

Vulnerability assessment to frost disaster in dieng volcanic highland using spatial multi-criteria evaluation

A Pradana¹, Y A Rahmanu¹, I Prabaningrum¹, I Nurafifa¹ and D R Hizbaron¹

¹Environmental Geography Department, Faculty of Geography, Universitas Gadjah Mada

adityapradana@mail.ugm.ac.id

Abstract. Dieng Volcanic Highland is one of frost disaster prone area which is very unique phenomenon in tropical region. Frost indicated by appearance of frozen dew or ice layer on the ground or vegetation surface due air inversion and cold temperatures during midnight in dry season. Appearance of frost significantly causes plant damage and losses on agricultural land, while the impacts were strongly influenced by level of vulnerability within agricultural communities. This study aims to analyze the impact of frost on agricultural land in Dieng, to identify characteristics of physical, social, economic vulnerability and coping capacity of agricultural communities to frost disaster in Dieng, and to estimate total vulnerability of frost disasters in Dieng through SMCE scenario. Research was conducted in Dieng Village, Wonosobo and Dieng Kulon Village, Banjarnegara. Method to assess vulnerability level is performed by Spatial Multi Criteria Evaluation (SMCE) method using ILWIS software through a combination of physical, social, and economic vulnerability regarding frost hazard, as well as coping capacity of farmers. Data collected by interview within different agricultural plots using questionnaire and in-depth interview method on frost affected agricultural land. Impact of frost mostly causes damage on potato agricultural land than any other types of commodities, such as carrot, leek or cabbage. Losses varies in range of 0 million to 55 million rupiah, at most events in range of 10 million to 15 million rupiah during frost season on July-August-September. Main factors determining vulnerability comes from crop losses, preparedness effort, and type of commodity. Agricultural land dominated by high level physical vulnerability (95.37 percent), high level social vulnerability (70.79 percent), moderate level economic vulnerability (79.23 percent) and moderate level coping capacity (73.18 percent). All five scenarios indicated that level of total vulnerability vary only from moderate level up to high level.

1. Introduction

Indonesia as a wet tropical climate region characterized by relatively high air humidity, heavy annual rainfall and high annual temperatures above 25°C [1]. Tropical climate conditions not possible to allow the emergence of natural ice phenomenon in Indonesia, but the emergence of natural ice occurred in the Dieng Volcanic Highland, Central Java. This condition characterized by appearance of "*embun upas*" in local language or well known as frost or freezing dew in the surface of thin leaves or soil during dry season. Theoretically, frost only can be found in sub-tropical regions [2]. The emergence of frost in Dieng Volcanic Highland became a unique phenomenon because it usually occurs only at the peak of the dry season between July, August and September at midnight. Frost is not only unique but causes losses on agricultural plants. Dieng Volcanic Highland is at an elevation between 1,200 meters to 2,000 meters above sea level. Physical characteristic causes Dieng has fertile soil and cool climate that is very suitable for agricultural activities mainly potato farming. Nowadays, Dieng became national potato cultivation center with harvest frequency two to three times a year [3]. Frost leads to freezing of outer leaf tissue in thin-leaved plants so that potato plants experience death



[4]. Highest damage and losses occur on thin-leaved plants up to tens of millions rupiah, mostly on potato as main commodities.

Distribution of frost occurs unevenly strongly determined by the condition of farming management, so there is a need for a frost disaster vulnerability mapping assessment as one of the foundations of disaster risk reduction policy in frost affected areas. Vulnerability assessment combines the physical, social and economic conditions of agricultural areas, so as to assist in the efficient delivery of disaster management directions. Frost disaster is very dynamic, while level of farmer's vulnerability is highly determined by many unstructured multi-level factors. In order to forecast future losses, the Spatial Multi Criteria Evaluation (SMCE) modeling is capable of generating various vulnerability scenarios for disaster management decision-making for future possibilities [5]. This study aims to analyze the impact of frost disaster on agricultural land in Dieng, to identify the characteristics of physical, social, economic vulnerability and coping capacity of community to frost disaster in Dieng, and to estimate the total vulnerability of frost disasters in agricultural land in Dieng through the SMCE scenario.

2. Methods

Research was conducted in Dieng, Kejajar, Wonosobo and Dieng Kulon, Batur, Banjarnegara. Research was conducted during May to September 2017. Vulnerability assessment was conducted on frost prone areas that have been mapped and located on 125.59 hectares Tulis river alluvial plain basin surrounded by four volcanic cone (Prau, Binem, Pongonan and Kendil) in Dieng Volcanic Highland which is very suitable the suitable location for frost formation [6] (figure 1). Vulnerability assessment undertaken on 110.15 hectares agricultural land located on frost prone area. During dry season (July until September), temperatures can reach 0°C in the mid night and create radiative frost that known as *embun upas* by locals. Frost causes damage and economic losses to potatoes agricultural crops as main commodities.



Figure 1. Satellite imagery of study area (blue area).

