Assessing the vulnerability of food farming system to support climate change adaptation: A case study in Java, Indonesia

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Abstract. Increasing resilience to climate change is one of the priorities of the Government of Indonesia. Climate change has a significant impact on the agricultural sector and is projected to global gross domestic product. Java Island, as a center of food production, has a strategic location because of its strong impact on food availability in Indonesia. The study aimed to provide information about the status of the vulnerability of farming system for food at the district/city level in Java Island and the determinant factors that affect the level of vulnerability. The analysis was based on soil fertility, water availability and demand, climate, and socio-economy expressed in terms of exposure and sensitivity index and adaptation capacity index using the quadrant method. The results show that 20\% of districts/cities in Java have very high levels of vulnerability. The main determinants identified in Java are the ratio of the number of extension agents and the number of farmer groups/rice field area and the rice consumption ratio to total carbohydrate food. The results of this study can be used as a reference in determining priority locations and formulating adaptation programs and actions to reduce the impact of climate change.

1. Introduction

The 2020-2024 mid-term development plan (RPJMN), which is a national planning document, states that one of Indonesia's national priorities is increasing disaster and climate change resilience as an integral part of strengthening economic resilience and building the environment. Climate change is a significant concern considering its considerable impact, which can affect the decline on global gross domestic product. Based on the Asian Development Bank data, the losses in the agricultural and coastal sectors due to climate change in 2,100 are estimated to be around 2.2\% of the total GDP \cite{1}. Therefore, adaptation as an effort to increase resilience to climate change needs to be supported by the results of studies to assist program formulation and implementation in Indonesia.

Indonesia is a tropical country with a position flanked by two oceans and two continents, which makes Indonesia's climate very complex and dynamic. Some of the advantages in the tropical regions are getting sunshine almost all year round, having relatively fertile soil because it is exposed to sunlight all year round, and having sufficient rainfall and only two seasons (rainy season and dry season).

On the other hand, the emergence of climate change has had a significant impact on various sectors, particularly agriculture. Climate change caused by increased emission of greenhouse gases to...
the atmosphere from anthropogenic activities has a direct effect on the functions of nature and agrosystems [2]. Changes in water systems and atmospheric temperature due to the anthropogenic greenhouse effect cause variations in crop productivity and hence affect food production [3]. Other studies showed that the most visible impact of climate change on the agricultural sector is on crop yields [4-13]. Meanwhile, the impact on the soil can be seen in the dynamics of soil carbon stocks [14].

The population that continues to increase has the consequence that food supply is also growing. FAO shows the need for food for an increasing population often threatens natural resources as people try to get the most out of the land that is already in production [15]. Based on the results of the 2015 inter-census population survey, it is estimated that Indonesia’s population in 2020 will be 269,670 million people [16], and most of them consume rice as the staple food. The agricultural centers in Indonesia are mostly areas that are significantly affected by climate change and climate extremes. The impacts faced include (1) seasonal shifts that cause conventional planting time to be inapplicable, (2) increased temperature and changes in rain patterns cause potential areas for food commodity cultivation to be less than optimal, (3) an increase in temperature causes a decrease in plant productivity, (4) seasonal shifts indirectly encourage the emergence of Plant Pest Organisms (OPT), and (5) sea level rise and salinity will reduce agricultural land on the coast, causing a decrease in production [17].

Java Island is the largest contributor to national rice production. BPS data shows that the total rice field area of Indonesia is 7.46 million ha, and about 45.7% of them are located in Java [18]. Therefore, most of the national rice production (54%) comes from Java. On the other hand, the share of rice production in Java Island towards total national rice production continues to decline due to the reduction in rice fields in Java Island. One of the causes is extreme climatic events that have an impact in the form of floods and droughts, which reduce planting areas, harvested areas, and production. An example is a case in the Brantas watershed in East Java. If paddy fields are affected by flooding and drought, it is projected that yield losses will reach 5.2 t ha⁻¹ [19]. Besides, other impacts include postponement of the start of the rainy season by 30 days due to seasonal shifts and extreme climatic events that frequently occur, especially in rice production centers in Java and Bali [20].

