Spatial assessment of socio-economic vulnerability to climate-related disasters at the local level: Study of coastal villages in Indramayu, Indonesia

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Abstract. Climate change has brought ecological impacts in the coastal area, such as seawater intrusion, coastal floods, and erosion, which have caused broader effects on non-physical aspects of human activities, including the coastal economy and society. This study aims to assess the socio-economic vulnerability to climate-related disasters in the coastal villages of Indramayu, Indonesia. Secondary data were collected based on available sources. Spatial and statistical analyses were applied. This study uses ten indicators to measure the socio-economic vulnerability of 41 coastal villages. These indicators include seven socio-demographic indicators and three economic indicators. The analysis shows that ten villages (24.39%) are socially vulnerable, and five villages (4.87%) are economically vulnerable. Overall, two out of seven socio-demographic indicators have high vulnerability levels, namely disaster mitigation systems and established community groups. Two out of three economic indicators also have high degrees of vulnerability, namely the availability of economic facilities and the employment-based sector. The other indicators with medium to low degree of vulnerability are population density, the elderly population, the disabled population (socio-demographic indicators), and poverty (economic indicator). From this study, local governments and other relevant actors can prioritize climate-related disaster reduction strategies in particular sectors and locations through spatial and development plans.

1. Introduction
Climate change, along with coastal development, has brought environmental impacts in the coastal area. These impacts include seawater intrusion, coastal flood, and erosion, which have caused wider effects on non-physical aspects of human activities [1], including socio-demographic and economic factors. As an archipelagic country, Indonesia consists of many islands where many people live alongside coastal areas due to their dependency on natural resources. This situation makes the country one of the most vulnerable countries affected by climate change impacts in the Southeast Asian region. Indonesia's typical case related to coastal development and climate change impacts has occurred in coastal villages of Indramayu, Indonesia.

Indramayu has experienced climate-related disasters, such as coastal abrasion, coastal flooding, seawater intrusion, and extreme weather events [2–5]. In 2017, the coastline length was decreased by 29% due to abrasion [5]. Also, the availability of clean water from surface water is inadequate because of seawater intrusion [2]. Based on Climatology and Geophysics Agency, the precipitation level increases by about 38.51% from 2012 to 2017. This condition was exacerbated by the existence of a coastal community’s activities. Some people such as fishermen and farmers are greatly dependent on natural resources that are influenced by climate conditions [6]. Most people in Indramayu's coastal
villages work in farming and fishery sectors, making them vulnerable people [7]. The effect of climate change has influenced socio-economic activities. For example, because of the strong wave in the ocean, the fishermen cannot catch fish, and they have to earn money by finding alternative work, such as livestock farmers or construction laborers [8].

Many studies related to vulnerability and adaptation measures in Indonesia are discussed at the city or regency level which is affected by natural disasters, such as flooding, earthquake, and volcanic eruptions [9,10]. For instance, the study of socio-economic vulnerability in fisherman’s community in Mumba, the vulnerability assessment in Semarang City, and coastal vulnerability in Bantul Regency. However, few studies explain the socio-economic vulnerability at the local level regarding climate-related disasters. Thus, this study attempts to investigate the socio-economic vulnerability to climate-related disasters in the coastal villages of Indramayu, Indonesia, through spatial assessment. The results are expected to give benefits and inputs to the local governments and relevant stakeholders as well as other coastal village areas to improve the coastal development planning and the well-being condition of the coastal community.

2. Contextual Considerations

2.1. Climate change impacts in the coastal area

The phenomenon of climate change can be caused by natural processes or external factors like human activities. It shows that climate change and variability are influenced by direct or indirect actions of human intervention that transform the composition of the global atmosphere and the natural observed climate variability in a particular period [1]. In the coastal area, climate change can cause heatwaves, changes in rainfall, an increase in storm intensity, changes in sea surface temperature, and increased carbon dioxide level. It results in disasters induced by climate change, such as coastal flooding, coastal erosion, seawater intrusion, and seawater increase. The lives of coastal ecosystems and urban settlements in the coastal areas are threatened as the sea level keeps rising. In addition to environmental impacts, climate change can alter income and livelihood patterns [11], affecting coastal areas’ social, physical, and economic conditions. In particular, the main livelihood of the areas particularly agriculture and fisheries sectors [6] and tourism activities [12] is still dependent on climatic and weather conditions.

