Flood disaster mitigation measure recommendations based on flood hazard and risk assessment: a case study in Brebes Regency, North Coast of Java

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Abstract. The concern over floods in the northern coast of Java is more pronounced. The increasing frequency of flood events, material damage and death rates underscore the importance of integrated efforts in controlling floods there. Brebes Regency has good prospects for economic growth and infrastructure. However, because its location on the north coast of Java makes it vulnerable to flooding. Considering this, it is necessary to carry out a comprehensive evaluation of flood hazards and risk assessment in Brebes Regency, as part of efforts to mitigate flood disasters and encourage the development of Brebes Regency as a resilient city. Flood hazard and risk assessment involves the use of spatial analysis techniques, which include the process of examining the level of vulnerability, determining flood hazard zones, and creating a flood risk map. Vulnerability analysis incorporates land use, population density, and economic activities. Flood hazard zoning assessment were carried out using rainfall data, tidal water levels and topography. The findings of the risk assessment indicate that the northern region of Brebes Regency has a high level of risk of flooding. Moreover, these flood risk maps can serve as a valuable tool to inform and guide the development of flood mitigation strategies and infrastructure.

1 Introduction

Floods represent the most commonly occurring natural calamities. In contemporary times, there has been an observable increase in the frequency of flood occurrences, a trend that is projected to further intensify in the coming years due to the effects of climate change and the consequential rise in sea levels. Floods have the potential to induce a range of consequences, encompassing economic ramifications, loss of human life, and infrastructure impairment. Floods in low- and middle-income nations, where there is less capacity for warning, evacuation, and protection, can result in more significant losses [1].

The demographic most susceptible to flooding consists of individuals residing in flood-prone regions or lacking adequate knowledge on the hazards associated with floods [2]. In addition to the aforementioned factors, it is crucial to evaluate the presence of infrastructure in flood-prone areas. This is due to the significant role that a well-developed infrastructure system plays in promoting economic well-being, ensuring security, and safeguarding the health and safety of the community [3].

The northern coastal region of Java, extending from the province of West Java to the province of East Java in Indonesia, is characterized by a susceptibility to floods. The primary factor contributing to the occurrence of floods along the northern coast of Java is the influence of sea tides, commonly referred to as *rob* in the local vernacular [4, 5]. This phenomenon is further intensified by land subsidence resulting from excessive extraction of groundwater, natural compaction processes, and the imposition of structural loads [5–7]. It is anticipated that the likelihood of flooding along the northern shore of Java would escalate in the next years.

Several major cities, such as Jakarta, Semarang, and Surabaya, are situated along the northern coastline of Java. In addition to the aforementioned major urban centers, there exist several cities and districts situated along the northern coast of Java that are experiencing notable economic growth. One example is Brebes Regency, which exhibits significant potential and demonstrates substantial economic development. The geographical location of Brebes Regency holds significant strategic value in the realm of trade within the Java Island, as it is situated at a pivotal intersection connecting the southern, western, and eastern regions of the island. The economic activities in Brebes Regency are significantly bolstered by the presence of thriving commercial and tourism sectors. In the realm of business, markets and outlets refer to commercial establishments dispersed across a given region. In the year 2021, the quantity of markets has risen to 26 units, while the number of outlets has increased to 137 units. In the year 2021, a significant proportion of the registered companies in

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Brebes Regency are classified as individual entities. Specifically, out of a total of 5305 registered businesses, 336 of them fall under the category of the individually owned category. In the realm of tourism, the Malahayu Banjarharjo Reservoir stands out as the foremost attraction, generating a total revenue of 402 million rupiah (equivalent to US$ 26,160) in 2021. This figure represents a decline from the preceding year's earnings of 458 million rupiah (equivalent to US$ 29,804) [8]. In addition to the Malahayu Banjarharjo Reservoir, another prominent attraction is the Randusanga Indah Beach, which generated a revenue of 589.57 million rupiah (equivalent to US$ 38,367) in the year 2022 [9].

In relation to calamities, floods have emerged as the most recurrent disasters in Brebes Regency. The year 2022 witnessed a total of 41 flood-related incidents, marking an increase from the 38 occurrences observed in 2021. The human toll of these floods has been substantial, with 579 fatalities reported in 2022, a stark contrast to the solitary fatality recorded in 2021. In the realm of property damage, it is noteworthy that the incidence of flooding resulted in the destruction of 9 residential structures in the year 2021, which subsequently escalated to 50 residences in the year 2022 [9].