2.1. Material and equipment

Research was collecting sets of geospatial data, includes; agricultural land owner's boundary, administrative boundary, rivers, and land use in shp format. Data obtained from land observation, RBI Indonesia sheet of Kejajar and Batur as well as from satellite imagery. Equipment used among others, include; questionnaire, interview guidance, and Global Positioning System (GPS). Data operation was conducted using ILWIS 3.3 and ArcGIS 10.3.

2.2. Procedure

Research aims to develop a method by using Spatial Multi Criteria Evaluation (SMCE) for determining vulnerability scenario. There were four main activities in this research, namely data preparation, data collecting, data processing and data analysis (figure 3). Preparation stages consist of literature study, geospatial database preparation and defining unit of analysis. Vulnerability

assessment undertaken based on land owner units analysis on agricultural land affected by frost. Site selection was performed only in frost affected areas precisely in the 125.59 hectare alluvial plains between Dieng and Dieng Kulon village. Data collection was done through structured interview techniques with questionnaires to identify vulnerability parameters as well as in-depth interviews to understand the conditions of frost loss and community preparedness. Determination of vulnerability parameters based on preliminary survey and literature study. Questionnaire interviews conducted on 40 different plots in frost affected area. In-depth interviews were conducted with key informants who were village administrators and heads of farmer groups.

Data processing was performed by ILWIS 3.3 and ArcGIS 10.3 software. Interview results are grouped into parameters of vulnerability either physical, social and economic, as well as coping capacity. Multi-scenario vulnerability assessment using Spatial Multi Criteria Evaluation (SMCE) in ILWIS is selected for several important reasons, such as to process vulnerability data into spatial data results and to allow weighting of vulnerability parameters through different scenarios to reduce bias compared to if parameters of frost vulnerability are processed by one scenario and multiple different scenarios can be used to accommodate decision making in disaster management for various future possibilities. Spatial Multi Criteria Evaluation (SMCE) possible to work with multi-level and diverse input data to explain unstructured future conditions based on mathematical logics using problem tree analysis, standardization, weighting scenarios and map generation to generate multiple scenarios, so that corresponds to real conditions in the research area since data are common only available in multiple proxies [5]. Data processing in SMCE was done by making model of through setting up problem tree and parameters (figure 2).

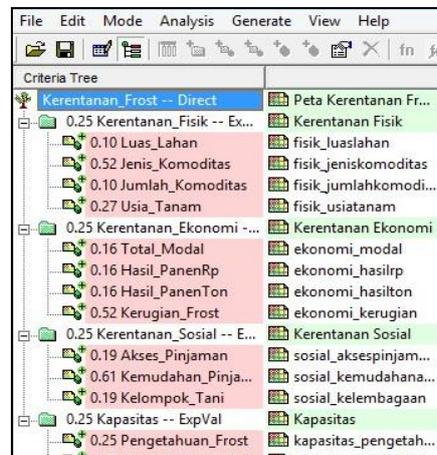


Figure 2. Problem Tree Criteria in ILWIS.

Each parameter must be standardized based on its effect on the level of vulnerability. Increase in the values of parameters (+) indicates that parameters have a positive linear relationship to increase level of vulnerability, while value (-) indicates that the parameter has a negative linear relationship with vulnerability. Weighting process for each vulnerability and coping capacity parameter uses a rank-order system by assessing primary, secondary and tertiary vulnerability determinants so resulting different value of weights and standard (figure 3b). Weighting process for total vulnerability parameters using pairwise system with five scenarios (figure 3a). Data analysis used descriptive analysis technique toward vulnerability assessment results. Descriptive analysis is used to describe the distribution of frost vulnerability based on the percentage of vulnerability levels. Vulnerability is classified into three criteria, i.e low vulnerability (0-0.33), moderate susceptibility (0.34-0.66), and high susceptibility (0.64-1). Analysis also emphasizes most influential factors on the five vulnerability scenarios whether physical, social, and economic vulnerabilities, as well as coping capacity.