For the agricultural sector, adaptation is a priority with mitigation as a co-benefit. Given the different impacts of climate change on each region, adaptation programs and actions should also be carried out based on the magnitude of the effect in each area. The realization of adaptation programs and efforts needs to be supported by related research and studies, one of which is the analysis of the vulnerability index of food farming. Vulnerability is the propensity to be affected by hazards caused by a lack of capacity to cope and adapt [21]. A vulnerability indicator is a credible tool for decision-makers to identify priority needs [22], whereas the biophysical indicators are agricultural products such as crop yields and socio-economic indicators, including income from crop production [23]. Research and vulnerability studies have been carried out in various sectors, such as agriculture, energy, and water resources [24-30]. In Indonesia, vulnerability assessments have been carried out by several agencies with different objectives, such as the Food Security Agency, the Meteorology, Climatology and Geophysics Agency, and the Ministry of Forestry and the Environment [31]. The success of adaptation is also primarily determined by the response of farmers to climate change. Apart from that, several studies on farmers’ perceptions and responses to climate change have also been carried out [32-35].

Java, which is a center for food production, especially rice, is a vital study location because of its event of an extreme climate. Any change in Java will have a significant impact on rice production, food supply, and even national food availability. By identifying the level of vulnerability and determinant factors, it is hoped that adaptation programs and actions can be developed to reduce the risk of climate change impacts. It is also an anticipatory measure to increase adaptation capacity and reduce the level of exposure and sensitivity to climate change. The study aimed to provide information about the status of the vulnerability of farming system for food at the district/city level in Java Island and the determinant factors that affect the level of vulnerability.
2. Materials and methods

2.1. Study area

The research was conducted in Java Island as the center for National rice production, where the largest staple food is produced for the Indonesian population. The area of Java Island was about 129,438.28 km\(^2\) or 6.8% of the total area of Indonesia covering 1,913,578.68 km\(^2\) [36]. Java Island consists of 6 provinces and 119 districts/cities.

2.2. Data

Vulnerability analysis involved four main data groups: soil fertility, water criticality level, climate type, and socio-economy. The data used in the study were soil fertility based on review ground level maps 1:250,000 [37], monthly rainfall [38, 39], a map of the availability of river water sourced from the Ministry of Public Works, socio-economic data (consumption, production, rice field area, farmer groups, extension workers, education, etc.) from BPS.

Soil fertility was analyzed based on soil type and slope identified from the 1: 250,000 scale reconnaissance soil map at the scale. The level of water criticality was analyzed based on the ratio of water availability and demand. Water availability was interpreted from the spatial water availability data of the river. In contrast, water demand was calculated from the agricultural land and water needs for paddy fields and dry land. Rainfall data were analyzed to obtain the type of climate based on the Oldeman method. The socio-economic data included production, consumption, and other supporting data. All data were expressed in an index form and grouped into the Exposure and Sensitivity Index (IKS) and the Adaptation Capacity Index (IKA). There were 15 IKS data (table 1) and 6 IKA data (table 2).

| Index  | Data                                                                                           | Index  | Data                                                                                           |
|--------|------------------------------------------------------------------------------------------------|--------|------------------------------------------------------------------------------------------------|
| IKS 1  | The ratio of rice consumption to total carbohydrate food                                      | IKS 9  | Soil fertility                                                                                    |
| IKS 2  | Rice consumption per capita                                                                    | IKS 10 | Agricultural Gross Regional Domestic Product (GRDP) ratio per total                              |
| IKS 3  | Entropy (shows the level of food diversification)                                              | IKS 11 | GINI index (income gap)                                                                          |
| IKS 4  | The ratio of expenditure on rice to total expenditure on food                                  | IKS 12 | Climate type                                                                                    |
| IKS 5  | Percentage of poor people                                                                     | IKS 13 | Ratio of farmer households to resident households                                               |
| IKS 6  | Rice and maize production to population ratio                                                 | IKS 14 | Population density                                                                              |
| IKS 7  | Soybean production to population ratio                                                         | IKS 15 | Ratio of land area for food agriculture to total area                                             |
| IKS 8  | Availability of water                                                                         |        |                                                                                                 |

| Index | Data                                                                                           |
|--------|------------------------------------------------------------------------------------------------|
| IKA 1  | School enrollment rates                                                                       |
| IKA 2  | Road length based on surface conditions                                                       |
| IKA 3  | The ratio of the number of extension agents to rice field area                                |
| IKA 4  | The ratio of the number of poktan to rice field area                                           |
| IKA 5  | The ratio of the number of types of agricultural machinery to rice field area                 |
| IKA 6  | The ratio of the value of food consumption to the total value of household expenditure         |
2.3. Methods