Despite the existence of initiatives undertaken by the local government, in collaboration with the local community in Brebes Regency [10, 11], these endeavours are deemed inadequate in light of the relatively significant economic development in the region and its geographical location on the northern coast of Java, which renders it susceptible to tidal floods, resulting in both tangible and intangible detriments. Therefore, it is imperative to implement comprehensive flood mitigation measures in order to enhance the resilience of Brebes Regency as a city. This process should commence with a thorough evaluation of the hazards and vulnerabilities associated with flooding in the region of Brebes Regency.

2 Study area

The present study was carried out in Brebes Regency, situated within the geographical coordinates of $6^0$44' – $7^0$21 South Latitude and $108^0$41' – $109^0$11' East Longitude. Brebes Regency shares its boundaries with Banyumas Regency to the south, Tegal City to the east, and West Java Province to the west.

The geographical extent of Brebes Regency spans across 1769.62 square kilometers, with a total of 17 sub-districts and 297 villages. The Bantarkawung District encompasses the largest land area, measuring 208.18 square kilometers, while the Kersana District is the smallest district, covering an area of 26.97 square kilometers. Based on topographical analysis, the majority of the southern region of Brebes Regency is characterized by highland terrain. Within this context, Sirampog District is identified as a sub-district situated at an elevation of 875 meters. Conversely, the northern section of the regency is predominantly characterized by lowland topography. In terms of climatology, it is seen that the most amount of precipitation in Brebes Regency for the year 2021 transpires in the month of February, exhibiting an average rainfall of 483 mm and an average of 28 days with rainfall. Based on data collected from seven measuring stations, it was found that the Banjarharjo area saw the highest amount of rainfall, with a recorded depth of 20,332 mm [8]. Figure. 1 displays the geographical representation of Brebes Regency, which serves as the designated research site.

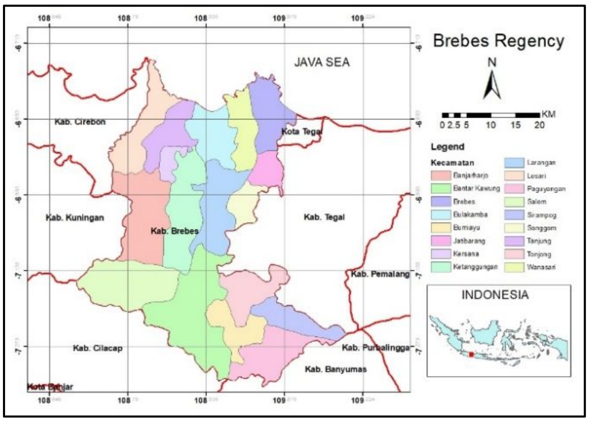

Fig. 1. Study area.

3 Method

The evaluation of flood hazard and risk in Brebes Regency was undertaken through a three-step methodology. This approach encompassed initial stages of investigation, involving a comprehensive review of relevant literature, conducting field surveys, and collecting pertinent data. Subsequently, a data analysis phase was carried out, which encompassed vulnerability analysis, hazard analysis, and risk assessment. Finally, recommendations were formulated based on the findings of the assessment. In order to conduct a flood risk assessment, it is important to initiate an examination of flood vulnerability and hazards, which is then represented in the form of a cartographic depiction. A comprehensive examination of literature was conducted to ascertain the issues related to flooding, the underlying factors contributing to flooding, and the various characteristics that exert an influence on the occurrence and severity of flooding events. The identification process involves assigning weights to each parameter using the Analytical Hierarchy Process (AHP) depending on their respective classifications. These weighted parameters are subsequently integrated using Geographic Information System (GIS) software, which facilitates the visualization and interpretation of hazard, vulnerability, and risk areas. The occurrence of a flood in a digital format.

There exist diverse methodologies for evaluating the extent of flood-prone regions. One such approach involves doing a spatial study utilizing Geographic Information Systems (GIS) in order to generate flood risk maps. The process of generating a flood risk map involves superimposing multiple maps and assigning weighted ratings to each map. When doing a disaster risk analysis, it is typically necessary to include two crucial components: hazard and vulnerability [12]. The term "hazard" encompasses potentially catastrophic factors that pose hazards to individuals and their surroundings, originating from both natural and technological sources. Vulnerability refers to the various factors, encompassing both physical and social aspects of a certain place, that are influenced by a disaster [13–16].