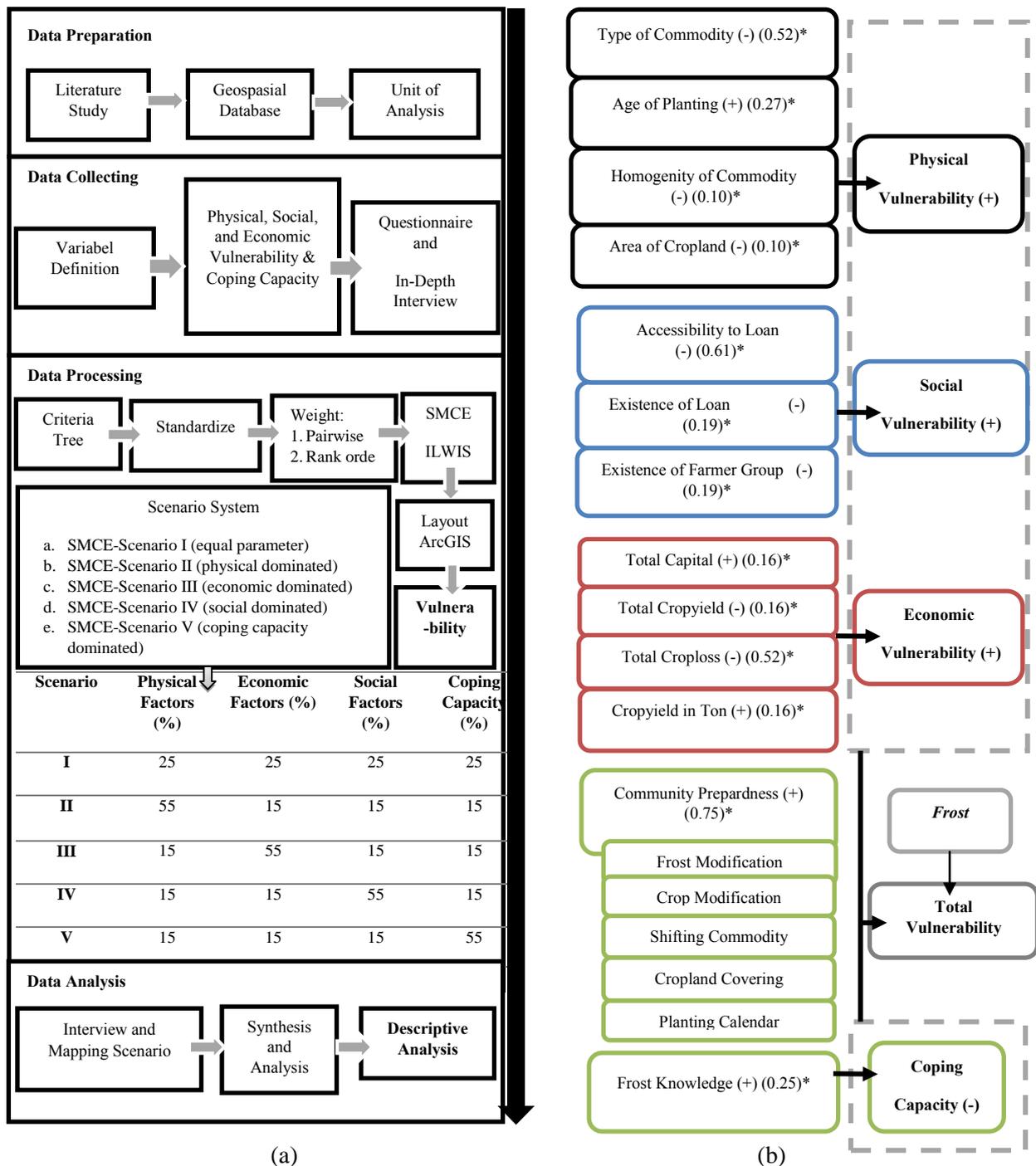


Figure 3. (a) Research Procedure and (b) Weighting and Standardized System of Parameters.

3. Result and Discussion

3.1. Frost impact on agricultural land

Frost causing harm on potato farmland during dry season. Loss determined by whether or not there is an element at risk or can be interpreted as all assets both physical and nonphysical vulnerable exposed

to losses [7]. Dieng Volcanic Highland has 125.59 ha frost hazard areas with varying magnitude [6]. Element at risk affected by frost disaster is agricultural land, so that all forms of non-vegetative land use and unproductive vegetation cover, i.e. grassland, swamp and shrub had no element at risk. Damage of frost can vary between one plots of farmland with others. Losses only occur on potatoes farming system, while other commodity i.e. carrot, leeks and cabbage in study area tend to be more resistant to frost occurrence. Plant damage strongly determined by the level of plant resistance to cold temperature conditions [2]. Based on table 1 potato has the highest level of vulnerability due to potato's critical temperature are at warmer degree than other commodities so that more easily damaged when exposed even to low-intensity frost [6].

Table 1. Critical temperature of agriculture commodities.

Commodities	Binomial Name	Critical Temperature (°C)
Carrot	<i>Daucus carota</i>	-7
Cabbage	<i>Brassica oleracea</i>	-5
Leek	<i>Allium porrum</i>	-6
Potato	<i>Solanum tuberosum</i>	-0,8

All frost hazard zones distributed in alluvial plains with dominance land use among others farmland, swamp and grass. Frost is formed at night in the dry season due to plains cooling faster than slopes. At night during dry season, ground and air above it loose radiation offset by earth radiation releases into space rapidly without any cloud cover as an insulating atmospheric blanket that prevents radiation escape into space [8]. Plains have better radiator properties than the air layer above it, so it tends to cooling faster [2]. Study area affected by the topographical effects which is surrounded by volcanic cone then generates gravitational cold air drainage from upper slope to the plains, so that the plains are cooling faster and causes frost appearance as can be seen in figure 4 [6]. Cold air drainage forms a warmer air layer above the soil surface called radiation inversion. The cold air descending from the slopes into the plains is accelerated by the absence of wind (calm) at night. Incidence of radiation inversion causes the alluvial plains to experience more intensive frost formation than the slopes.



