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Beyond Exposure: Examining the Relationship between Tidal Flood Risk and Community Relocation Preferences Using Google Earth Engine

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ABSTRACT

Tidal flooding has increasingly threatened coastal settlements in low-lying regions of Indonesia, generating complex challenges that extend beyond physical exposure to encompass social vulnerability and long-term livelihood risks. This study examines the relationship between tidal flood risk and community relocation preferences in selected coastal communities of Kendal Regency, Central Java. The novelty of this research lies in three integrated contributions: (1) the application of a Google Earth Engine based composite risk index to a household relocation preference study, (2) the operationalization of the Impoverishment Risk and Resettlement (IRR) framework in a tidal flooding context where relocation risk is ongoing rather than event-driven, and (3) a comparative multi-village analysis that links spatial vulnerability gradients to differentiated community responses. A mixed-methods approach was employed, combining Google Earth Engine–based spatial analysis integrating SRTM elevation data, JRC Global Surface Water occurrence frequency, and ESA WorldCover 2020 land cover with household-level socio-economic surveys. A weighted composite risk index was constructed using elevation score (weight 0.4), water occurrence frequency (weight 0.4), and land cover type (weight 0.2). Coastal vulnerability was further assessed through a seven-indicator Coastal Vulnerability Index (CVI) scored on a 1–5 ordinal scale adapted from Gornitz (1991). Household survey data from 150 respondents (50 per village, stratified by flood-risk zone) were analyzed to capture relocation preferences and potential impoverishment risks. Results reveal substantial spatial variation in tidal flood risk across the three study villages, with Kartika Jaya and Mororejo classified as Very High risk (CVI scores 34 and 35, respectively) and Karangsari as High risk (CVI score 26). A significant share of affected households over 60 percent overall expressed preference for collective relocation supported by cash-based transitional assistance, reflecting concerns over livelihood continuity, social cohesion, and housing security. These findings underscore the need for datadriven, participatory relocation planning that simultaneously addresses physical risk reduction and socio-economic resilience in tidal flood–prone coastal areas.

Keywords: *coastal vulnerability assessment, household relocation decision, livelihood risk, participatory adaptation planning, tidal flooding*

ABSTRAK

Banjir rob semakin mengancam permukiman pesisir di wilayah dataran rendah Indonesia dan memunculkan permasalahan yang tidak hanya bersifat fisik, tetapi juga sosial dan ekonomi. Penelitian ini mengkaji keterkaitan antara risiko banjir rob dan preferensi relokasi masyarakat di kawasan pesisir Kabupaten Kendal, Jawa Tengah. Kebaruan penelitian ini terletak pada tiga kontribusi terintegrasi: (1) penerapan indeks risiko komposit berbasis Google Earth Engine dalam studi preferensi relokasi rumah tangga, (2) operasionalisasi kerangka Impoverishment Risk and Resettlement (IRR) dalam konteks banjir rob yang bersifat kronis dan berkelanjutan, serta (3) analisis komparatif multi-desa yang menghubungkan gradien kerentanan spasial dengan perbedaan respons masyarakat. Pendekatan campuran diterapkan dengan mengintegrasikan analisis spasial berbasis Google Earth Engine menggunakan data elevasi SRTM, frekuensi genangan JRC Global Surface Water, dan tutupan lahan ESA WorldCover 2020 dengan survei sosial ekonomi rumah tangga. Indeks risiko komposit dibangun menggunakan bobot elevasi (0,4), frekuensi genangan air (0,4), dan jenis tutupan lahan (0,2). Kerentanan pesisir dinilai lebih lanjut melalui Coastal Vulnerability Index (CVI) tujuh indikator, dan data survei dari 150 responden (50 per desa,

distratifikasi berdasarkan zona risiko banjir) dianalisis untuk menangkap preferensi relokasi dan potensi risiko kemiskinan. Hasil menunjukkan variasi spasial yang signifikan dalam tingkat risiko banjir rob, dengan Kartika Jaya dan Mororejo diklasifikasikan sebagai risiko Sangat Tinggi (skor CVI 34 dan 35) dan Karangsari sebagai risiko Tinggi (skor CVI 26). Lebih dari 60 persen rumah tangga menyatakan preferensi relokasi kolektif dengan dukungan bantuan transisi berbasis tunai. Temuan ini menegaskan pentingnya perencanaan relokasi berbasis data dan partisipatif yang secara bersamaan mengatasi pengurangan risiko fisik dan ketahanan sosial ekonomi.
Kata kunci: adaptasi pesisir, banjir rob, keputusan relokasi rumah tangga, kerentanan wilayah, risiko penghidupan

1. INTRODUCTION

Coastal areas are increasingly exposed to the impacts of climate change, particularly sea-level rise and tidal flooding, which pose significant threats to low-lying settlements worldwide. In many parts of the Global South, tidal flooding has shifted from episodic events to chronic inundation, driven by the combined effects of sea-level rise, land subsidence, and intensive coastal land-use change (IPCC, 2022; Nicholls et al., 2021). These dynamics not only damage physical infrastructure but also undermine housing quality, environmental health, and livelihood security, placing coastal communities in conditions of compounded physical and socio-economic vulnerability.

