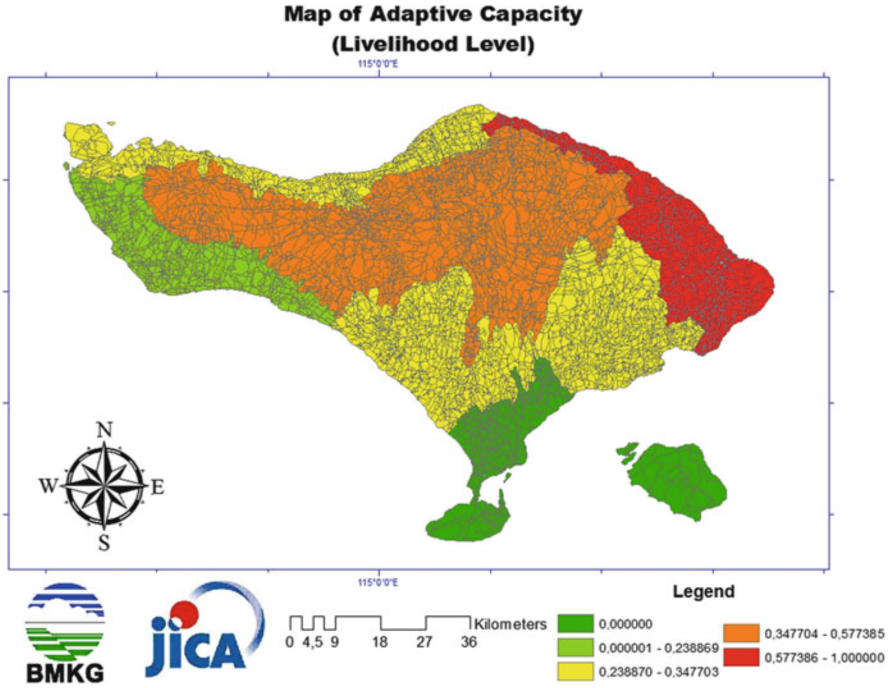

Fig. 7 Adaptive capacity for livelihood zone: green means high adaptive capacity and red means low adaptive capacity. Colors divide the adaptive capacity by 25 percents based on the ranking

When the most and least productive subaks are compared (Fig. 6), the difference clearly reflects the factors affecting rice paddy production in the regression model. For example, in the five most productive subaks, 62.86 % of the farmers own their paddy field; in the five least productive subaks, only 34.48 % of farmers own their land. In terms of location, all farmers in the five most productive subaks are located in lowlands, whereas only 24.24 % of the farmers are located in the lowlands in the five least productive subaks. 71.42 % of the farmers crop twice in a year in the most productive subaks, and only 6.90 % farmers crop twice in the least productive subaks. Moreover, 80 % and 20 % of the most productive farmers/subaks are, respectively, located in Zones 1 and 3. In contrast, all of the least productive farmers/subaks are located in Zone 7.

The adaptive capacity scores in each livelihood zone are shown in Table 8. The score of adaptive capacity is an index, so meaning arises only through comparisons. On average, Zone 5 has the highest adaptive capacity score followed by Zones 1, 6, 2, 3, 4, and 7. The index for the adaptive capacity of the livelihood zones is mapped in Fig. 5. Generally, the southern and southwestern regions, which have excellent paddy production, have higher adaptive capacity scores, and the central and northeastern regions have lower adaptive capacity scores (Fig. 7).