Vulnerability is a function of the sensitivity of agriculture to climate change, the adaptive capacity of the system, and the level of exposure to climate hazards [40]. The assessment of the level of vulnerability was carried out by an approach based on a combination of three key indicators, namely, exposure, sensitivity and adaptation capacity. The classification used the quadrant method [41] modified by Boer [42]. Modifications were made in the weight assessment aspect determined based on Expert Judgment.

Based on the quadrant classification method, five levels of vulnerability in food farming system were produced, i.e., Very Low, Low, Medium, High, and Very High. The vulnerability classifications were then mapped to determine the distribution at the district/city level in Java. The determinant factors were identified using the respective spider diagrams for IKA and IKS with index values ranging from 0 to 1. Based on the level of vulnerability and additional information on determinants, recommendations were made to support adaptation to climate change in Java (Figure 1).

3. Results and discussion

Twenty four districts/cities (20%) in Indonesia were classified as very highly vulnerable in food farming. The distribution of vulnerable districts were found in West Java Province (7 districts), Central Java Province (7 districts), East Java Province (6 districts), Banten Province (4 districts), and Jakarta Province (1 district, Table 3). The distribution of districts in high food farming vulnerability in provinces is respectively Cianjur, Garut, Cirebon, Indramayu, Subang, Karawang, and West Bandung (West Java Province), Grobogan, Rembang, Pati, Demak, Pemalang, Tegal, and Brebes (Central Java Province), Malang, Lumajang, Jember, Situbondo, Magetan, Bangkalan, and Sampang (East Java Province), Pandeglang, Lebak, Tangerang and Serang (Banten Province, Figure 2).
Most of the districts or cities that have a very high level of vulnerability are food production centers, but infrastructure support and human resources are limited, such as the number of extension agents or a combination of farmer groups compared to the area of their rice fields, thus affecting their adaptive capacity.

The identification of the determinant factor of the very high level of vulnerability in Java indicates that the adaptation capacity in this area is generally still low, and the levels of exposure and sensitivity are still high. The level of vulnerability will decrease if the adaptation capacity increases to a medium level. The "Medium" level of IKA is represented by the dashed line (Figure 3a), whereas for IKS it must be increased to medium level to reduce the level of vulnerability. The "Medium" level of IKS as represented by the dashed line (Figure 3b). For example IKA 1 (school participation) must be increased from 0.3 to 0.5, IKA 3 (the ratio of the number of extension worker to rice field area) must be increased from 0.2 to 0.4, the IKA 4 (the ratio of total group of farmer to rice field area) must be increased from 0.2 to 0.4 and the IKA 6 (the ratio of the value of food consumption to the value of total household expenditure) must be increased from 0.4 to 0.6. Parameters that are good enough to

Figure 2. Distribution of vulnerability of food farming in Java at the district/city level.

Table 3. Distribution of the number of districts at each level of vulnerability in Java.

| No | Province     | Very Low | Low  | Moderate | High | Very High | Total |
|----|--------------|----------|------|----------|------|-----------|-------|
| 1  | DKI Jakarta  | 2        | 0    | 3        | 1    | 0         | 6     |
| 2  | Jawa Barat   | 2        | 8    | 10       | 0    | 7         | 27    |
| 3  | Jawa Tengah  | 0        | 10   | 18       | 0    | 7         | 35    |
| 4  | DIY          | 0        | 3    | 2        | 0    | 0         | 5     |
| 5  | Jawa Timur   | 4        | 7    | 21       | 0    | 6         | 38    |
| 6  | Banten       | 0        | 3    | 1        | 0    | 4         | 8     |
|    | Total        | 8        | 31   | 55       | 1    | 24        | 119   |

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support adaptation capacity are IKA 2 (road length based on surface conditions) and IKA 5 (ratio of the number and types of machinery per rice field unit), whose values are greater than 0.5.