Along the northern coast of Java, Indonesia, tidal flooding locally known as rob has become a persistent hazard affecting coastal settlements and productive land. Prior studies have documented how tidal inundation in Indonesian coastal regions is closely associated with land subsidence, tidal dynamics, and coastal geomorphology, resulting in extensive and recurrent flooding of residential areas (Marfai et al., 2008; Takagi et al., 2020). These processes have intensified pressures on coastal communities, particularly those whose livelihoods depend on fisheries, aquaculture, and small-scale coastal activities.

Research on tidal flooding has largely focused on spatial risk mapping and hazard assessment using geospatial and remote sensing approaches. Techniques based on digital elevation models, land cover analysis, tidal observations, and satellite imagery have been widely applied to delineate flood-prone areas and support technical mitigation planning (Kulp & Strauss, 2019; Ward et al., 2018). Coastal vulnerability assessments, often operationalized through composite indices such as the Coastal Vulnerability Index (CVI), have been used to capture the combined influence of physical exposure, environmental sensitivity, and adaptive capacity in coastal zones (Marfai & King, 2008). These methods provide valuable insights into spatial patterns of risk and vulnerability, yet they primarily emphasize environmental and physical dimensions while leaving the social and behavioral dimensions of community response underexplored.

Parallel to this body of work, social science research has examined community responses to climate-related hazards, particularly in the context of relocation and planned retreat. Studies on climate-induced displacement and managed retreat highlight that relocation decisions are shaped not only by exposure to hazards but also by livelihood considerations, social networks, place attachment, and perceptions of risk (Cernea, 2000; de Sherbinin et al., 2011; Hino et al., 2017). The Impoverishment Risk and Resettlement (IRR) framework has been widely recognized as a foundational tool for understanding the socio-economic risks associated with

involuntary relocation, including landlessness, joblessness, social disarticulation, and increased vulnerability among affected households (Cernea, 2000). However, the IRR

framework was originally developed in the context of infrastructure-driven displacement and has been less frequently applied to settings where relocation risk is chronic and environmentally driven.

Despite these advances, a critical limitation in existing research lies in the limited integration between spatially explicit tidal flood risk assessments and community relocation preferences. Many studies remain hazard-centered, focusing on exposure and physical risk without adequately examining how variations in risk and vulnerability influence household-level decision-making regarding relocation (Siders, 2019). Furthermore, cloud-based geospatial analysis platforms such as Google Earth Engine, while widely used for flood mapping, have not been systematically combined with household relocation preference surveys in the Indonesian coastal context.

This study addresses these limitations through three integrated contributions. First, it applies a Google Earth Engine–based composite risk index integrating SRTM elevation, JRC Global Surface Water occurrence frequency, and ESA WorldCover land cover to produce spatially differentiated tidal flood risk assessments across three villages with contrasting vulnerability profiles. The use of globally available, open-access GEE datasets (SRTM, JRC GSW, ESA WorldCover) ensures methodological transparency and replicability in data-limited developing-country contexts. Second, it operationalizes the IRR framework in a tidal flooding context where relocation risk is ongoing and community-initiated rather than externally imposed, extending the framework's original scope. Third, it generates a comparative multivillage analysis that links spatial vulnerability gradients with differentiated community relocation preferences, enabling a more context-sensitive understanding of adaptive responses. Taken together, these contributions respond to calls for integrative approaches that connect physical risk assessment with social vulnerability and livelihood considerations to inform more equitable and sustainable relocation strategies (Siders et al., 2021).

Accordingly, the objective of this study is to examine the relationship between tidal flood risk and community relocation preferences by integrating Google Earth Engine–based spatial analysis with household socio-economic assessments, in order to support adaptive, participatory, and socially resilient relocation planning in tidal flood–prone coastal regions of Indonesia.

2. METHODOLOGY

2.1 Research Design

This study adopts a mixed-methods research design that integrates spatial analysis and socioeconomic assessment to examine the relationship between tidal flood risk and community relocation preferences. The approach combines quantitative geospatial analysis using cloudbased remote sensing with household-level survey data to capture both physical risk characteristics and social responses. This design enables a comprehensive assessment that moves beyond hazard exposure to include coastal vulnerability and potential livelihood implications associated with relocation.

