Vulnerability assessment of residential buildings to tidal flood hazards in Sriwulan Village, Sayung District, Demak Regency

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Abstract. Tidal floods are among the destructive hazards to coastal settlements. In December of 2017, extreme tidal floods impacted 3,500 houses in Sriwulan Village, Sayung District, Demak Regency. This research was intended to (1) asses the vulnerability levels of the residential buildings and (2) analyze the most influencing factors. The assessment was based on the scenarios built with a 150cm-high tidal flood, as observed during the 2017 event and projected for the subsequent five years (2022). The Analytical Hierarchy Process (AHP) and Spatial Multi-Criteria Evaluation (SMCE) were used in four scenarios, namely, hazard, physical, environmental, and economic. The equal scenario was also developed as a comparison to the first four scenarios to achieve the second objective. Based on the physical, environmental, and equal scenarios, 22 houses distributed throughout most of the areas of Nyangkringan Sub-Village fell into the category of highly vulnerable. The most determinants of the vulnerability are related to the physical and environmental parameters. The former includes the design flood elevation, building maintenance, and building materials, while the latter consists of the source of tidal floods and their preventive measures, distance to water bodies, and accessibility.

1 Introduction

The Indonesian shore stretches as far as 81,000 km, constituting up to 14% of the total shoreline worldwide [1]. With this condition, there are different threats to coastal areas, starting from erosion to floods, high waves, and even tsunamis. Tidal floods, locally known as *rob*, commonly take place in coastal lowlands, including Demak Regency that has been hit repeatedly by these disasters since the 1980s [2]. The high frequency of occurrences is attributable to a local factor, that is, land subsiding at 0.06-1.15 m per year [3]. Sayung is the most severely affected district in the regency. It has a relatively flat morphology with altitudes in the range of 0-5 meters, which is partially responsible for the chronic flooding [4].

Sriwulan, a village of the district, receives the most adverse impact. In 2010, hundreds of houses in the village were inundated as deep as adult knee and up to one meter [5]. Towards the end of 2017, seawater tides flooded 3,500 houses up to 50-150 cm due to the impact of Tropical Cyclone Dahlia [6].

Apart from the year-to-year variation of tidal floods, inundation also varies in depth depending on the average height of the design flood elevation. Without raised foundations, houses are expected to be submerged permanently by the floods. Tidal floods cause physical damages to local residential buildings and economic losses due to inevitable retrofitting costs.

Both of these are believed to be the detrimental effects because, typically, these buildings can last for approximately 25 years without repair [7]. In this context, houses are one of the elements at risk, and the

majority of settlements in coastal areas do not have long-term planning to deal with disasters; for this reason, their vulnerability must be analyzed [8].

Vulnerability analysis demands multifaceted development to incorporate various parameters and, consequently, accommodate types of factors that control the vulnerability level of a residential building. Therefore, from many methods of vulnerability, this research use Spatial Multi Criteria Evaluation (SMCE) due to its ability to accommodate vulnerabilities in various scenarios that use variables sourced from many types of data as the input [9]. Then, this research was designed to (1) assess the vulnerability level of residential buildings to tidal flood hazards in some scenarios and (2) identify the most influencing factors.

2 Research Method

This research took place in Sriwulan Village, Sayung District, Demak Regency with residential buildings as the unit of analysis. Due to the large size of the research population (i.e., all houses in the village that had experienced tidal floods), the sample size was determined by the Slovin method. The equation used was as follows.

$$n = \frac{N}{1 + (Ne^2)} \dots \dots \dots (1)$$

where:

n = Sample Size

N = Population Size

e = Error Level = 5% or equal to 95% accuracy

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The tidal floods in 2017 inundated 3,500 houses in Sriwulan Village [6]. Therefore, based on the Slovin's equation, the sample size was 359 houses and added with 20 more houses to anticipate data biases. As a result, the total sample was 379 houses.