2.2. Vulnerability indicators

Vulnerability is the level of a system that is vulnerable to cope with the effects of climate change, including climate variability and extreme events. It is a function of the character, distance, climate change rate and open system variation, sensitivity, and adaptive capacity [1]. The vulnerability level can vary from place to place because of some features and capacities in each location. It challenges local governments, researchers, and policymakers in formulating policies to deal with vulnerability in their regions [13]. Understanding the relative vulnerability of population groups and their spatial distribution can help operations management reduce the value of its vulnerability [14].

The socio-demographic vulnerability can be seen based on the population characteristics of the coastal area, which will later affect the population’s capacity in dealing with disasters [15]. Meanwhile, economic vulnerability describes the community’s exposure to disasters regarding their population and physical assets [16]. Indicators representing socio-demographic and economic vulnerability are presented in Table 1.

| Table 1. Selected Socio-Economic Vulnerability Indicators |
|------------------------------------------|----------|----------------|
| Indicator                                | Factor   | Unit           |
| **Socio-demography**                     |          |                |
| Population density [17]                  | Person/sq km |
| Female population [18]                   | Percentage |
| Children population [18]                 | Percentage |
| Elderly population [18]                  | Percentage |
| Disabled people [19]                     | Percentage |
3. Research Area
The research area covers all coastal villages in Indramayu with 41 administrative village areas (“desa”) and 11 districts (“kecamatan”). The definition of a coastal village area is based on the Law of the Republic of Indonesia No. 27/2007 regarding Small Islands and Coastal Area Management, which is a village with a distance of 100 meters from the transition of land and ocean ecosystems. According to the spatial plan, the research area is directed as a marine cultivation fishery area.

The population is varied in each village, with the average is 6,216 people per village. The total population in the coastal villages of Indramayu is 2,547,858 people. Dadap Village has the highest population (13,238 people), and the lowest is Cemara Kulon (1,788 people). In terms of gender, the percentage is almost equal with 51.66% and 48.34% for males and females, respectively. Based on age, the population in the research area is dominated by productive age, 15-64 years old (68.38%) [20].

The economic condition of low-income people in the research area has a percentage of 12.04%. The dominance of the labor absorption sector in the coastal villages of Indramayu is the agricultural sector with the farming sub-sectors: rice, capture fisheries, aquaculture, and horticulture. In terms of economic facilities, the villages have 3,065 units, including a market, minimarket, shops, restaurants, and accommodation.

4. Methods
Secondary data was gathered from the available online database, such as journal articles, reports from relevant institutional websites, statistical data from the statistical center agency, and spatial data from the geospatial information agency. The data mainly consists of socio-economic vulnerability indicators, which is used later for analysis.

A weighted analysis which aimed to give weight to each indicator was performed. The analysis was carried out by comparing literature and previous research to see the priority and importance of each indicator in affecting the vulnerability level. The weights of the indicators were obtained by calculating each indicator based on 15 literature and previous research. Next, the weights were summed based on two vulnerability variables (socio-demographic and economy). Then, the weights of each indicator were divided by the total weights of socio-demographic and economic vulnerability.

Furthermore, this study applied descriptive statistical analysis and spatial analysis. Descriptive analysis is used to depict data collected without generalizing, for example, minimum, maximum, and mean. Spatial analysis is carried out to describe spatial data, including the vulnerability of each indicator. There are three degrees of vulnerability for each indicator, namely high, medium, and low vulnerability, which are determined based on the criteria of each indicator.

