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Community Adaptation to Tidal Flooding in a Coastal Settlement: A Risk-Based Study of Kemijen Subdistrict, Semarang, Indonesia

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Abstract. This study examines tidal flood risk and community adaptation in the coastal settlement of Kemijen Subdistrict, Semarang Timur, Semarang City. While studies on tidal flooding commonly focus on either hazard assessment or adaptation strategies, research integrating spatial risk analysis with community adaptive capacity remains limited. This study addresses this gap through a quantitative approach combining GIS-based risk assessment, scoring-overlay analysis of hazard, vulnerability, and capacity, and a questionnaire survey involving 100 respondents. The results indicate that tidal flood risk ranges from low to moderate, with an index of 0.23–0.48. Despite Kemijen's exposure to recurrent tidal flooding, the relatively moderate risk level reflects the influence of existing adaptive capacities and mitigation efforts. Community adaptation is dominated by structural measures, particularly raising house floors (average score = 175), whereas non-structural adaptation remains limited (average score = 126). These findings highlight the need to strengthen preparedness, risk communication, and risk-based coastal spatial planning to enhance long-term resilience to tidal flooding.
Keywords: *tidal flooding; community adaptation; structural adaptation; non-structural adaptation; disaster risk*

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Introduction

Coastal settlements are among the most exposed urban environments to climate-related and hydrometeorological hazards. In archipelagic countries such as Indonesia, coastal areas have strategic social, economic, and ecological functions, yet they also face increasing pressure from urban growth, land conversion, sea-level dynamics, land subsidence, drainage problems, and recurring tidal inundation. Tidal flooding, locally known as banjir rob, occurs when seawater enters low-lying land during high tide and may be intensified by sea-level rise, inadequate drainage, and physical changes in coastal landscapes. For coastal communities, tidal flooding is not only an environmental phenomenon but also a daily risk that affects houses, roads, sanitation, health, household assets, local mobility, and livelihoods.

Semarang City, the capital of Central Java Province, is one of Indonesia's coastal cities that has long experienced tidal flooding. The northern coastal corridor of the city functions as an important transportation and economic gateway, yet many surrounding settlements are located in low-lying areas with high exposure to inundation. Previous studies have shown that tidal flooding in Semarang affects physical infrastructure, household activities, health conditions, and local economic activities (Syafei et al., 2017). The risk becomes more complex in dense settlements because residents often remain in hazard-prone areas due to livelihood proximity, social networks, land tenure, limited financial capacity, and attachment to place.

Kemijen Subdistrict in Semarang Timur is a relevant case for understanding the relationship between tidal flood risk and community adaptation. The area has experienced tidal flooding for decades and was among the settlements affected by a major tidal flood event in 2022. Although the Banger Polder system has been constructed as a mitigation measure, tidal flooding still threatens residents' physical, social, and economic conditions. Earlier research in Kemijen found that residents had undertaken several forms of adaptation, including house floor elevation, infrastructure repair, housing adjustment, and social adaptation (Kencana & Yuliastuti, 2016; Wiratuningsih et al., 2018). However, repeated flood events indicate that existing adaptation remains uneven and needs to be reassessed within a broader risk framework.

The literature on coastal adaptation shows that communities respond to tidal flooding through both structural and non-structural measures. Structural adaptation refers to physical interventions such as raising floors, constructing barriers, elevating roads, using pumps, improving drainage, and building multi storey houses. Non-structural adaptation refers to social, institutional, informational, and preparedness-based actions, including early warning systems, disaster education, community groups, emergency planning, and government support. Studies in

coastal areas of Java have shown that structural actions are often more visible because they directly protect houses and household assets, while non-structural actions are frequently weaker due to limited coordination, information, and institutional support (Sarasadi & Rudiarto, 2021; Sutigno & Pigawati, 2015).

This study contributes to coastal settlement and disaster risk studies by linking GIS-based tidal flood risk assessment with household adaptation practices. Specifically, this study aims to identify the level of tidal flood risk in Kemijen Subdistrict and to examine the forms of adaptation undertaken by local residents. The study addresses two research questions: first, what is the level of tidal flood risk in Kemijen Subdistrict? Second, how do residents adapt to tidal flooding through structural and non-structural measures?

Methods

This study was conducted in Kemijen Subdistrict, Semarang Timur District, Semarang City, Central Java, Indonesia. Kemijen is a dense coastal urban settlement divided into 11 neighbourhood units (RW). The area is influenced by tidal flooding, low land elevation, drainage conditions, and the Banger River system. The population used as the sampling frame was 14,543 residents based on 2024 monographic data.