Figure 4. Cold air drainage mechanism.

Frost recorded on August 14, 2015, destroying about 100 hectares farmland in Dieng and Dieng Kulon villages with losses reaching 15 million rupiah per hectare [9]. On August 24, 2015, frost resulted losses reaching 10 million rupiah per hectare, while on 3 August 2016 area affected almost 25 hectares and losses occurred in potato fields aged less than 60 days [10]. Newest in early September 2017 frost resulted in leaf wilting on a two-hectare potato field in Dieng Kulon [11]. Potato plants damaged by frost are characterized by wilting, twig and dry condition even blackened (figure 5). Losses could reach tens of millions of rupiah, depending on age of planting (phenological stage) when frost and mitigation efforts undertaken in order to reduce losses. For potatoes at young age (1-2 month), losses can reach up to 100%. At adult age (3 months), after the frost one to two days, the

potatoes should be quickly harvested so losses are only in 50% range. Potatoes at the age of 4 months (ready to harvest) have smallest losses i.e. 20% because the potatoes more resistance to combat cold air and big enough, so then potatoes still can be sold.

Based on figure 6, losses caused by frost at most are in the range of 10 million to 15 million rupiah (37.1 percent). Cost of losses incurred by farmers includes the cost of seed, fertilizer, medicines and daily labor. Most small losses can reach 0 rupiah (zero losses) due to the success of mitigation on the land, such as shifting commodity into carrots or leek and granting of mulch on the soil surface to prevent frost. The highest losses suffered farmers can reach up to 55 million rupiah, generally owned by land with a fairly high capital input and large farmland located in Dieng Kulon. No losses (0% loss) only appear on plots of farmland who do frost disaster preparedness in a manner not to plant potatoes on its land and replace them with other commodities or conducting active preparedness like using mulch, sprinkle irrigation during night, and furnace.



Figure 5. (A) Strong Frost (2015): Thickness More Than 3cm, Potato Experienced Death and Rot, Leek Not Damaged, (B) Low Frost (2017): Thickness Less Than 1cm, Potato Withered Leaves, Leek Does Not Wilt.

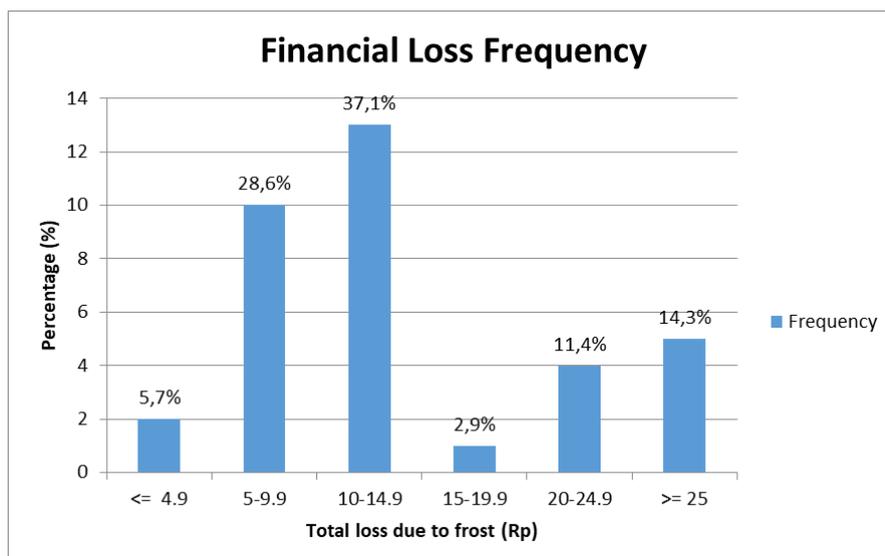


Figure 6. Financial loss due to frost.

3.2. *Physical, social, and economic vulnerability and coping capacity level*

Magnitude of potential damage or loss (V) of an element of risk (E) that is exposed to disaster with frequency (F) and certain quantity (M) is expressed as a degree of vulnerability [12]. Vulnerability is

conceptually expressed as the degree of damage or loss of 0 (no damage) scale to 1 (total damage) occurring to the element of disaster risk due to a specific threat of frequent [13]. Vulnerability of frost strongly determined by physical, economic, and social factors, as well capacity of farmers and exposure area to frost hazard [14]. Results vulnerability level can be represented in various vulnerability level maps to reduce disaster risk and losses, among others; physical, economic and social vulnerability (figure 7). Generally physical vulnerability indicates potential damage to risk elements such as buildings, infrastructure and other physical characteristics present on the earth's surface that are beneficial to humans [15; 16]. Factors affecting physical vulnerability in this study focuses on physical aspects of agricultural land, include type of commodity (potatoes or non-potatoes), homogeneity of commodity (monoculture or polyculture), the age of plants and total land area.