The research used systematic sampling to produce evenly distributed samples against the population by firstly dividing the study area into 30x30 m² grids. In addition, Sriwulan Village consists of six (6) sub-villages, namely Nyangkringan, Sriwulan, Pututan, and Pondok Raden Patah Housing Phases 1, 2, and 3. The sampled houses in every sub-villages are presented in Figure 1.

Fig. 1. The Distribution Map of House Sampling Points.

This research consists of four phases, known as preparing, collecting, processing, and analysing data. Preparing data included geospatial database, sample size, and literature review. The first one was collected from relevant agencies, while the others were carried out from desk research.

The parameters were determined based on the results of the data availability from literature study and preliminary survey of households (Table 1). Collecting data used two methods. At the beginning, structured interviews with questionnaire were conducted with the head or member of households who were able to describe variables or factors that constructed hazard, physical, and environmental parameters. On the next occasion, in-depth interview technique was obtained to explain economic parameter that represented losses as a result of tidal flood disaster. This technique was retrieved with key informant who was the head of development affairs in Sriwulan Village.

Table 1. Research Variables and Their References

Variables	Definitions	Source
Hazard		
Depth	Water depth inside the house during the highest tidal flood with reference to the ground floor	[10]
Frequency	Recurrence flood with a current size that will be the same or exceeded in period of the years.	[11]
Duration	Long-time of water to recede from the house during the highest tidal flood	[10-11]
Physical Parameter		
Design Flood Elevation	Specific elevation constructed by local community perception to protect the house building from peak of highest flood	[11-12]
Building maintenance or existing damage	Percentage of existing damage presenting the building maintenance	[13]
Type of Materials	Building construction based on type of materials related to salt weathering	[14]
Environmental Parameter		
Source of tidal flood and their preventive measures	The source of tidal flood and the availability of a pump as a preventive measure due to its duration	[15]
Distance to water bodies	Distance of house building to water bodies (pond/river connected to the sea) related to the potential damage from salt weathering	[16]
Accessibility	Availability of a way or bride during the flood	[17]
Economic Parameter		
Retrofitting cost	Cost needed to make changes within 7 years (2013-2019) for an existing building in order to protect it from flooding	[12]
Building type	Type of building representing investment cost	[7,18]
Building area	Total area of building related to the cost for elevating base floor	[19]

The vulnerability data were processed in two steps, namely variables weighting by Analytical Hierarchy Process as well as vulnerability level mapping using several scenarios set in the Spatial Multi-Criteria Evaluation.

Last of all was data analysis. This phase used interpolation to understand the spatial patterns in some scenario. Subsequently, these spatial patterns were compared to identify the most determining factor(s) of the vulnerability.

2.1 Analytical Hierarchy Process (AHP)

This research used Analytical Hierarchy Process (AHP) to obtain weight values of variables within parameters (physical, environmental, hazard, and economic) to create vulnerability map. AHP was chosen because it was able to accommodate analytical object, both quantitative and qualitative information into mathematical models [20]. Decomposition as the onset would be considered to separate that information by problem into hierarchy based on the results of field survey and literature studies [21].

AHP step were subsequently decision comparison, which was based on how one parameter took priority over the other parameters at the same level [22]. It was known as pairwise comparison that consisted of nine points (Table 2).

Table 2. Scales of Priority in the Analytic Hierarchy Process (AHP)

Process (A/H)					
More important	Equally important	1	Less important	Equally important	1
	Slightly more important	3		Slightly more important	1/3
	More important	5		Less important	1/5
	Extremely important	7		Slightly less important	1/7
	Absolutely important	9		Absolutely less important	1/9
2,4,6,8	Values between the two considered adjacent values				

This step produced eigenvectors with their rank which is representing relative importance of variables in each parameter, as presented in Table 3. Eigenvector below has been throughout consistent evaluation which is marked with consistency ratio (CR) value at <10%, as shown in figure 2. CR is resulted by dividing consistency index (CI) with random index (r.i). ri value relies on the number of criteria (n) according to Saaty (1980) [22]. In this case, an add-in program for Microsoft Excel, namely, the AHP calculator, was used. This program would generate CR value automatically after adding the number of criteria(s) and their name.