The allocation of assessment weight for each aspect is conducted through the utilization of the Analytical Hierarchy Process (AHP). The Analytic Hierarchy Process (AHP) was initially proposed by Saaty in 1977 and has since gained significant traction among scholars and decision-makers for the examination of intricate situations encompassing multiple parts [17, 18]. The Analytic Hierarchy Process (AHP) allows for the determination of the weight criteria associated with each element, depending on their relative importance to the situation at hand.

4 Results and discussion

4.1 Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a theoretical framework that facilitates measurement by means of pairwise comparisons. The derivation of priority scales is dependent on the expertise and judgments of an expert [18]. The comparisons can be derived from either empirical measurements or from a foundational framework that represents the relative intensity or subjective inclinations and emotions. According to existing literature, it is generally accepted that the hierarchy should possess a level of complexity that adequately reflects the intricacies of the situation at hand. However, it is also important for the hierarchy to have a compact and adaptable structure that can effectively respond to any potential changes that may arise [17].

Pairwise comparisons are the fundamental basis of the Analytic Hierarchy Process (AHP). The Analytic Hierarchy Process (AHP) commences by establishing a problem definition and constructing a hierarchical structure that encompasses the decision's overarching purpose as the parent element, along with its corresponding derivatives as the child components. Subsequently, construct pairwise comparison matrices for the child elements and evaluate each element using a numerical scale ranging from 1 to 9. The relative magnitude of a scale denotes the significance of a child element in relation to other child elements inside the parent element. The outcomes derived from the Analytic Hierarchy Process (AHP) consist of the weighted factors assigned to each child element in relation to the parent element.

In the context of evaluating the magnitude of subordinate components, decision makers may encounter inconsistencies in their decision-making processes. Hence, it is imperative to conduct a comprehensive investigation utilizing paired comparisons to ascertain the ratio of consistency (RC). The acceptable threshold for the ratio of consistency (RC) in the Analytic Hierarchy Process (AHP) analysis is below 0.1. In order to obtain the ratio of consistency (RC), it is necessary to determine the values of the index of consistency (IC) and random index (RI). The calculation of the value of the index of consistency (IC) is determined by Equation 1, where λ_{max} represents the greatest eigenvalue of the comparative matrix derived from a set of x criteria, as computed by Equation 2. The value of the Random Index (RI) is denoted by the average of the index of consistency (IC) values obtained from the random simulation of Saaty pairwise comparison matrices ICs, as seen in Table 1. Once the IC and RI values have been acquired, the calculated RC is determined using Equation 3.

Table 1. Random index.

X	1	2	3	4	5	6	7	8	9
RI	0	0	0,5	0,9	1,1	1,2	1,3	1,4	1,4
			8	0	2	4	2	1	5

$$CI = \frac{\lambda_{max} - x}{x - 1} \quad (1)$$

$$\lambda_{max} = \sum_{j=1}^{x} \frac{(S.v)_j}{x.v_j} \quad (2)$$

$$RC = \frac{IC}{RI} \quad (3)$$

In this context, the variable "x" denotes the number of independent rows in the matrix. The variable "S" represents the pairwise comparison matrix, while "V" refers to the eigenvector matrix.

4.2 Flood vulnerability

Flood vulnerability pertains to the state in which different physical, economic, and social elements have the capacity to be affected due to the incidence of a flood [19]. Based on the examination of the topographical characteristics, it can be inferred that the regions primarily impacted by floods encompass flat terrains and inclined relief formations, including alluvial regions, eroded river terraces, sea terraces, and pseudo plains. Hilly terrain has a less susceptibility to floods due to its inclination, which facilitates the direct diversion of rainwater into land runoff. The classification of vulnerability by the National Disaster Management Agency (BNPB) encompasses four distinct types: physical vulnerability, social vulnerability, economic vulnerability, and environmental vulnerability [20]. The examination of literature and field observations has revealed three key factors that contribute to the susceptibility of Brebes Regency to flooding: land use patterns, population density, and economic activity. Consequently, a thematic map was generated based on the aforementioned three characteristics. These factors were initially assigned weights through the Analytic Hierarchy Process (AHP), with land use, population density, and economic activity being assigned weights of 3, 2, and 1, respectively.