Physical vulnerability describes a physical condition that is vulnerable to certain disaster factors, i.e. frost. Farmland with potato farming system experience losses compared to farmland with non-potato farming, i.e. carrot, cabbage and leek. Crop damage due to sensitive frost usually occurs at temperatures of 0 °C to below -5 °C. During these temperatures, ice formation in plants from super cool water will destroy the nature of plant intercell [4]. Plants with thin leaf such as tomatoes, potatoes, peppers, and soybeans can be destroyed. Areas that have a monoculture potato commodity with young planting age (1-2) have a higher vulnerability than land that has more than two types of commodities. Agricultural land in frost prone area has a high vulnerability rate of 95.37 percent although there is 4.63 percent of land with moderate physical vulnerability. High vulnerability triggered by many agricultural lands consists of only one type of commodity (monoculture) that is potato which is very vulnerable to frost, especially young potato plants. Some lands planted with young age potatoes (1-2 months) during frost season (June until August), so the plant is not yet mature and prone to wilt when exposed to frost phenomenon. Moderate level only exists on non-potatoes farming system. Farmer chooses to plant carrots to avoid losses due to frost disaster.

Economic vulnerability is the potential financial loss suffered by humans due to disaster phenomenon [17]. Potential financial loss for frost vulnerability assessment focusing on the total financial flow within one land owner system, which is included total capital in rupiah during one harvest period (4 months), total yield in rupiah and ton during one harvest period (4 months), and total financial losses due to frost phenomenon during one year. Economic capability of individuals or communities greatly determines the extent of vulnerability to disaster threats. Amount of capital covers the whole capital of farming, such as seeding, fertilizer, plant medicine, rents of land and labor payment. Greater value of capital then increases potential loss of money if there is a frost occurrence, while the greater agricultural yield increases economic profit so as to serve as a saving economy to cope with losses in the disaster period. The results show the dominance of income from agricultural business is large enough but followed by high risk of loss due to frost almost every year. Level of economic vulnerability dominated at a moderate level of 79.18 percent. This shows losses due to frost and lost capital are large, but farmers still have the saving yield because the amount of crops during the non-frost period is much greater than the value of loss. High vulnerability to agricultural land amounted to 20.84 percent and only found on agricultural land with total losses equivalent with value of yield (100% loss). Very high level of losses generally experienced by farmers who plant young potatoes are still very young (1-2 months) in July-August. Variation of plant damage depends on plant sensitivity to cold temperatures [2]. Plants with younger age are more susceptible to damage than older plants because young plants have very soft tissue conditions that are sensitive to cold weather changes.