Vulnerability Assessment Maps

Several versions of vulnerability maps and indexes were developed. Combining the three components changes the characteristics of the maps and indexes. For example, the maps were developed according to the livelihood zones, so the results are closely related to the actual activities of local people. If the maps had been developed based on political boundaries, such as kabupaten, then they might not have reflected the activities on the ground; nevertheless, political maps can be easier for public officers to interpret and use. Similarly, sensitivity can be defined as an exact rice paddy location or as a density/percentage in a given rice paddy area, such as kabupaten (district) or a livelihood zone. Giving a binomial value to an exact location (1 = exist, 0 = not) produces

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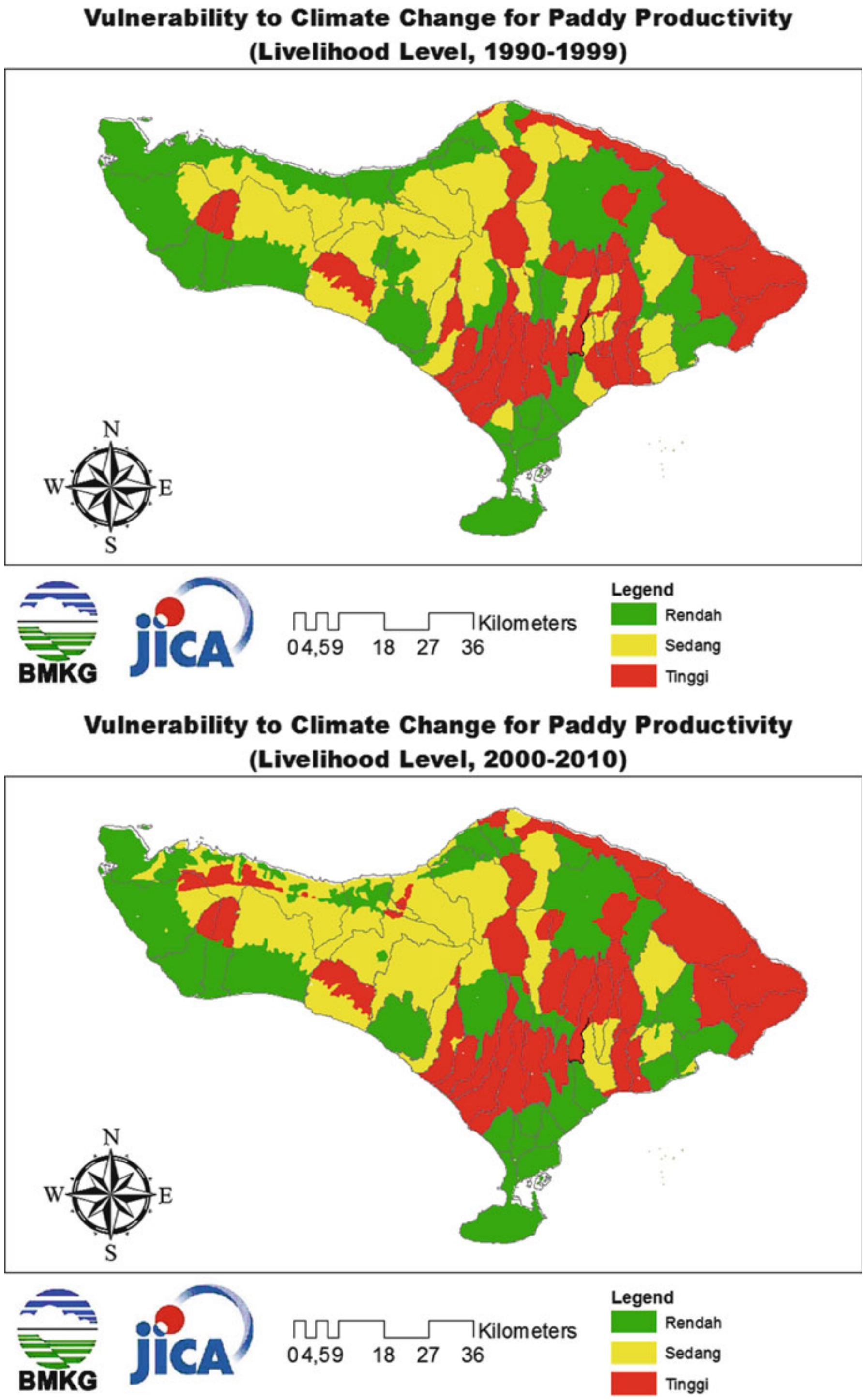

Fig. 8 Vulnerability map for rice paddy production: The *red color* indicates the higher indicate high vulnerability and the *green color* indicates low vulnerability. The *top figure* is the vulnerability based on 1990s climate and the *bottom figure* is based on 2000s climate

results that are easier to interpret. For example, one can conclude, "If there is no rice paddy field in the area, then the area will not sustain any damages to rice production." However, it can be harder to get a general overview of each political boundary or zone with binomial values.