The land use parameter holds the highest weighting factor of three (3) due to its representation of the positive and negative aspects of human development and its significant impact on the environment. There exists a positive correlation between land use value and the likelihood of flooding. This relationship can be attributed to the fact that as the built-up area expands, a bigger proportion of open green land is utilized as a catchment area for rainwater. Consequently, this increased impervious surface area leads to greater runoff and prolonged inundation of land. Moreover, the impact of population density on flood susceptibility is significant, as indicated by a weighting factor of two (2). Nevertheless, regions characterized by a high concentration of inhabitants sometimes exhibit significant challenges for human social well-being, including various aspects such as public health, food accessibility, residential land availability, and the proliferation of epidemics and diseases, among others. There exists a positive correlation between the population density of a given area and its susceptibility to flood vulnerability. The last component is economic activity, which carries a weighted value of one (1). The occurrence of flood disasters has the potential to significantly impact economic activities. When a flood occurs, it can hinder or even halt community mobilization in economic activities and transactions. Consequently, this phenomenon can serve as an indicator of the extent to which non-physical conditions in a particular area contribute to its vulnerability to floods. Figure. 2 displays the vulnerability map of Brebes Regency.

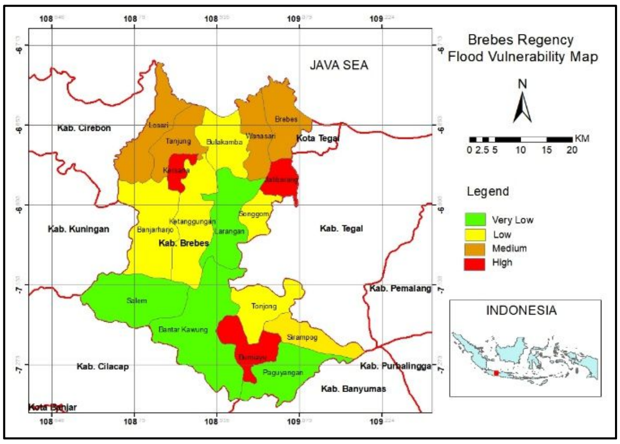

Fig. 2. Brebes regency flood vulnerability map.

4.3 Flood hazard zoning

There are a multitude of factors that exert impact over the occurrence and magnitude of flood dangers. The research undertaken by [21] provides a thorough examination of several factors that contribute to the occurrence of flood hazards. These factors encompass aspects such as patterns of precipitation, the slope of the topography, the composition of the soil, geological attributes, land management practices, drainage systems, and the extent of vegetation cover. The flood hazard zoning in Brebes Regency employs factors that are specifically tailored to the local environment, including rainfall patterns, tidal water levels, and topographical features.

The rainfall parameter holds the greatest weighting factor of 3 (three) due to its significant impact on the incidence of flood disasters. This is attributed to the fact that rainfall is a physical parameter with substantial influence on such occurrences. There exists a positive correlation between rainfall levels and the likelihood of flooding, as precipitation on terrestrial surfaces can lead to the accumulation of runoff and the formation of standing water. Moreover, the elevation of the sea water level is a significant determinant that exerts a substantial impact on the vulnerability to floods, carrying a weightage factor of 2. Coastal regions possess a higher susceptibility to flooding compared to inland locations, mostly because to the presence of sea water tidal waves. There exists a positive correlation between the elevation of tidal sea levels and the associated risk of flooding within a certain geographical region. The final element under consideration is topography, which has a weighting factor of 1. The term "topography" refers to the average elevations and depressions found in the Brebes Regency area. These variances are visually apparent and have a significant role in determining the possible risk of flooding in the region. Fig. 3 displays the flood hazard zoning map of Brebes Regency.