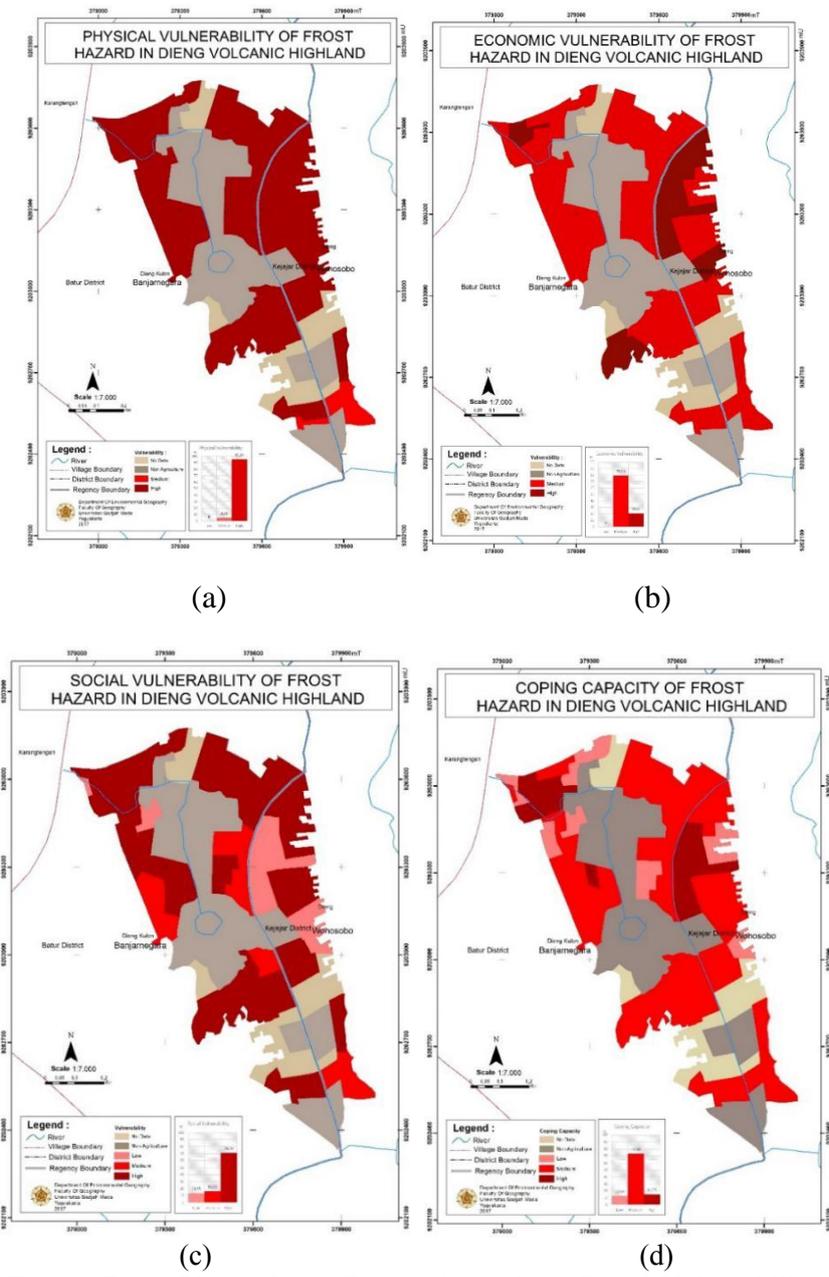


Figure 7. (a) Physical, (b) Economic, and (c) Social Vulnerability, (d) Coping Capacity.

Social vulnerability indicates the potential for loss of specific risk elements referring to human circumstances or socio-demographic condition [17]. Factors affecting social vulnerability in this research focus on social aspects of farming system such as the presence of access to loans, the ease of obtaining loans and the presence of farmer groups. Social vulnerability describes condition of social fragility in farmer community to facing the damage of frost disaster. In vulnerable social conditions, appearance of disaster will cause large losses and impact because low social capital within community. Level of social vulnerability dominated at a high vulnerability level of 70.45 percent. Main factor that affecting level vulnerability due to the absence of farmer groups who are expected to help the distribution of crops, socialize mitigation plan among farmer members and provide ease of

lending capital when losses crop failure due to frost. Difficulty in obtaining capital also becomes an obstacle for farmers. Plots of land with high social vulnerability generally borrow money to banks or cooperatives with a tight lending system. High losses due to frost causes debt system can accumulate into several periods. Plots of land with moderate vulnerability of 15.92 percent can generally borrow money easily from relatives so there is no need for interest payments on the loan. Plots of land with a low vulnerability of 13.35 percent have generally been incorporated into farmer groups and have sufficient financial capability so no need to borrow money after the frost. Existence of farmer groups very helpful to direct the farmer gain preparedness effort before the frost appearance results in a loss.

Coping capacity is a combination of all potency and resources between communities or organizations that have a role in disaster risk reduction [7]. Indicators of coping capacity in Dieng communities to reduce the impact of frost disaster are assessed from the level of community preparedness and the level of community knowledge regarding frost phenomenon. Capacity assessment shows that agricultural land is dominated by farmers with moderate capacity that is 73.18 percent, while there are 12.44 percent with low capacity and 14.57 percent with high capacity. High capacity farmland only found in few farm land that already implemented frost modification using furnace with high investment input, others using sprinkle, mulch covering and shifting commodities to carrot-leek commodities so that losses can be reduced (figure 8). Farmlands with low capacity level generally do not implement preparedness efforts due to lack of understanding, awareness and financial incapacity.

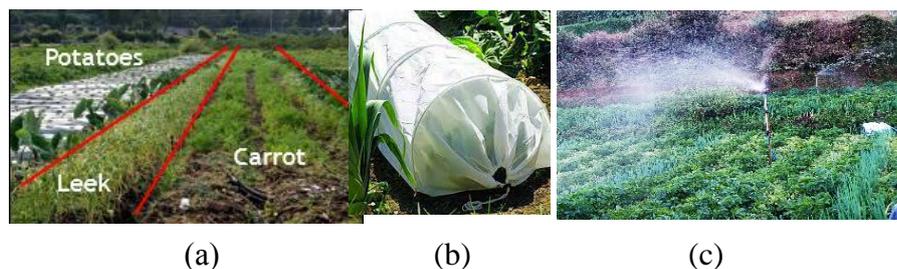


Figure 8. Identified preparedness on agricultural land; (a) shifting commodities, (b) mulch covering, and (c) sprinkle irrigation.