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As there is no universal agreement on how to make a vulnerability map, the project team verified their maps with stakeholders and local experts. Thus, the vulnerability map is based on a soil-climate suitability map as exposure, a paddy proportion at kecamatan as sensitivity, and rice paddy productivity with socioeconomic factors at livelihood zones as adaptive capacity. The combination was selected according to the needs and purpose of this vulnerability assessment.

After a discussion about the components with local experts, the weighting between the three components were determined as exposure = 0.3, sensitivity = 0.2, and adaptive capacity = 0.5 (Fig. 8). This figure describes all three characteristics of vulnerability in rice paddy production in Bali. The northeastern regions are vulnerable because of lower suitability which comes from drier climate and lower adaptive capacity. The central regions are vulnerable because of lower adaptive capacity. Tabanan is vulnerable because of its high density of paddy areas. The southern region is less vulnerable than Tabanan, because the region enjoys good climatic conditions and high adaptive capacity. Also, comparing the two maps in Fig. 8, there are changes in vulnerabilities in paddy production in Bali. The vulnerability has increased in northwest region and southeast region. The Tabanan area also has some rise in vulnerability.

Discussion

A vulnerability index gives the overall picture of a vulnerability assessment. However, a vulnerability index will not give policymakers an entry point to plan adaptation measures, because they do not provide enough details about each component's unique characteristics. It is necessary to check the index of each component to understand the starting points for policy actions. An exposure index shows potential disasters, a sensitivity index shows the existence of exposure units, and an adaptive capacity index shows where abilities to handle the potential disasters are weak. For example, if policymakers need to know the location where potential disasters will happen, they need to check an exposure index and map. However, they also need to see a sensitivity map to check whether disaster-prone area has an exposure unit, and they must consult an adaptive capacity map to verify whether the exposure unit and related livelihood and stakeholders have enough adaptive capacities. The point is that checking each component is more practical than checking the weight of three components. Therefore, normative and abstract weighting between the three components is enough when a vulnerability assessment is implemented.

For example, the vulnerability map indicates high vulnerability in the northeastern region, and this vulnerability exists because of high exposure and low adaptive capacity. In this case, it is important to have proper policy actions to support the rice farmers in this region. Agricultural extension is one of policy tools that is used by a local government to encourage the development of agriculture, where agriculture extension workers have a significant role in helping farmers offering the information related to climate change and climate impacts and teaching new technologies to cope with the climatic impacts. It can be done among others through agricultural training. Our preliminary results show that a farmer who has received training from an agricultural extension worker is likely to increase their rice paddy production by 4 kg per acre, which is a 12 % gain in productivity. Strengthening the current extension system is one approach. If that is difficult due to the change in institution and management, other players such as universities, agrobusinesses, NGOs, and farmers' organizations may need to play a greater role. BMKG's climate field school is a successful example. Another way to strengthen the adaptive capacity is supporting the cooperative that can help the people to prepare for the high exposure in the region, because adaptive capacity is low there. Tabanan is a vulnerable area, but that is mainly due to high sensitivity. Therefore, policy actions will

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be different in Tabanan than they will be for the northeastern region. In Tabanan, the gravest concern will be catastrophic disasters and diseases, because the majority of land and farmers are engaged with rice paddy production. Therefore, the support for Tabanan can be ad hoc. For example, when a heavy drought is likely to come, the local authority may provide drought-resilient seeds and fertilizers to the farmers in Tabanan. Both climate and adaptive capacity are generally in good condition in Tabanan, so policymakers might not need to focus on training and cooperatives in this region.