Then, a scoring technique was applied to calculate the overall vulnerability degree of the socio-demographic and economic variables. Finally, the socio-economic vulnerability degree was calculated. The formulas for this technique are presented as follows.

\[
\text{Sociodemographic/economic vulnerability} = \frac{[(N_i - \text{Nimin})/(\text{Nimax} - \text{Nimin}) \times B_i]}{\text{number of indicators}} \quad \text{and} \quad \frac{[(N_i - \text{Nimin})/(\text{Nimax} - \text{Nimin}) \times B_n]}{\text{number of indicators}} \\
\]

\[
\text{Socio-economic vulnerability} = \frac{\text{sociodemographic vulnerability} + \text{economic vulnerability}}{2}
\]

Ni1 is indicator 1, Nimin1 is the minimum score of indicators 1, Nimax1 is the maximum score of indicator 1, B1 is the weight of indicator 1, Nin is indicator n, Niminn is the minimum score of indicator n, Nimaxn is the maximum score of indicator n, and Bn is the weight of indicator n.
5. Result and discussion

5.1. Socio-demographic vulnerability analysis

The socio-demographic vulnerability analysis was conducted on seven indicators: population density, percentage of female population, percentage of children population, percentage of the elderly population, percentage of the disabled people, number of disaster mitigation systems, and number of community groups. The weight and criteria of each indicator are listed in Table 2.

| No. | Indicator                        | Weight | Criteria                                      |
|-----|----------------------------------|--------|-----------------------------------------------|
| 1   | Population density               | 0.164  | Low: < 1892.03 people/sq.km                   |
|     |                                  |        | Moderate: 1892.03 – 3692.47 people/sq.km      |
|     |                                  |        | High: > 3692.47 people/sq.km                  |
| 2   | Female population                | 0.178  | Low: < 46.99 %                                |
|     |                                  |        | Moderate: 46.99 – 48.95 %                     |
|     |                                  |        | High: > 48.95 %                               |
| 3   | Children population              | 0.192  | Low: < 22.91 %                                |
|     |                                  |        | Moderate: 22.91 – 29.57 %                     |
|     |                                  |        | High: > 29.57 %                               |
| 4   | Elderly population               | 0.205  | Low: < 5.75 %                                 |
|     |                                  |        | Moderate: 5.75 – 8.75 %                       |
|     |                                  |        | High: > 8.75 %                                |
| 5   | Disabled people                  | 0.082  | Low: < 0.45 %                                 |
|     |                                  |        | Moderate: 0.45 – 0.87 %                       |
|     |                                  |        | High: > 0.87 %                                |
| 6   | Disaster mitigation system       | 0.096  | Low: > 3 systems                              |
|     |                                  |        | Moderate: 2 – 3 systems                       |
|     |                                  |        | High: < 2 systems                             |
| 7   | Established community groups     | 0.082  | Low: > 20 groups                              |
|     |                                  |        | Moderate: 12 – 20 groups                      |
|     |                                  |        | High: < 12 groups                             |

Population Density. The analysis result shows that out of 41 coastal villages in Indramayu Regency, 31 villages (75.60%) have low vulnerability degrees, eight villages (19.51%) have moderate vulnerability degrees, and two villages (4.78%) are highly vulnerable. The village with the highest population density is Dadap Village, with a population density of 5,493 people/sq.km, while Cemara Kulon Village has the lowest population density of 92 people/sq.km.

Female Population. Villages with higher female population have higher vulnerability degrees. According to the analysis results, from a total of 41 coastal villages in Indramayu Regency, four villages (9.75%) have low vulnerability degrees, 27 villages (65.85%) are moderately vulnerable, and ten villages (24.39%) are highly vulnerable.

Children Population. Villages with higher children population have a higher vulnerability. Four out of 41 villages (9.75%) have low vulnerability degrees, 28 villages (68.29%) are moderately vulnerable, and nine villages (21.95%) are highly vulnerable. The village with the highest percentage is Singaraja, with 36.27% children population, while Cemara Kulon Village has the lowest rate of children population (16.22%).

Elderly Population. The higher the percentage of elderly population, the higher the vulnerability degree. 32 out of 41 villages (78.04%) have low vulnerability degrees, seven villages (17.07%) have moderate vulnerability degrees, and two villages (4.87%) have high vulnerability degrees. The village with the highest percentage of elderly population is Cemara Kulon Village (12.02%), while village with the lowest rate of elderly population is Pabeanudik Village (2.60%).
Disabled People. Villages with higher disabled population have higher vulnerability degrees. 30 out of 41 coastal villages in Indramayu Regency (73.17%) have low vulnerability degrees, eight villages (19.51%) are moderately vulnerable, and three villages (7.31%) are highly vulnerable. Luwunggesik Village has the highest percentage of people with disabilities (1.33%), while Bugel Village has the lowest disabled population (0%).

