Climate Change-Related Hazards on Paddy Fields: A Case of Lombok Island, Indonesia

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Abstract. Natural disaster frequency has increased in the last 20 years and the danger become greater in vulnerable communities. An effective multi-hazard assessment using the analytical hierarchy process (AHP) supported by a Geographical Information System (GIS) is utilised in observing several hazards in one location and mitigating the impact of future natural disasters. This study develops a multi-hazard map induced by climate change on paddy fields including flood, drought, and landslide. Lombok Island, as one of the National rice barns in Indonesia, is selected due to this small island is vulnerable to climate change. The findings reveal that approximately 3,875.21 km2 (88%) areas in Lombok Island are at the medium multi-hazard level. However, approximately 1.40 % and 10.41 % of the total land area respectively, are estimated to be experiencing high and low multi-hazard level. Ultimately, the final map of the multi-hazard was overlaid with the paddy field maps in the study area. The result showed that 97.75% of paddy fields are located within areas of medium risk. The results presented in this study can be useful for local authorities to carry out various climate change adaptation activities as a strategy to anticipate the impacts of climate change on paddy fields.

Keyword: Climate, Change Hazards, Paddy Fields, Lombok Island, Indonesia

1. Introduction

Global climate change is now a pressing concern of our time. Negative impacts of climate change include increasing the frequency of extreme weather events and natural hazards potential[1]. Weather significantly affects the rainfall intensity, escalating the risk of flooding [2]. At the same time, some parts of the world have experienced drought due to less rainfall frequency, which jeopardizes food security and negatively impacts the economy [3]. Drought due to climate change is also enhancing along with the increased population and air demand, while air availability is increasingly limited [1]. Simultaneously, climate change affects slope stability, contributing to landslide events [4].

The impact of climate change is now being felt in every aspect of human life, especially in food security. Southeast Asia is predicted to experience the adverse effects of climate change because most of their economic activities depend on agriculture [5]. Lombok Island is one of the national rice barns in Indonesia yet this small island is threatened with drowning or experiencing flooding due to the sea-level rise impact of global warming [6]. The impact of climate change has also disrupted the growth of food crops in WNT. Besides, diversity and

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dynamics in Lombok Climate are also influenced by the El-Nino phenomenon that impacts crop failure [7]. The aim of this research is to evaluate the impact of climate change disasters on paddy fields using AHP-GIS method. Spatial assessment of the impact of disasters on paddy fields is urgently needed along with accelerating climate change to maintain food security and prevent damage to production. Ultimately, this study can provide the up-to-date and accurate assessment of multi-hazard induced by climate change impact on paddy field for decision-makers to determine the most urgent and integrated mitigation measures for reducing disaster risk.

2. Research Methodology

Hazards induced by climate change can damage the environment and the economy, so their evaluation and monitoring is a global priority [8]. The study investigated climate change related hazards by using AHP analysis, explicitly focusing on GIS Technology. Three hazard maps and multi-hazard map are constructed using AHP-GIS methods. Then, Spatial analysis was performed based on overlapping analysis of the multi-hazard map generated with the Lombok rice field map to spatially assess the multi-hazard impacts caused by climate change on paddy fields.

2.1 Preparation of Thematic Layers

The following eleven different parameters have been identified in this study as factors that support each hazard. Parameters are carefully selected through a literature survey so that they can represent decision-making and contribute to the ultimate goal.

Table 1. All parameters associated with climate change related hazards

Parameters	Explanation
Rainfall (mm)	Rainfall is one of the main factors in generating floods, drought and landslides. Heavy rainfall can produce flooding, which encourages the occurrence of landslides [9].
Slope (%)	This parameter plays a vital role in determining the amount of surface runoff and infiltration [10]. Lombok island is dominated by a moderate slope between 5 - 10%, covering 33% of the total study area.
Elevation (m)	The elevation is the only parameter used for developing flood hazards. The elevation and slope maps are obtained from the Digital Elevation Model of Indonesia. The height variation of Lombok Island is 0 to 3635 m.
Drainage Density (km/km²)	Drainage density is a sensitive parameter because it depicts the erosion strength of surface runoff, soil, and rock surface resistance and connects landforms along the river [11].
Land-use	Land use is able to identify areas that are vulnerable to flooding because this factor influences the infiltration rate [11]. Land use classification in Lombok Island is divided into five classes: agriculture, built area, fallow land, forest, and water.
Distance from the river (m)	The distance from the river denotes the risk of flooding due to its proximity to the channel [12]. The further area from the river usually experiences an increase in slope and elevation.
Land surface temperature (LST)	LST is commonly used to monitor and investigate drought conditions in an area because this parameter is able to indicate temperature conditions on