Dominance of moderate level show that the preparedness efforts have been done by farmer communities are quite good. Most of community has understood the signs of weather and frost events as local wisdom through natural observations. Forms of preparedness efforts that have been identified and implemented include;

- a) Shifting agricultural commodities to non potatoes, that replacing the plants are not susceptible to frost during the season, example; carrots and leek;
- b) Modification of plants, that is done by intercropping to overcome a farmer who still wants to plant potatoes, by planting potatoes in conjunction with non-commodity of potato that resistant by frost on the same farm;
- c) Cover the potato field with mulch or nets with a height over one meter, which is done to prevent moisture in the air contact with the ground super cooled [6];
- d) Determining the appropriate planting calendar, that is ensuring planting potatoes during the season when the frost has reached adulthood so that the potatoes are more resistant to cold temperatures.
- e) Modification of frost, in-depth interview showed that modification of frost was done before by destroying the forming of frost during the night, this preparedness plan have more financial or investment needed, example:
 - Providing heating temperature near the ground by installing a furnace at night, in order to prevent the temperature cools below the *frost point* [2].

- Spraying potato field during the early days with the sprinkles irrigation system to interrupt process of frost formation.

3.3. Total vulnerability scenarios

Total vulnerability refers to a set of conditions and/or effects of circumstances that adversely affect disaster prevention and mitigation. The total vulnerability using Spatial Multi Criteria Evaluation (SMCE) resulted in five scenarios, namely scenario I (equal), scenario II (physical dominated), scenario III (economic dominated), scenario IV (social dominated), and scenario V (coping capacity dominated). Total scenario is strongly influenced by dominant parameters such as the level of total crop loss, type of commodity (potato or non-potato), preparedness aspect, and existence of loan. Vulnerability assessment in all scenarios shows that the study area only has moderate (0.33-0.66) up to high (0.64-1) vulnerability level (Table 2), so the potential loss due to frost can be various moderate up to very high (figure 9). Total vulnerability mapping on figure 3.7 shows that scenario I dominated by vulnerability at moderate level (56.45 percent). High vulnerability (43.55 percent) found in potatoes farmland with relatively low preparedness aspect. Scenario II shows dominant vulnerability at high level (83.05 percent) higher than other scenarios. Physical factors as dominant variable in Scenario II shows that dominant commodities which is potatoes plants that covers large areas have high vulnerability, while farmland of non-potatoes (leek and carrot) and several potato farm land with good preparedness aspect classified into moderate area (16.95 percent).

Table 2. SMCE Scenario on Vulnerability Level.

Scenario SMCE	Low (%)	Medium (%)	High (%)
Scenario I (Eq)	0	56.45	43.55
Scenario II (Ph)	0	16.95	83.05
Scenario III (Ec)	0	71.61	28.39
Scenario IV (Sc)	0	29.25	70.75
Scenario V (Cc)	0	87.57	12.43

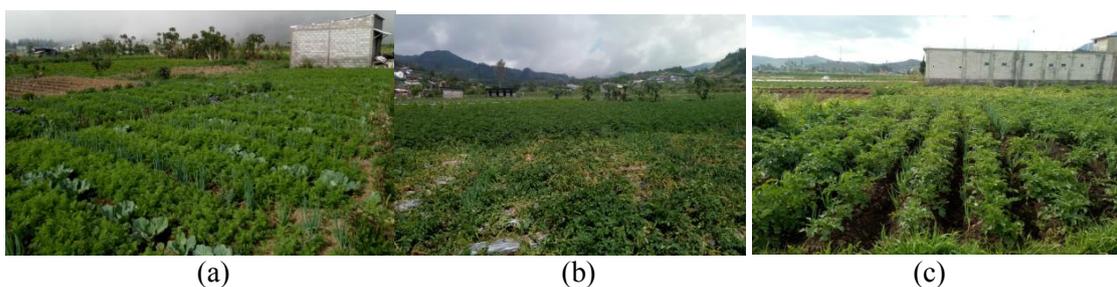


Figure 9. Moderate vulnerability; (a) Non-potato farmland (carrot, cabbage, leek), and (b) 3,5 months policulture potato farmland mixed with leek with plastic covering and High vulnerability; (c) 1,5 months monoculture potato farmland.

Scenario III shows dominant vulnerability level at the medium level (71.61 percent) higher than the result in Scenario I. High vulnerability (28.39 percent) only experienced by farmland with large economic losses due to frost, which is more than 20 million rupiah and located only in few farm land with quite large areas more than 3 hectares. Scenario IV shows dominant vulnerability at high level (70.75 percent) due to agricultural land dominated by potato plots with high losses tend to have difficult condition to get access into capital loans, either from cooperation, bank or family. The

existence of farmer group have relatively low contribution to minimize the impact of frost because farmer group tend to focussing on productivity socialization, have no program about frost mitigation and have lack access to help the farmers get any loans. Scenario V indicates that dominant vulnerability at medium level (87.57 percent) higher than other scenarios which is shows that increasing dominant level of capacity will reduce the number of high vulnerability farmland. High understanding of farmers related to frost and the number of plots of land that have implemented preparedness efforts causes vulnerability level in scenario V is lower than other scenario. Based on table 2, this study argues that coping capacity and physical factors of agricultural areas are the most sensitive criteria compared to other criteria because they have the most different vulnerability patterns than other scenarios (> 80 percent in percentage).