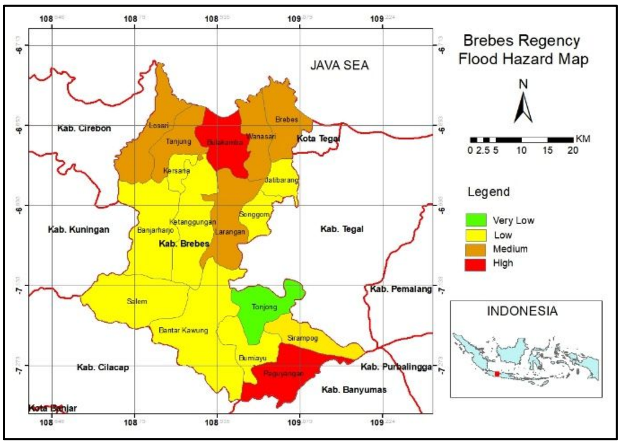

Fig. 3. Brebes regency flood hazard map.

4.4 Flood risk

The analysis and assessment of flood risk are fundamental components of the flood risk management strategy. Flood risk analysis and assessment are employed to inform decision-making processes related to flood hazards and mitigation strategies. The analysis of flood risk was conducted using the usual risk equation as presented in Equation 4 [22].

$$R = H \times V \tag{4}$$

where, R is Risk, H is Hazard, and V = Vulnerability.

The level of risk increases to an intermediate to high range (as indicated by the upper level of the picture) under three conditions: (1) when the hazard is high, (2) when there is a significant number of exposed elements at risk, or (3) when the vulnerability is high [14]. The increase in either hazard or vulnerability will result in an escalation of risk levels. The reduction of either hazard or vulnerability, or both, will result in a decrease in the amount of risk. The spatial study of flood risk in Brebes Regency was conducted by superimposing hazard maps and vulnerability maps utilizing Equation 4. The overlay findings of the flood risk map are depicted in Figure. 4.

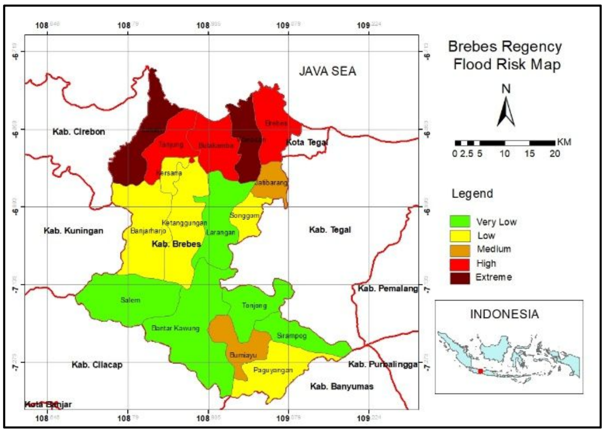

Fig. 4. Brebes regency flood risk map.

A distribution diagram was generated in order to visualize the distribution of hazard, vulnerability, and flood risk categories. This figure is depicted in Figure. 5.

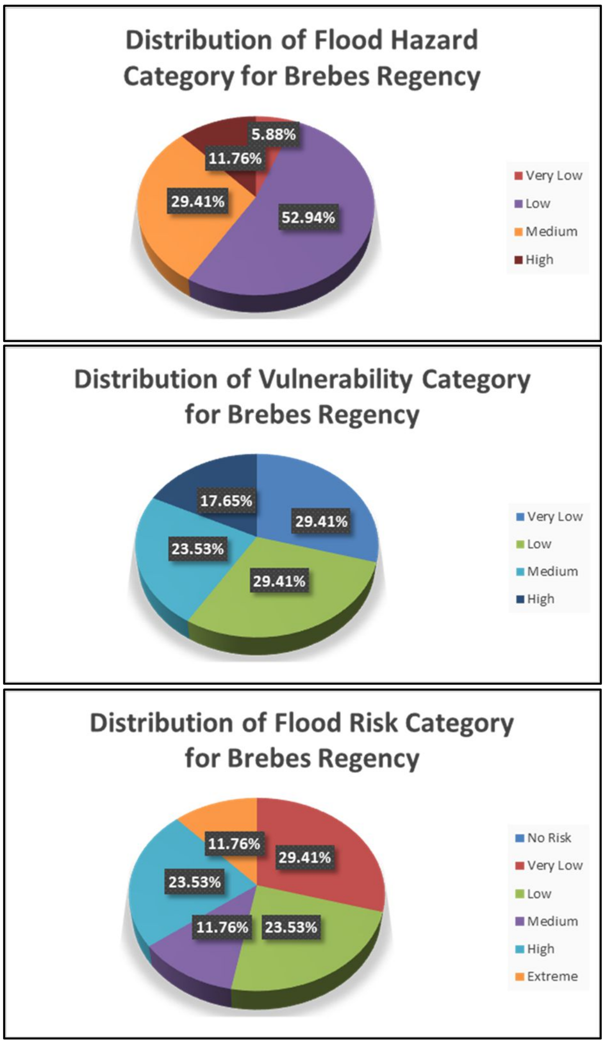

Fig. 5. Distribution diagram of flood hazard categories, flood vulnerability and flood risk.