Parameters	Explanation
(0C)	the earth's surface. This parameter assumes that higher temperatures induce severe drought because it leads to vegetation stress [13].
Geomorphology	Geomorphology influences drought hazards through water availability and surface runoff [11]. Area study has various geomorphology, starting from flat to mountainous.
Geology	This parameter is utilised to generate landslide hazard. Geology plays a role in slope stability because it is related to the weathering properties of the soil [9].
Topographic wetness index (TWI)	TWI is derived from DEM using flow accumulation and slope functions. The highest value of TWI is associated with increased water infiltration, which causes an increase in pore water pressure and further reduces soil strength, making it susceptible to slope failure and causing landslides [14].
Distance from the road (m)	The road is able to change the topographic properties and reduce the shear strength of the slope foot. Roads also affect slope water infiltration and evoke extra pressure due to traffic load[9].

2.2 Analytical Hierarchy Process (AHP) Model

The Analytical Hierarchy Process method was applied to analyze hazard maps and multi-hazard maps. This method has several stages: (1) Defining the problem and identifying the level of participation of each parameter [10], [15]. Each factor is organized into independent elements and represented in a hierarchical diagram (2) Preparing a pairwise comparison matrix. Each factor is assigned an arithmetic value from 1 to 9 (Table 2).

Table 2. Level of Preference Weight for AHP Analysis

Level of Importance/ Preference Weight	Definition	Explanation
1	Equally Preferred	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly favour one activity over another
5	Strong Importance	Experience and judgment strongly or essentially favour one activity over another
7	Noticeable Dominance	An activity is strongly favoured over another and its dominance demonstrated in practice
9	Extreme Importance	The evidence favouring one activity over another of the highest degree possible of affirmation
2,4,6,8	Intermediate Values	Used to represent compromise between the preferences listed above

The weights indicate the relative significance of the relevant factors after the pairwise comparison matrix is constructed [16]. A value of 1 indicates that both factors are equally significant, and a value of 9 indicates that the row factor is much more significant than the column factor [10]. The study's significance and specificity were obtained using the hierarchical analysis method and interviewing experts. The experts were asked to complete the matrices of the paired comparisons of each level using questionnaires [17]. (3) Conducting a consistency test to prevent incidental judgments in the pairwise comparison matrix. The result of the Eigenvector matrix created by the AHP method needs to be evaluated for consistency. The value of the eigenvector is the weight of each element. The Consistency Ratio (CR) is calculated using the deviation ratio value [18]. This allows the user to conclude whether the evaluation is sufficiently consistent [19]. If CR ≤ 0.1 or CR ≤ 10%, the matrix is considered relatively consistent, but the assessment requires revision if the value exceeds 10% [12].

3. Result and Discussion

3.1 Hazards Assessment Maps

All parameter was assigned weight values and ratings based on the factors affecting the three hazards on Lombok Island (Table 3). The decision-making process is determined by disaster management and agricultural experts who were asked to provide an assessment or weights regarding the significance of the analysis's factors to each hazard. The estimated Consistency Ratio (CR) for flood, drought, and landslide maps are 0.04, 0.03, and 0.03, respectively, so that the consistency of the weights is accepted. The hazard maps are categorized into three classes: High, Medium, and Low (Figure 3).

Table 3. Weighted Hazards rankings for all related climate change hazards.