This research used a descriptive quantitative design. The analysis combined spatial risk assessment and questionnaire-based adaptation assessment. Primary data were collected through field observation, visual documentation of housing and infrastructure conditions, and questionnaires distributed to residents in each RW. Secondary data included administrative boundaries, Digital Elevation Model data, slope, elevation, soil type, rainfall, land-use maps, monographic data of Kemijen, official statistics, InaRisk data, and the Semarang City Disaster Risk Assessment document for 2023–2027.

The number of respondents was determined using the Slovin formula:

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

where n is the sample size, N is the population, and e is the tolerated error. With a population of 14,543 residents and a 10% error tolerance, the sample size was 99.28 and was rounded to 100 respondents. Respondents were distributed across the 11 *RW* areas. The field selection focused on residents who continued to live in the affected settlement environment and whose housing conditions reflected ongoing exposure or adaptation to tidal flooding.

Tidal flood risk was analysed using GIS-based scoring and overlay. The risk framework followed the disaster risk formula:

$$R = H \times \frac{V}{C}$$

where R represents disaster risk, H represents hazard, V represents vulnerability, and C represents adaptive capacity. The hazard component was constructed from slope, land elevation, soil type, rainfall, and land cover. The vulnerability component consisted of social, economic, physical, and environmental vulnerability indicators. The capacity component was based on institutional rules, early warning and disaster risk assessment, disaster education, reduction of underlying risk factors, and preparedness development. The spatial layers were scored, weighted, and overlaid using GIS raster calculation to classify hazard, vulnerability, capacity, and final risk.

Community adaptation was assessed using a three-point Likert scoring system. Each adaptation action was scored as 1 when the respondent did not implement the action, 2 when the respondent was in the process of implementing the action, and 3 when the respondent had implemented the action. Structural adaptation indicators included participation in polder and pump maintenance, raising or filling the main house floor by more than 30 cm, constructing door barriers or small embankments, building a second floor, raising roads or local infrastructure, elevating household furniture, and constructing soakaways. Non-structural indicators included government assistance, disaster-response education, community groups for flood problem-solving, and early warning signs or systems.

Results

The spatial overlay of slope, elevation, soil type, rainfall, and land cover indicates that Kemijen Subdistrict is located in a moderate-to-high tidal flood hazard zone. The hazard index ranges from 0.64, classified as moderate, to 0.75, classified as high. Most RW areas were classified as high hazard areas, while moderate hazard classes were found only in limited parts of RW III and RW IV. This result confirms that the physical characteristics of Kemijen, especially its low elevation and dense settlement land cover, create persistent exposure to tidal inundation.

The vulnerability analysis shows that Kemijen's risk is not determined only by physical exposure but also by social, economic, physical, and environmental conditions. Social vulnerability varied from low to high, with an index range of 0.10 to 0.70. The Semarang City Disaster Risk Assessment document classifies Semarang Timur as having high social vulnerability for flood risk. Economic vulnerability in Kemijen ranged from 0 to 0.48, indicating low to moderate

vulnerability. Physical vulnerability was classified as low, with an index from 0 to 0.08, although field observations still found houses and infrastructure that had undergone repeated repair due to tidal flooding. Environmental vulnerability was influenced by the presence of shrubs and swamp areas. The swamp parameter covered 37.8 hectares and was classified as high, while shrubs covered 5.6 hectares and were classified as low.

The capacity analysis indicates that Kemijen has a moderate capacity level, with a capacity index of 0.573. At the district scale, Semarang Timur is also classified as having moderate flood-disaster capacity. The final tidal flood risk index in Kemijen ranges from 0.23 to 0.48, meaning that the study area falls into low and moderate risk classes. Low-risk areas indicate relatively smaller potential impacts supported by existing capacity, while moderate-risk areas indicate more significant vulnerability, particularly for residents living near drainage channels and riverbanks or in houses lower than the road surface.

The questionnaire results show that structural adaptation is more dominant than non-structural adaptation. The average score for structural adaptation was 175, which falls into the moderate category. The strongest structural measure was raising and filling the main house floor by more than 30 cm, with a total score of 294 and a high classification. This action was implemented by most respondents and was considered effective in reducing direct water intrusion into houses. Other structural actions with moderate classification were constructing door barriers or small embankments and elevating household furniture. In contrast, participation in polder and pump maintenance, building a second floor, raising roads or local infrastructure, and constructing soakaways were still classified as low.

Non-structural adaptation was weaker than structural adaptation, with an average score of 126, classified as low. The only non-structural indicator reaching a moderate classification was the existence of an early warning sign or system, with a score of 159. Other indicators, including government assistance, disaster-response education, and community groups for discussing flood strategies, remained in the low category. These results show that residents have developed practical household-level physical responses, but collective preparedness, formal support, and institutionalized learning are still limited.