According to the data presented in Fig. 5, it appears that the majority of regions within Brebes Regency exhibit elevated and severe flood risk classifications, accounting for a cumulative proportion of 35.29%. This observation highlights the imperative of developing and implementing mitigation strategies to address flood disasters in Brebes Regency.

4.5 Flood disaster mitigation

Mitigation refers to the implementation of risk management measures aimed at preventing, minimizing, or redirecting potential hazards. The objective is to decrease the adverse consequences of disasters, safeguard against their occurrence, enhance response capabilities, and expedite recovery endeavors, thereby fostering a society that is better equipped and more resilient. Mitigation measures can be implemented in the form of structural and non-structural interventions, contingent upon the specific geographical context and characteristics of the flood event. Nevertheless, it is important to note that while these mitigation techniques can effectively decrease the consequences of floods, it is imperative to acknowledge that humans are unable to completely prevent heavy rainfall or high tides.

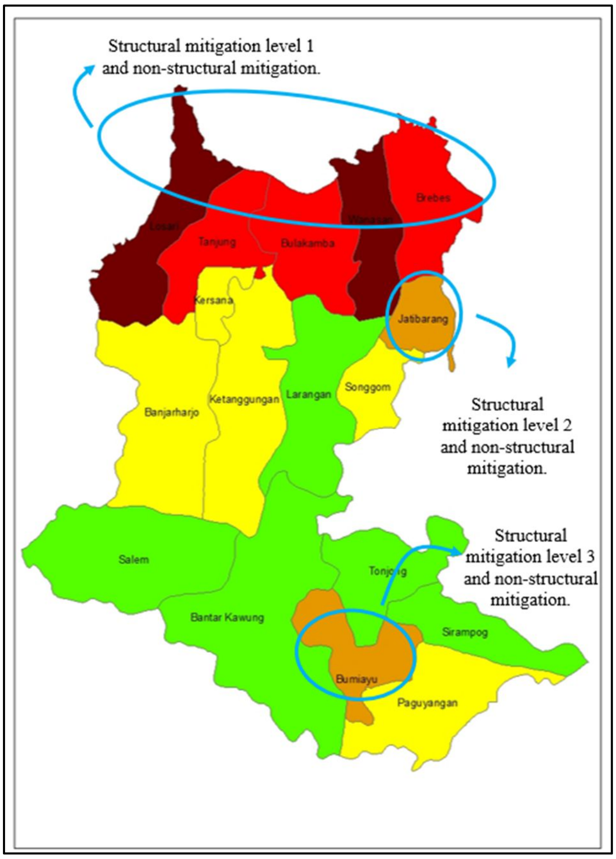

Fig. 6. Flood mitigation recommendation.

Considering the prevailing circumstances, the initiation of flood disaster mitigation measures in Brebes Regency can be facilitated through the implementation of land use management and strategic planning of mitigation initiatives. Effective land use planning plays a crucial role in identifying regions susceptible to flooding and implementing measures to restrict the construction of residential, commercial, and industrial infrastructure in these areas. Concurrently, the process of mitigation action planning aids in identifying appropriate mitigation strategies tailored to the specific requirements of the affected regions. The flood disaster risk map in Brebes Regency was utilized to formulate suggestions for land use planning and mitigation action planning, as seen in Figure. 6.

Table 2. Mitigation measures recommendation.