For the average condition of Java Island, there are still many parameters that need to be lowered, namely: IKS 3 (Entropy), IKS 1 (Ratio of rice consumption to total carbohydrate food), IKS 12 (Oldeman climate type), IKS 4 (Expenditure ratio for the rice to total expenditure on food), IKS 5 (Percentage of poor people), IKS 15 (Ratio of land area for food agriculture to the area), IKS 8 (availability of water), IKS 9 (level of soil fertility) and IKS 14 (population density). Each of these parameters still has an index of more than 0.5. For this reason, it must be decreased so that the level of vulnerability from "Very High" becomes "Medium" (Figure 3b).

Determinant factors can also be identified at the provincial and district levels according to the needs and purposes of the information to be provided. Based on the identification results, the vulnerability levels in Java Island, the dominant determinants that affect the level of vulnerability of food farming are IKA 4 (the ratio of the total indicates of farmers to rice field area) and IKS 1 (Ratio of rice consumption to total carbohydrate food).

In the framework of adaptation to climate change, the level of vulnerability of food farming can be used as a reference in determining adaptation priority locations, while the determinant factors can be used as the basis for programming and adaptation actions. Areas with a "very high" level of vulnerability certainly require much greater adaptation efforts than regions with a "medium" level of vulnerability. The starting point that can be used as adaptation efforts is to know the determinant factors, whether to increase or decrease in line with the three components of vulnerability, namely sensitivity, exposure, and adaptation capacity.

The dotted line is the medium index value. To reduce the level of vulnerability, the IKA index must be increased at least to a medium value (dashed line in green, (a)), while for IKS it must be lowered from a minimum value to a medium value (dashed line in red, (b)).

Figure 3. Spider diagram of IKA (a) and IKS (b) at a very high level of vulnerability in Java

Based on the vulnerability of food farming at high and very high levels in Java, several recommendations can be proposed for the identified determinants of IKA 4 and IKS 1. To increase the ratio of the total group of farmer to rice field area (IKA 4) the proposed recommendations are: (1) improving the institutionalization of farmer groups and increasing the number of farmer groups, (2) increasing the capacity of farmer groups and (3) empowerment of farmer groups. While recommendations for decreasing the ratio of rice consumption to total carbohydrate food (IKS 1) are: (1) food diversification, especially from rice to non-rice and local food, (2) development of local non-
rice food technology production, including the development of processing technology, and (3) development of sustainable food house area. Besides, efforts that can be made in the context of climate change adaptation are increasing capacity to promote food diversification programs among the community, to promote non-agricultural sectors that can increase district income, and to promote production aspects by utilizing sub-optimal lands, idle land, land management, water and fertilization that is environmentally friendly and sustainable. The implementation of integrated cropping calendars in the field to adapt to a climate with very dynamic variability. The integrated cropping calendar is a guideline that provides spatial and tabular information on the current state of food agriculture activities in Indonesia [43].

Adaptation technology recommendations are compiled based on determinant factors and aligned with adaptation programs and actions in the regions as outlined in the Regional Medium Term Program Plan (RPJMD), which aims to reduce the level of vulnerability through adaptation options to climate change. Therefore, recommendations are site-specific and are made to be implemented in the regions. To implement the proposed recommendations it is necessary to have discussions with several stakeholders such as the Center for the Assessment and Application of Agricultural Technology (BPTP), the Regional Planning Agency (Bappeda), the Agriculture Office, the Plant Protection and Pest Control Center (BPTPH), Agricultural Extension Centers (BPP), extention worker, farmer groups and farmers.

The implementation of climate change adaptation is relatively complex, considering Indonesia's geographical position in the tropics, topographic variations, the extent of land and sea areas, and the response of the implementers in the field. However, it is not impossible to do this. A comprehensive approach, outreach and assistance is needed so that adaptation programs and actions can be implemented to minimize impacts and risks due to climate change.

4. Conclusions
Based on the results of the study concluded that approximately 20% of districts/cities in Java Island are at a high to very high level of vulnerability of farming system for food. The determinant factors that affect the level of vulnerability in Java are ratio of the total group of farmer to rice field area for IKA and Ratio of rice consumption to total carbohydrate food for IKS.

Locations with high and very high levels of vulnerability are priority sites for adaptation. Adaptation programs and actions can be prepared based on the determinant factors of IKA and IKS.

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