Table 3. The Weighting Results of the Research Parameters

Variables	Eigenvector	Ranks
Physical Parameters		
Design flood elevation	0.47	1
Building materials	0.38	2
Types of materials	0.15	3
Environmental Parameters		
Source of tidal floods and their preventive measures	0.44	1
Distance to water bodies	0.39	2
Accessibility	0.17	3
Economic Parameters		
Retrofitting cost	0.65	1
Building type	0.23	2
Building area	0.12	3
Hazards		
Depth	0.49	1
Frequency	0.31	2
Duration	0.20	3

Criterion	Comment	Weights	+/-
1 Retrofitting cost		59.4%	13.6%
2 Building type		24.9%	5.7%
3 Total area		15.7%	3.6%
4		0.0%	0.0%
5		0.0%	0.0%
6		0.0%	0.0%
7		0.0%	0.0%
8		0.0%	0.0%
9	for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10	question section ("+" in row 66)	0.0%	0.0%
Eigenvalue			
		Lambda: 3.054	MRE: 23.0%
Consistency Ratio			
		0.37 GCI: 0.16	Pst: 33.3% CR: 5.6%

Fig. 2. Consistency Ratio <10%

Furthermore, AHP calculator had an ability to give recommended scale for relative weighting to create better consistency (Figure 3), considered as an illustration of inconsistent pair-wise comparisons. The darkest red highlight which is showing the relative importance between retrofitting cost (A) and total area (B), is the most inconsistent judgement, therefore, AHP Calculator recommend 1 for A criteria rather 3 scale for better consistency ratio.

Name	Weight	Date	Consistency Ratio				
Criteria		more important ?	Scale				
i	j	A or B	(1-9)				
1	2	Retrofitting cost	Building type	A	5	2	A3
1	3		Total area	A	3	1	A5
1	4						
1	5						
1	6						
1	7						
1	8						
2	3	Building type	Total area	A	3	3	A2

Fig. 3. Scale Recommendation from AHP Calculator

2.2 Spatial Multi-Criteria Evaluation (SMCE)

SMCE can explain future uncertainties with mathematical logics using criteria tree analysis, standardization, weighting, and generate scenarios [23]. The criteria tree consists of maps of the research variables or criteria (Figure 4).

Fig. 4. The Criteria Tree.

Standardization is a process in which all different unit indicators are equated with the corresponding data standards or normalization. SMCE can standardize the inputted data that have various categories or classifications. The study used the standardization of benefits (+), which indicate that all of the variables have greater contribution to the vulnerability [23]. The method used was fuzzy logic, which produced values in the range of 0 to 1 [24]. The higher the score of category, the higher the vulnerability (Table 5).

Afterward, the weighting was carried out by the direct method, i.e., a technique used to input the quantitative data obtained from the previous AHP calculation. Generating scenarios played an important role in producing vulnerabilities in various by first deciding the dominant parameter and then assigning equal values to the other parameters, known as weighting scenario [23].

There were four scenarios: physical, environmental, economic, and hazard. The economic scenarios emphasized the contribution of economic parameters to vulnerability. The same case applied to the environmental, physical, and hazard scenarios, which relied on to what extent the corresponding parameters controlled the vulnerability. In each of these scenarios, the dominant parameters were given the highest weight value, while the remaining parameters were assigned the same weight. An equal scenario was also carried out to determine the level of vulnerability with the assumption that all parameters observed had an equal weight value (Table 4).