No	Regional Risk	Mitigation Measures Recommendation
1	High and Extreme	Structural flood mitigation measures level 1: flood management infrastructure (sea walls, river embankments, eco drainage, river normalization, mangrove planting, providing pumps and sluice gates), maintenance of existing flood control infrastructure, individual flood prevention measures, and improving traffic access.
		Non-structural mitigation measures: providing property flood surveys, urban planning control, building development control, flood area modeling, early warning systems, developing emergency planning, access to information and warnings, understanding and awareness of the dangers and risks of flooding through education and training in schools.
2	Medium	Structural flood mitigation measures level 2: flood management infrastructure (river embankments, eco drainage, river normalization, providing pumps and sluice gates), maintenance of existing flood control infrastructure, individual flood prevention measures, and improving traffic access.
		Non-structural mitigation measures: providing property flood surveys, urban planning control, building development control, flood area modeling, early warning systems, developing emergency planning, access to information and warnings, understanding and awareness of the dangers and risks of flooding through education and training in schools.
3	Low and Very Low	Structural flood mitigation measures level 3: flood management infrastructure (eco drainage), maintenance of existing flood control infrastructure, individual flood prevention measures, and improving traffic access.
		Non-structural mitigation measures: providing property flood surveys, urban planning control, building development control, flood area modeling, early warning systems, developing emergency planning, access to information and warnings, understanding and awareness of the dangers and risks of flooding through education and training in schools.

Figure 6 presents a range of suggested mitigation strategies, both structural and non-structural, which are tailored to the specific level of disaster risk. There are 3 levels of structural mitigation recommendations. Level 1 is a recommendation for areas that experience severe flooding problems, and the flooding comes from rain and tidal floods. Structural mitigation level 2 is also recommended for floods originating from tidal floods or rain, but for milder cases, while structural mitigation level 3 is recommended for areas where flooding is only influenced by rain, with a lighter risk. In regions characterized by elevated and severe susceptibility to flooding, such as Losari, Tanjung, Bulakamba, Wanasari, and Brebes Districts, it is advisable to implement structural interventions for flood mitigation. These interventions primarily involve the establishment of flood management infrastructure, including the construction of sea walls, river embankments, eco drainage systems, river normalization initiatives, and the implementation of mangrove planting programs. Additionally, the installation of pumps and sluice gates is recommended. Furthermore, it is crucial to conduct regular maintenance of existing flood control infrastructure, promote individual flood prevention measures, and enhance traffic access in the affected areas. In addition, non-structural mitigation strategies encompass a range of interventions such as conducting property flood surveys, implementing urban planning regulations, enforcing building development controls, utilizing flood area modeling techniques, establishing early warning systems, formulating emergency response plans, facilitating access to information and warnings, and enhancing knowledge and awareness of flood hazards and risks through educational initiatives and school-based training programs. In the case of regions categorized as having a moderate risk level, it becomes imperative to strategize for both structural and non-structural mitigation efforts, albeit on a more modest size. Conversely, regions classified as having low or very low risk levels implement both structural and non-structural mitigation measures, but on a more limited scale, as illustrated in Table 2. Further research and strategic planning are required to enhance the efficacy of structural mitigation measures, hence facilitating the acquisition of optimal infrastructure design.

5 Conclusion

According to the flood risk map, a significant proportion (35.29%) of the geographical areas within Brebes Regency are situated in regions characterized by high and extreme levels of vulnerability to flooding. Therefore, it is imperative that future regional spatial design incorporates considerations of vulnerability, hazards, and flood risk. In addition to the aforementioned, it is imperative to initiate contemplation on mitigation endeavors aimed at flood disasters, with the objective of minimizing losses resulting from the repercussions of floods in Brebes Regency. Initiating these endeavors is imperative despite their arduous and costly nature, as they are essential for the transformation of Brebes Regency into a resilient city. This transformation is crucial for enhancing the quality of life for its residents and ensuring the optimal maintenance of vital infrastructure. Notably, Brebes Regency boasts exceptional potential and is endowed with significant infrastructure, including toll roads, the north coast of Java highway, and various other pivotal assets.

This article presents a number of structural recommendations as mitigation measures, derived from the flood disaster risk map in Brebes Regency. However, it is important to note that these mitigation methods primarily focus on reducing the impact of the catastrophe rather than completely eliminating it. Therefore, it remains imperative to implement non-structural initiatives to enable local communities to withstand potential disasters. Disasters, by their inherent nature, are not entirely preventable; yet, through the use of scientific knowledge and techniques, humans have the capacity to mitigate their impact and reduce associated losses.

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