Parameters/Factors	Weighting score			
	Flooding	Drought	Land-slide	Multi-hazards
Rainfall (mm)	0.25	0.35	0.19	Flood = 0.41
Slope (%)	0.19	0.06	0.32	Drought 0.50
Elevation (m)	0.11			Land-slide =
Drainage Density (km/km^2)	0.14	0.16	-	0.09
Distance From River (m)	0.18	-	-	
Land use	0.13	0.16	0.04	
LST (0C)	-	0.15	-	
Geomorphology	-	0.12	-	
TWI	-	-	0.18	
Distance from the road (m)	-	-	0.14	
Geology	-	-	0.13	

The total area with a high flood hazard level is 1,086.50 km2 or 24.33%. Besides, Lombok Island is dominated by medium-flood hazard levels, reaching 49.13% of the total area. Moreover, the broadest medium hazard level is in East Lombok Regency, reaching 55.78% compared to the total area. The drought hazard map denotes approximately 743.13 km2 (16.83%) under a high level of drought hazard. Meanwhile, 61.91% of the study area is classified as a medium-level drought hazard. Overall, East Lombok experiences the widest drought hazard of 314.98 km2, followed by West Lombok and Central Lombok, 234.89 km2 and 169.60 km2, respectively. Moreover, approximately 6.20% of areas in Lombok Island have a high level of landslide hazard. However, almost half areas of Lombok Island, approximately 52.13%, are in medium-level hazards. West Lombok is the widest regency with a medium-level landslide hazard of 652.10 km2.

3.2 Multi-Hazard Assessment on Paddy Field

The multi-hazard is a good approach to observing several hazards in one location, even though each hazard can be monitored separately and integrally [20]. Many areas are vulnerable to various natural hazards, which can coincide or be in stages, thus requiring consideration of combined hazard risks [21]. The high level of multi-hazard spread all over Lombok in a small area. It only covers 1.4% of the total area, where West Lombok is the widest. Nevertheless, 88.18% of total areas are in a medium level of multi-hazard induced by climate change, where East Lombok is the widest regency affected, covering 91.48% of the total area. The vulnerability to multi-hazard caused by climate change on Lombok Island is encouraged because most of the land use is agriculture, which requires large water availability. Using the overlay technic, 0.58 % of paddy fields are at a high level of multi-hazard, and 97.75 % of paddy fields are at a medium level of multi-hazard. West Lombok is the most expansive area of paddy fields at a high-level hazard of 2.73 km2. At the same time, central Lombok is the most expansive area of paddy fields affected by a medium level of multi-hazard.

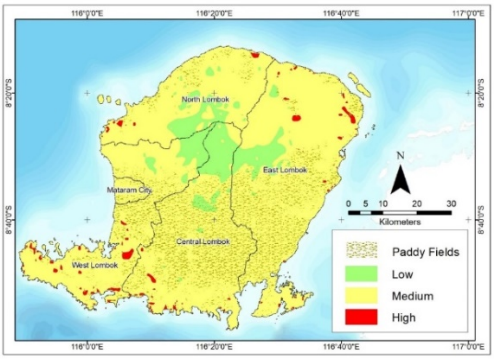

Figure 1. Multi-hazard Impact on Paddy Fields Map

The abundance of agricultural land on Lombok Island makes the agricultural sector the most significant economic supporter and the community's main livelihood. Nevertheless, the ENSO phenomenon significantly affects extreme weather events, directly impacting rice production growth. Therefore, to prevent a decline in paddy production due to disaster induced by climate change, the government related to agriculture, agricultural experts and farmers need a deep understanding of the phenomenon of climate change and ENSO. This multi-disaster mapping can help describe rice fields on the island of Lombok, which can assist the Lombok government in determining adaptation policies and strategies. Climate change is a formidable challenge for the agricultural sector in the present and future because agricultural production must continue to increase to achieve food security, reduce poverty and malnutrition, and maintain the livelihoods and welfare of farmers.

4. Conclusions

The results highlighted that most paddy fields in Lombok Island are quite vulnerable to multi-hazard induced by climate change. The multi-hazard analysis applied using AHP-GIS in this study achieved reliable results regarding depicting areas prone to hazards. Lombok Island is one of the islands that play an essential role in food security in Indonesia, particularly as a rice barn. Hence, hazards caused by climate change need to be a big concern for the government. This assessment can be utilized as a tool to identify the highest potential exposure of paddy fields to multi-hazard induced by climate change spatially. Mapping the impact of multi-hazard induced by climate change can assist the local government in implementing effective adaptation strategies to anticipate crop failure in the future and carry out integrated urban development planning.

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