Discussion

The findings demonstrate that tidal flood risk in Kemijen is shaped by the interaction between high physical exposure, socially differentiated vulnerability, and moderate adaptive capacity. Although the final risk level is low to moderate, the hazard component is moderate to high and the social vulnerability component remains significant. This means that risk reduction

cannot be interpreted only from the final index; the underlying exposure and vulnerability structure must also be considered. Areas classified as moderate risk may still experience serious household-level impacts when houses are located below road level, when drainage channels are blocked or located too close to buildings, and when residents have limited financial capacity to upgrade their dwellings.

The dominance of structural adaptation confirms the practical and immediate nature of household responses to tidal flooding. Raising house floors, constructing barriers, and elevating furniture are rational strategies because they directly reduce water entry and protect household assets. These findings support previous studies in Kemijen and other coastal settlements, which found that floor elevation, house modification, and local infrastructure adjustment were among the most common and effective responses to tidal inundation (Kencana & Yuliastuti, 2016; Sarasadi & Rudiarto, 2021; Wiratuningsih et al., 2018). However, the uneven score distribution also shows that not all structural measures are equally accessible. Building a second floor, raising roads, and maintaining polder or pump infrastructure require higher financial capacity, collective action, or institutional coordination; therefore, they remain relatively weak at the community level.

The low level of non-structural adaptation is an important finding. Disaster education, community organizing, and government assistance scored low, while early warning practices only reached a moderate level. This suggests that adaptation in Kemijen remains largely reactive and household-based rather than collective, preventive, and institutionalized. Such a pattern may reduce immediate losses but does not fully strengthen long-term resilience. Non-structural measures are essential because they improve risk awareness, preparedness, evacuation readiness, maintenance behaviour, and community coordination. Without these measures, physical adaptations may become fragmented and less effective, especially when flood conditions exceed household-level protection capacity.

The results also highlight the importance of integrating household adaptation with urban infrastructure and spatial planning. Raising house floors can protect indoor spaces, but it may not solve neighbourhood-scale flooding when drainage remains inadequate or roads and alleys become lower than surrounding structures. In some cases, individual house elevation may even shift water problems to public spaces if it is not coordinated with drainage improvement. Therefore, structural adaptation should be strengthened through neighbourhood drainage normalization, maintenance of polder and pump systems, and coordinated road or alley elevation.

These efforts require collaboration between residents, local government, and disaster management institutions.

Risk-based spatial planning is also necessary. Although Kemijen currently shows low-to-moderate risk in the final index, hazard and vulnerability conditions indicate that risk could increase under future tidal, rainfall, land subsidence, or drainage failure scenarios. Development control in vulnerable zones, housing improvement support, monitoring of drainage performance, and targeted assistance for vulnerable households are required to prevent risk accumulation. This is particularly important for residents with limited resources, who may be unable to implement costly structural adaptation without external support.

This study has several limitations. First, the analysis used a cross-sectional design, so it captures adaptation conditions at one point in time rather than long-term changes. Second, the questionnaire involved 100 respondents, which is adequate for descriptive assessment but may not fully represent all socio-economic variations in the settlement. Third, some secondary data, especially detailed economic data at the subdistrict scale, were limited. Future studies should combine longitudinal observation, household income analysis, and participatory mapping to better explain why certain adaptation strategies are adopted while others are not.

Conclusion

This study concludes that Kemijen Subdistrict faces persistent tidal flood risk despite existing mitigation infrastructure. The hazard level is moderate to high, while the final tidal flood risk index ranges from 0.23 to 0.48, placing the area in low and moderate risk classes. The moderate risk classification should not be read as the absence of serious problems because social vulnerability, environmental conditions, and household-level exposure remain important drivers of risk. Community adaptation in Kemijen is dominated by structural measures. Raising and filling the main house floor by more than 30 cm is the most widely implemented and most effective household adaptation strategy. Overall, structural adaptation is classified as moderate, while non-structural adaptation remains low. The weakest non-structural aspects are government assistance, disaster education, and community organization, although early warning practices are beginning to develop. A more balanced adaptation strategy is required to build long-term coastal resilience. Structural adaptation should be supported by drainage improvement, maintenance of polder and pump systems, and coordinated infrastructure upgrading. At the same time, non-structural adaptation should be strengthened through inclusive early warning systems, continuous disaster education, community-based preparedness groups, targeted support for

vulnerable households, and risk-based spatial planning that limits development in hazard-prone zones.

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