Table 4. The Weighting Results of the Research Parameters

Scenarios	Percentage of Weighting (%)			
	Hazards	Physical	Environmental	Economic
Hazards	55	15	15	15
Physical	15	55	15	15
Environmental	15	15	55	15
Economic	15	15	15	55
Equal	25	25	25	25

Because the SMCE produced data with a normal distribution, the classification was conducted by the equal method [25]. In this case, each scenario has the same class size, which consist of three classes, i.e., low, moderate, and high classes.

2.3 Interpolation

The data were interpolated to distinguish the spatial patterns of vulnerability in each scenario using geostatistical wizard tool in Arc-GIS 10.3. This technique used the Radial Basis Function (RBF) due to its ability to produce spatial patterns that are more detailed than other methods from a large size of data point [26] (Figure 5a). Furthermore, it produces smaller root mean square error (RMSE) values than Inverse Distance Weighting (IDW) that produces the same characteristics (Table 6). The smaller of RMSE, the better performance of the spatial pattern model [27].

Table 6. The RMSE Value of Some Methods

Interpolation Methods	RMSE Value
Kriging	0,462
Local Polynomial	0,463
Radial Basis Functions	0,491
Inverse Distance Weighting (IDW)	0,497

2.4 Determination of the most influencing factors

Future risks can be minimized by understanding factors that have the most significant role in shaping the vulnerability of a residential building to tidal floods. In this study, the most influencing factor(s) was determined by compiling as many scenarios as possible to be able to recognize the factor(s) that frequently appeared on the maps produced. Besides, it also used equal scenario in order to emphasize the finding [28]. The research stages are presented in details in the flow chart below (Figure 6).

Table 5. Standardizations Definitions, and Source of Criteria Used in the Research

Variables	Standardization Definitions	Category	References
Hazard			
Depth	(+) The deeper the tidal flood, the higher the vulnerability	Very low (0.2) = no flood (0 cm) Low (0.4) = Ankle to leg (1-49 cm) Moderate (0.6) = Knee to stomach (50-100 cm) High (0.8) = Chest to neck (101-150 cm) Very High (1.0) = Above neck (>150 cm)	[7,24, and Field survey]
Frequency	(+) The higher the frequency of tidal flood, the higher the vulnerability	Low (0.3) = Never flooded within 5 years Moderate (0.6) = flooded, maximum 5 times within 5 years High (1.0) = Flooded, more than 5 times within 5 years	[12, and field survey]
Duration	(+) The longer the duration of tidal flood, the higher the vulnerability	Very low (0.2) = No flood Low (0.4) = 0.5 hour- 12 hours Moderate (0.6) = 13 hours - 24 hours High (0.8) = 25 hours - 48 hours Very high (1.0) = >48 hours	[10, 15, and field survey]
Physical Parameter			
Design Flood Elevation	(+) The lower the design flood elevation toward spring tide, the higher the vulnerability	Low (0.3) = Above storm tide 2017 Moderate (0.6) = Below storm tide 2017 High (1.0) = Below spring tide	[7 and field survey]
Building maintenance or existing damage	(+) The bigger the percentage of building damage, the higher the vulnerability	Low (0.3) = 0-25% existing damage Moderate (0.6) = 50% existing damage High (1.0) = 100% existing damage	[13 and field survey]
Type of Material	(+) Wood is more vulnerable than brick	Low (0.3) = brick Moderate (0.6) = brick + wood High (1.0) = Wood	[14, 19]
Environmental Parameter			
Source of tidal floods and their measures	(+) Source of tidal flood that impacts on longer duration will cause the higher vulnerability	Low (0.3) = Pump Moderate (0.6) = pond/river/drainage High (1.0) = bad drainage	[15 and field survey]
Distance to water bodies	(+) The closer the distance of building to water bodies, the higher the vulnerability	Low (0.3) = >100 meter Moderate (0.6) = 50-100 meter High (1.0) = 0-50 meter	[16 and field survey]
Accessibility	(+) The lower the accessibility, the higher the vulnerability	Low (0.3) = No inundation Moderate (0.6) = There is inundation, but there is a way too High (1.0) = There is inundation	[17 and field survey]
Economic Parameter			
Retrofitting cost	(+) The higher the retrofitting cost, the higher the vulnerability	Very low (0.2) = 0 Low (0.4) = IDR < 9.000.000 Moderate (0.6) = IDR 10.000.000-IDR 59.000.000 High (0.8) = IDR 60.000.000 – IDR 100.000.000 Very high (1.0) = IDR >100.000.000	[10 and in-depth interview]
Building type	(+) The higher the investment cost, the higher the vulnerability	Low (0.3) = non-permanent Moderate (0.6) = semi-permanent High (1.0) = permanent	[7, 18]
Building area	(+) The wider the area of building, the higher the vulnerability	Very low (0.2) = (36-49 m ²) Low (0.4) = (50-69 m ²) Moderate (0.6) = (70-119 m ²) High (0.8) = (120-200 m ²) Very high (1.0) = (201-360 m ²)	19 and field survey]