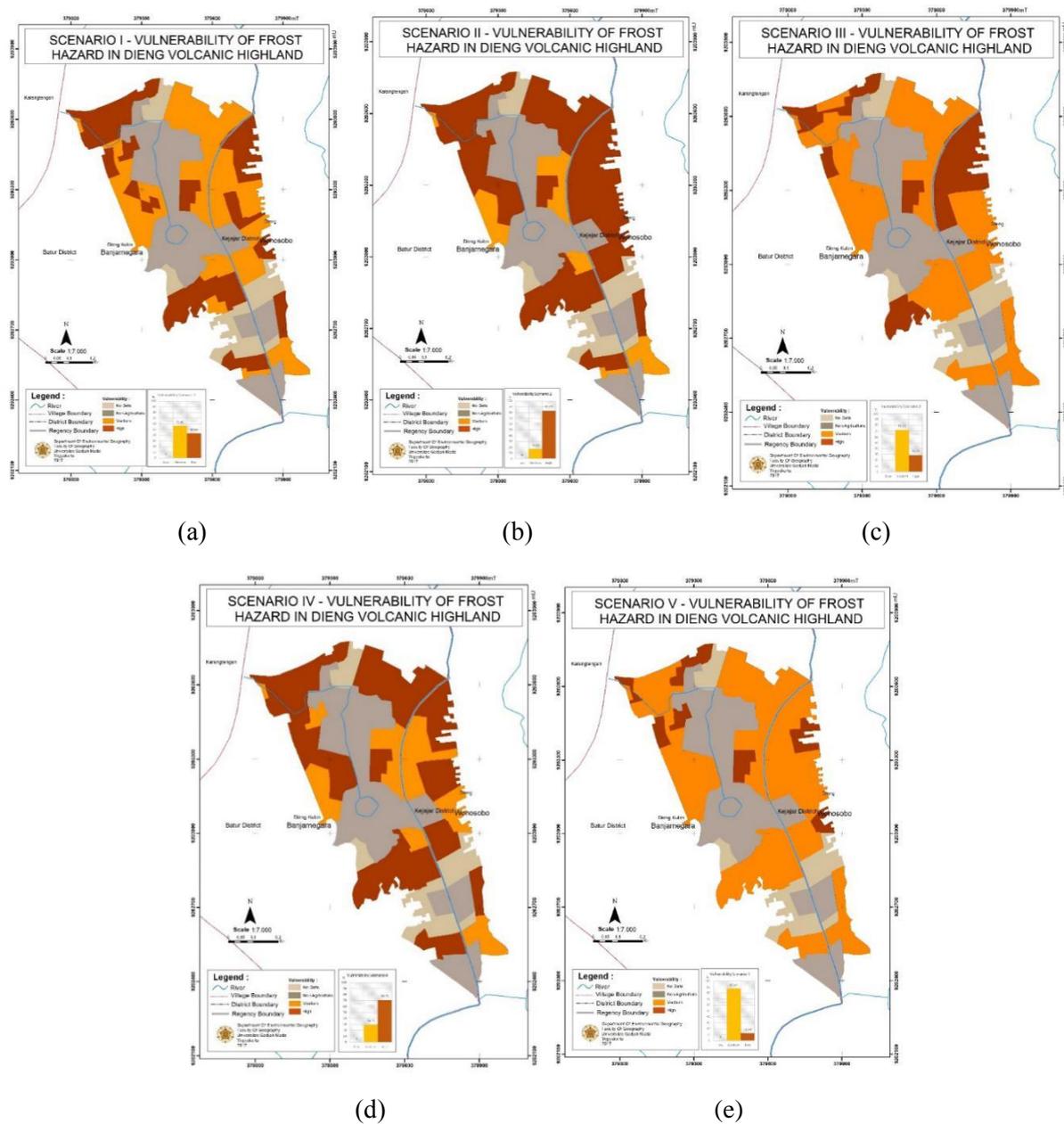


Figure 10. (a) Scenario I, (b) Scenario II, (c) Scenario III, (d) Scenario IV, and (e) Scenario V.

4. Conclusion

Impact of frost in agricultural losses mostly causes damage on potato agricultural land than any other types of commodities. Losses varies in the range of 0 million to 55 million rupiah, at most events in the range of 10 million to 15 million rupiah. Main factors determining the level of vulnerability comes from crops losses, preparedness effort, and type of commodity. Agricultural land in frost prone areas generally dominated by high level physical vulnerability (95.37 percent), high level social vulnerability (70.79 percent), moderate level economic vulnerability (79.23 percent) and moderate level coping capacity (73.18 percent). All five scenarios indicated that level vulnerability vary only on moderate level (16.95-87.57 percent) up to high level (12.43-83.05 percent). Physical factors and coping capacity of agricultural areas are the most sensitive criteria compared to other criteria determining level of vulnerability. Further appropriate preparedness need to be taken in order to reduce losses due to frost and achieve disaster resilience agriculture community in Dieng Volcanic Highland.

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