Disaster Mitigation System. A good disaster mitigation system can reduce vulnerability degree. Based on the analysis, two out of 41 villages (4.87%) are lowly vulnerable, and 39 villages (95.12%) are highly vulnerable. This result indicates that most of the villages do not have an appropriate disaster mitigation system.

Established Community Groups. The presence of community groups will improve information sharing that can reduce vulnerability degrees. Only three villages (7.31%) have low vulnerability degrees, eight villages (19.51%) have moderate vulnerability degrees, and 30 villages (73.17%) are highly vulnerable. The village with the highest number of community groups is Kalianyar Village, with 30 community groups. Meanwhile, the village with the smallest number of community groups is Cemara Kulon Village, with two community groups.

The Socio-Demographic Vulnerability Score. Based on the formula in the fourth section, the score for each indicator was calculated. Then, the scores were classified as high, moderate, and low socio-demographic vulnerability degree, as shown in Table 3. The analysis result showed that out of 41 coastal villages in Indramayu Regency, ten villages (24.39%) have low sociodemographic vulnerability degree, 20 villages (48.78%) are moderately vulnerable, and 11 villages (26.82%) are highly vulnerable. Furthermore, two are highly vulnerable out of seven indicators: disaster mitigation systems and established community groups.

| No. | Score   | Classification |
|-----|---------|----------------|
| 1   | 0.044 – 0.058 | Low           |
| 2   | 0.059 – 0.070 | Moderate      |
| 3   | 0.071 – 0.084 | High          |

5.2. Economic vulnerability analysis

The economic vulnerability analysis was carried out based on three indicators: the employment-based sector, the percentage of low-income people, and the number of economic facilities. The weight and criteria of each indicator are listed in Table 4.

| No. | Indicator                     | Weight | Criteria                        |
|-----|-------------------------------|--------|---------------------------------|
| 1   | Employment-based sector       | 0.409  | Professional / do not depend on natural resources |
|     |                               |        | Professional and depend on natural resources |
|     |                               |        | Non-professional and depend on natural resources |
| 2   | Proportion of low-income people | 0.409  | < 17.92 %                       |
|     |                               |        | 17.92 – 35.61 %                 |
|     |                               |        | > 35.61 %                       |
| 3   | Number of economic facilities | 0.182  | > 150 units                     |
|     |                               |        | 77 – 150 units                  |
|     |                               |        | < 77 units                      |

Employment-Based Sector. Professional jobs that do not depend on natural resources have a lower vulnerability degree. Just one village (2.43%) has a low level of vulnerability, and 40 villages (97.56%) are highly vulnerable. The only village with a low vulnerability degree is Pringgacala Village, and the agricultural sector dominates people’s occupation in other villages.

The Proportion of Low-Income People. Villages with higher number of low-income people are more vulnerable than the ones with fewer low-income people. Out of 41 villages, 35 villages (85.36%) have
low vulnerability degrees, two villages (4.87%) have moderate vulnerability degrees, and four villages (9.75%) are highly vulnerable. The village with the highest population of poor household is Majakerta Village, with the percentage of low-income families reaching 53.33%. On the other hand, Lombang Village was the village with the lowest rate of low-income families (0.19%).

**Number of Economic Facilities.** It can be known that the bigger the number of economic facilities, the lower the vulnerability degree. Six out of 41 villages in Indramayu Regency (14.63%) have low vulnerability degrees, 11 villages (26.82%) are moderately vulnerable, and 24 villages (58.53%) are highly vulnerable. The village with the highest number of economic facilities is Dadap, with 224 units of economic facilities, while Kalianyar Village has the fewest economic facilities (only three units).

**Economic Vulnerability Score.** The score for each indicator was calculated by using the formula. Then, the scores were classified as high, moderate, and low economic vulnerability degree, as shown in Table 3. The analysis result showed that out of 41 coastal villages in Indramayu Regency, only two villages (4.87%) have low economic vulnerability degree, 34 villages (82.92%) are moderately vulnerable, and five villages (12.19%) are highly vulnerable. Moreover, two out of three indicators are highly vulnerable, namely the employment-based sector and economic facilities.