Fig. 5. Interpolation Map of Some Methods.

Fig. 6. Research Flow Chart

3 Result and Discussion

3.1 Hazard-Based Vulnerability Scenario

The high tides on the Coast of Demak estimated would reach 145.42 to 163.50 cm in 2020-2025 [3]. In December of 2017, storm tide as the combination of spring tide and storm surge hit the coast of Demak due to Tropical Cyclone Dahlia. With these references, the hazard scenario was generated to mimic the depth, duration, and frequency of the 2017 tidal floods with a height of 150 cm.

The vulnerability mapping made with this scenario showed heterogeneous levels of vulnerability among the houses observed. Nevertheless, a dominant pattern of moderate vulnerability was apparent (Figure 7). Fifty-three houses or 14% of the total samples fell into the category of low vulnerability because they were not flooded during a storm tide that led to 150cm-deep inundation. In other words, a similar tidal flood in the future will not directly affect these houses [3]. Meanwhile, the other 291 houses (77%) were classified as moderately vulnerable, and the remaining 35 houses (9%) were highly vulnerable.

Fig. 7. Vulnerability Maps of Residential Buildings Based on Hazard Scenario.

Buildings with high vulnerability were identified mostly in Nyangkringan Sub-village. Few of them in Pondok Raden Patah Housing Phase 1, as well as one house in Pututan Sub-village. These houses are chest-to-cheek-deep in water.

Besides, the frequency of inundation was more than five times within 5 years in some houses. The houses

were flooded every day because the type of tidal waters of Demak Regency was mixed tide prevailing diurnal tide [4]. It was characterized by one tide and one ebb tide in a day, but sometimes for a while there were two tides and two ebb tides with the distinction of height and period [29]. Therefore, these houses were flooded at least once a day during daily tides (Figure 8)

Fig. 8. House which was flooded at least once a day

On the other hands, there were some houses that inundated more than 48 hours in Pondok Raden Patah Housing Phase 1. Seawater flowing into these houses take a relatively long time to recede because it is retained in a long discharge channel before disposed to the sea. In addition, a few drainages in some houses became waste disposal sites, so it did not dry out before other drainages dried.

3.2 Physical-Based Vulnerability Scenario

Vulnerability scenarios that considered the current condition of design flood elevation, building maintenance, and types of materials revealed that more than half of the residential buildings were moderately vulnerable (226 houses or 60% of the total samples) and that the rest showed a heterogeneous pattern (Figure 9). Around 25 houses were highly vulnerable, while the remaining 128 houses (34%) had a low vulnerability.

Most of these houses with low vulnerabilities were located in the centre of Pondok Raden Patah Housing Phase 1, mainly due to the design of flood elevation with a height at least 2 meters.

In some parts of Nyangkringan Sub-village, the high physical vulnerability was dominant, but only a few shares of the houses in Sriwulan and Pututan Sub-villages and Pondok Raden Patah Housing Phases 1, 2, and 3 were highly vulnerable to tidal floods. The residential buildings in these areas were mostly low to moderately vulnerable. The spatial pattern of physical vulnerability tends to change following modifications in its determinants.