If an area's productivity is low because of low adaptive capacity, policies on agricultural training and cooperatives can help adaptive capacity significantly and directly, and eventually, capacity development works will raise rice productivity. For adaptation planning based on a vulnerability assessment, the information from the three components is likely to be more useful than the final vulnerability value. Having said that, the vulnerability value is still useful for gaining a big picture of a region or a sector, but, to plan a policy, it is necessary to get information from the component level.

Moreover, Fig. 8 shows there are some changes in the vulnerability in the two periods between 1990s and 2000s. The assessment did not change sensitivity and adaptive capacity; therefore, the changes are all based on exposure such as climatic factors. Some parts of Bali have gotten drier, if the vulnerability increased. The final vulnerability map indicated not only climate change but also a vulnerability change in rice paddy production in Bali.

Perceptions of Climate Change and Impacts

Correlation and causation have to be carefully distinguished in the vulnerability assessment. In the survey result of adaptive capacity, farmers who do not perceive extreme events like flooding and their effects on paddy qualities and quantities as related to climate change have better production than other farmers, with a 95 % statistical significance. For example, farmers who do not consider the adverse effects of climate change generally produce about 5 kg of rice paddy per acre more than farmers who consider the effects. However, this does not mean that "no perception of climate change" results in better rice paddy production. Instead, these farmers already have better rice paddy production; therefore, they are likely to "not care about climate change." In other words, "good rice paddy production" can make these farmers ignorant of climate change and its potential impact. Thus, the ignorance factor should not be included to set up a paddy production function or vulnerability factors, because the causation from these factors to paddy production cannot be explained.

The climate-ignorant farmers enjoy good productivity now, but if impacts from climate change worsen and farmers continue to ignore them, then these farmers may not cope well with the adverse effects of climate change in the future. This is the definition of vulnerability from IPCC. The farmers who do not perceive climate change and its potential impact can be more vulnerable than other farmers, as the actual paddy qualities and quantities are affected by the change in climate. Moreover, the climate change assessment in the current project suggests that climate change seems to be happening in Bali. Ignoring these changes may affect future rice paddy production significantly for these uninformed farmers.

Roles of Agencies to Disseminate Climatic Information

Results show that farmers who have received training from an agricultural extension worker are likely to increase their rice paddy production by 4 kg per acre, which is a 12 % gain in productivity. Centennial Group International (2012) mentioned that the agricultural extension worker system has

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been weakened due to institutional and management changes, such as funding responsibility and provision of services. Therefore, at the present time, the agricultural extension system is not uniform. For example, only 2,560 extension workers, or 6 % of the total number, hold bachelor's degrees, and the rest hold lower qualifications. The agricultural extension system has a significant role to play in rice paddy production, and if the system declines, then productivity may also decline.

Conclusion

This report demonstrated how to develop a vulnerability index and maps with a quantitative and normative qualitative approach. Exposure as a potential disaster was presented by a soil-climate suitability map, and the map indicates climate change in Bali. Sensitivity was displayed as rice paddy production. Adaptive capacity was estimated by a regression model of social factors related to rice paddy production. The final map successfully indicated the regions that are vulnerable to reductions in rice paddy production due to climate change, which are, namely, the northeast, central west, and Tabanan regions.

The results of this assessment can be used for policy implementation, such as agricultural training. Since agricultural training will improve the production of rice more than 4 kg per acre, policymakers can improve the adaptive capacity of rice farmers by reinforcing agricultural training programs, which have been degrading. In addition, the results of the adaptive capacity assessment will be used to assess the vulnerability of rice paddy production. This assessment requires two more components: exposure to climatic impacts and sensitivity to such impacts. To utilize the vulnerability assessment in the future, continuous assessment and engagement with stakeholders will be necessary. Usually, less-capable farmers should receive higher attention in the vulnerability assessment, because the results indicate that they are vulnerable to the current climate and that the adverse effects of climate change will hit them harder. It is important to provide correct climate information to farmers, and developing vulnerability maps that are matched to the needs of users will help to support farmers and policymakers by providing comprehensive vulnerability information.

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