5.3. **Socio-economic vulnerability analysis**

The total score of socio-economic vulnerability was obtained by adding the socio-demographic and economic vulnerability scores and divided them by two. The results are depicted in Figure 1. According to the social and economic vulnerability analysis, most villages are moderately vulnerable (34 out of 41 villages or 82.92%). Two villages (4.87%) are lowly vulnerable, and five (12.19%) are highly vulnerable. Pringgacala Village is one of the villages with a low socio-economic vulnerability degree. The employment in this village is dominated by retail and restaurants sector, while the agricultural sector is dominated by other villages. The people in Pringgacala Village do not exploit natural resources for their main activities, thus making it less vulnerable than other villages. Furthermore, according to Regional Spatial Plan of Indramayu Regency (RTRW) 2011-2031, Dadap Village is the center for settlements in Juntinyuat District, while Karangsong Village is planned to be a strategic urban area of Minapolitan, with a specialty on capture fisheries. Moreover, Majakerta Village has a coral reef conservation area, and Kertawinangun Village has a weir that functions as a water reservoir to prevent seawater intrusion. Brondong Village is part of the Marine Fisheries Cooperative (Koperasi Perikanan Laut) Mina Sumitra with various businesses such as fish auction, mina mart, savings and loan unit, fisherman refueling station, and shipyard. These villages have significant roles, either socially, economically, or environmentally. The analysis result shows that these villages are highly vulnerable.

![Figure 1. Social and economic vulnerability maps, and the composite map.](image-url)
5.4. The Proposed Strategies

The strategies are formed based on the results of the vulnerability analysis obtained, which is based on the indicators used to see the vulnerability in the coastal villages of Indramayu Regency. In terms of the employment-based sector, nature-based works in farming and fishery dominate the main occupation in the study; consequently, adaptation strategy for sustainable agriculture is needed. Furthermore, the improvement of a disaster mitigation system is required to enhance coastal resilience. Regarding the coastal community, enhancing people’s understanding is essential to improve their awareness and knowledge about the threat and impacts of climate-related disasters, especially for vulnerable people such as disabled people, women, children, and older people. The other significant measures that need to be considered are building community-based institutions and improving community welfare. The implementation of such vulnerability reduction strategies can be carried out by at least of three actors: government, private sector, and community/NGOs. Agricultural adaptation strategies and improving community institutions can be carried out directly by the community with government assistance or without government assistance, while other strategies such as additional disaster mitigation systems, giving understanding to the community, and improving community welfare must be carried out with the help of the government as the community cannot implement these strategies directly. The private sector has a special role in the addition of agricultural adaptation infrastructure and disaster mitigation systems.

6. Conclusion

Climate change has brought impacts in the coastal area not only environmentally but also economically and socially. Coastal villages in Indramayu Regency are a few of the coastal areas in Indonesia that are prone to climate change, especially with most of the population working in the agricultural sector. A socio-economic vulnerability analysis was conducted using several indicators: population density, percentage of female population, percentage of children population, percentage of elderly population, percentage of disabled population, number of disaster mitigation systems, and number of community groups for the socio-demographic variable. The employment-based sector, the percentage of low-income people, and the number of economic facilities were used for the economic variable.

The analysis result shows that most of the coastal villages in the Indramayu Regency have moderate levels of socio-economic vulnerability (82.92%). Only two villages are in low level of vulnerability (4.87%), and five are highly vulnerable (12.19%). Most villages with high vulnerability degrees have essential roles to the Regency, especially in the agricultural and fisheries sector.

Therefore, the local government can consider strategies to reduce socio-economic vulnerability, especially in the highly vulnerable coastal villages. These strategies can include building sustainable agricultural adaptation [21], improving disaster mitigation systems, enhancing the community’s understanding, as well as improving community-based institutions and welfare [22,23]. Local governments and other relevant actors can replicate this framework analysis to assess the coastal socio-economic vulnerability with selected additional indicators. This study can be an input for policy decision-makers to prioritize the climate-related disaster reduction strategies in making spatial and development plans.

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