3.3 Environmental-Based Vulnerability Scenario

The combination of distance to water bodies, source of tidal floods and their preventive measures, and accessibility generated an environmental vulnerability scenario, therefore, varying degrees of vulnerability

with moderate levels dominating the houses (284 buildings or 75% of the total samples) (Figure 10). Seventy-one houses (19%) fell into the category of low vulnerability, while only 24 houses (6%) were highly vulnerable.

High vulnerabilities were found in the northern part of Pondok Raden Patah Housing Phase 1, mainly due to some drainage canals in this area are in poor condition. The floods originating from poor drainage systems will last longer than floods originating from the sea [15]. Another factor that caused the vulnerability was the distance to water bodies. The wooden walls decayed easily and the brick walls were prone during the calcification due to the highest saline content in buildings that was close to the water bodies [16]. Most of them were found in Nyangkringan Sub-village, as shown in figure 11.

Fig. 9. Vulnerability Maps of Residential Buildings Based on Physical Scenario.

3.4 Economic-Based Vulnerability Scenario

The economic vulnerability scenario represents the economic losses due to tidal flood. This vulnerability took into account the current retrofitting costs, building type, and building area. The results also showed that, economically, three-quarters of the total samples (284 houses) were moderately vulnerable, while the rest samples had varying levels of vulnerability (Figure 12). Seventy-one houses (19%) were categorized with low vulnerability, and another 24 houses (6%) were highly vulnerable.

Fig. 10. Vulnerability Maps of Residential Buildings Based on Environmental Scenario

Fig. 11. House with high saline content in the wall

The economic vulnerability scenarios showed a slight spatial variation in high vulnerability in the east of Pondok Raden Patah Housing Phase 1, mainly due to the high retrofitting costs of several houses in this region. The highest cost of retrofitting method was when a homeowner rebuilt a new house from existing house, which was known as demolish (Figure 13) [12]. According to local people perception, this method usually needed at least IDR 60.000.000.

Fig. 13. House with Demolish Retrofitting Method

Fig. 12. Vulnerability Maps of Residential Buildings Based on Economic Scenario.

Another factor that caused vulnerability of house building toward tidal flood was building area. Based on in-depth interview, the cost that required to elevate ground floor with one-meter high for 72 m² was 10 dump truck of material, which was equal to IDR 8.000.000. The dominance of the buildings with 72 m² was in Pondok Raden Patah Housing Phase 1, 2, and 3 because most of the buildings in this area had type 21.

3.5 The Most Determinants of Vulnerability

An essential finding of this study is the specific spatial pattern produced in each scenario (Figures 14a-e). The scenarios revealed specific patterns that shared similarities, and when observed thoroughly, some factors emerged more frequently than the others. For instance, the physical and environmental scenarios had nearly identical spatial patterns, meaning that both scenarios have a robust pattern [23].

Fig. 14. The Spatial Patterns of Vulnerability in (a) Hazard, (b) Physical, (c) Environmental, (d) Economic, (e) Equal Scenarios.

The striking characteristics are the high vulnerability in most areas of Nyangkringan Sub-village. Also, a small proportion of high vulnerability was found in Pondok Raden Patah Housing Phase 1, Sriwulan and

Pututan Sub-villages and Pondok Raden Patah Housing Phases 2 and 3, as marked by the blue circle (Figures 14b-c). As for the equal scenario, it also produced the same spatial pattern as the physical and environmental scenarios (Figure 14e). It is intended as a comparison to the other four scenarios because it assumes that all parameters contribute to vulnerability at the same degree, and with this assumption, this scenario is deemed neutral [28].

Based on the above findings, the influencing factors of vulnerability are those included in the physical and environmental vulnerability scenarios. The environmental factors which are source of tidal floods and their preventive measures, as well as accessibility, while the physical determinants are the design flood elevation, building maintenance, and type of materials. These factors were embedded to house building itself. Moreover, they were very likely to experience changes in the future because most residents of Sriwulan Village made improvements at least once every five years [30]. Therefore, physical and environmental factors played important roles as “agent of change” to minimized the future risk.

Based on the previous explanation, the houses that need to be immediately modified are the ones that fall into the category of high vulnerability in the physical and environmental scenarios. There are 22 houses consistently present in this category, as shown in Table 7.

3.6 Mitigation Measures

Learning from previous tidal floods, the residents of Sriwulan Village have applied several mitigation efforts to the physical and environmental features that potentially contribute to vulnerability. The mitigation efforts are as follows:

3.6.1 Design Flood Elevation

Houses that were not affected by the tidal floods in December 2017 had been elevated by at least 2,5 meters from the original foundation (Figure 15). According to [7], to deal with tidal flood in residential areas was by raising the design flood elevation above the highest high-water level (HHWL) [9]. Regarding the value of HHWL in Demak sea water as observed during 2016 was about 2.14 meters [31].

Fig. 15. House with at least 2 Meters Design Flood Elevation

3.6.2 The Source of Tidal Floods and Their Preventive Measures

Pumps are used to shorten the duration of seawater inundating the house. Low vulnerabilities were found in the center of Pondok Raden Patah Housing Phase 1 and Pututan Sub-village due to their privately owned pump or borrow one from the neighbourhood association, as shown in Figure 16.

Fig. 16. House with privately owned pump

3.6.3 Accessibility

Bridges are installed in frequently flooded yards (Figure 17). This measure has been a great help to maintain accessibility in the event of tidal floods.

Fig. 17. House with bridge installation in the yard

3.6.4 Building maintenance

The residents routinely check and tend to their houses, especially the walls, which are highly vulnerable to damage. This building maintenance often includes cleaning the salt formed on brick walls, replacing wood walls at least once within five years [32], and painting cemented walls regularly, as presented in Figure 18.

Fig. 18. House with painting cemented walls regularly

Table 7. The Vulnerability Levels of the Sampled Houses in Physical, Environmental, and Equal Scenarios

Vulnerability levels	Number of houses	Number of houses in every Sub-village	Address (Sub-village)
High	22	13	Nyangkringan
		1	Sriwulan
		2	Pututan
		4	Pondok Raden Patah Housing Phase 1
		2	Pondok Raden Patah Housing Phase 2
		1	Pondok Raden Patah Housing Phase 3
Moderate	196	18	Pondok Raden Patah Housing Phase 3
		28	Pondok Raden Patah Housing Phase 2
		66	Pondok Raden Patah Housing Phase 1
		7	Pututan
		38	Sriwulan
		42	Nyangkringan
Low	45	2	Pondok Raden Patah Housing Phase 3
		6	Pondok Raden Patah Housing Phase 2
		27	Pondok Raden Patah Housing Phase 1
		5	Pututan
		5	Sriwulan

4 Conclusion

Referring to the results of the analysis, this research has concluded several things as follows:

1. The varying conditions of the residential buildings observed contribute to their heterogeneous degrees of vulnerability to tidal floods, i.e., low, moderate, and high. Generally, moderate vulnerability dominates the study area in all scenarios. Based on the physical and environmental scenarios, 22 houses are highly vulnerable to tidal floods, creating a robust pattern. Most of these houses are located in Nyangkringan Sub-village and a few of them are in Sriwulan and Pututan Sub-villages and Pondok Raden Patah Housing Phases 1, 2 and 3.
2. The most influencing factors of vulnerability are related to physical and environmental parameters. The physical parameters in question are the design flood elevation, building maintenance, and type of materials, while the environmental parameters include the source of tidal floods and their preventive measures, distance to water bodies, and accessibility.

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