2.2 Study Area, Scope, and Timeframe

This study was conducted in three coastal villages of Kendal Regency, Central Java, Indonesia, recurrently affected by tidal flooding (rob). The villages Mororejo (Kaliwungu

Subdistrict), Karangsari (Kendal Subdistrict), and Kartika Jaya (Patebon Subdistrict) were purposively selected to represent a gradient of tidal flood risk, from high to very high vulnerability, while also exhibiting variation in socio-economic conditions and land-use characteristics. This selection strategy supports comparative analysis across different risk levels and community contexts. The study was carried out between 2023 and 2024, encompassing spatial data analysis and field-based socio-economic data collection.

2.3 Data Types and Sources

This study utilizes both primary and secondary data sources. Spatial data were accessed and processed entirely through Google Earth Engine (GEE) using three globally available openaccess datasets: (1) the USGS SRTM 30 m Digital Elevation Model (USGS/SRTMGL1_003), which provides terrain elevation data used to identify low-lying areas susceptible to tidal inundation; (2) the JRC Global Surface Water dataset version 1.4 (JRC/GSW1_4/GlobalSurfaceWater), which records the historical frequency of surface water occurrence from 2000 to the present at 30 m resolution, serving as a proxy for long-term inundation frequency; and (3) the ESA WorldCover 2020 dataset (ESA/WorldCover/v100/2020) at 10 m resolution, used to classify land cover into built-up areas (class 50), permanent water bodies (class 80), and wetland/mangrove areas (classes 90 and 95). The choice of these datasets reflects the practical constraints of data availability in the study area and the methodological goal of producing a replicable, cloud-based risk assessment workflow. Primary socio-economic data were obtained through structured household surveys administered in 2024, while secondary demographic and administrative data were sourced from local government records and the Indonesian Central Statistics Agency (BPS).

2.4 Google Earth Engine Workflow

Tidal flood risk mapping was conducted using Google Earth Engine (GEE) following a fivestep workflow as summarized in Table 4. The workflow integrates three data layers into a continuous composite risk index. First, elevation risk was derived from SRTM by clamping values to the 0–10 m range, normalizing to a 0–1 scale, and inverting the result so that lower elevation produces a higher risk score. Second, water occurrence frequency from JRC Global Surface Water was normalized from its native 0–100 percent scale to 0–1, with pixels showing less than 10 percent historical water occurrence masked out. Third, land cover risk scores were assigned from ESA WorldCover 2020 classes: built-up areas (class 50) received a score of 1.0, wetland and mangrove areas (classes 90 and 95) received 0.7, and all other land cover types received 0.3. The three normalized scores were then combined into a composite risk index using fixed weights: elevation (0.4), water occurrence (0.4), and land cover (0.2). These weights reflect the judgment that long-term inundation history and terrain elevation are the two strongest physical determinants of tidal flood risk in low-lying coastal settings, while land cover modulates exposure at the settlement level. The composite index was subsequently normalized to the 0–1 range across each village's area of interest (AOI, defined as the village boundary plus a 500 m buffer) and classified into three risk categories: Low (<0.4), Moderate

(0.4–0.7), and High (≥0.7). The resulting risk heatmaps were spatially overlaid with residential land cover to identify settlements in each risk category.

Table 4. Summary of Google Earth Engine Processing Workflow

Processing Step	Data / Tool	Output
1. Elevation data	USGS SRTM 30 m DEM (ee.Image: USGS/SRTMGL1_003); elevation clipped to AOI; classified into ≤3 m and ≤5 m zones	Elevation risk score (inverted, normalized 0–1); low elevation = high risk
2. Water occurrence frequency	JRC Global Surface Water v1.4 (JRC/GSW1_4/GlobalSurfaceWater); 'occurrence' band = % of time pixel covered by water, 2000–present; pixels with occurrence >10% retained	Water frequency score (normalized 0–1); higher occurrence = higher risk
3. Land cover classification	ESA WorldCover 2020 (ESA/WorldCover/v100/2020); classes: built-up (50) = score 1.0; wetland/mangrove (90, 95) = score 0.7; other = score 0.3	Land cover risk score (0–1); residential areas receive highest weight
4. Composite risk index	Weighted combination: elevation score × 0.4 + water occurrence score × 0.4 + land cover score × 0.2; normalized to 0–1 range	Continuous risk index (0–1)
5. Risk classification	Thresholds applied to normalized index: Low (<0.4), Moderate (0.4–0.7), High (≥0.7); overlaid with residential land cover to identify at-risk settlements	Tidal flood risk heatmap: Low / Moderate / High

Source: *Author, 2025*

2.5 Coastal Vulnerability Index

To assess broader coastal vulnerability, a Coastal Vulnerability Index (CVI) was constructed following the methodological approach of Gornitz (1991) and Abuodha & Woodroffe (2010), as adapted for tropical low-lying coastal settings (McLaughlin & Cooper, 2010). Seven physical and environmental indicators were selected based on their relevance to tidal flooding in low-elevation coastal environments and data availability: (1) elevation, (2) tidal flood frequency, (3) inundation duration, (4) coastal abrasion/erosion rate, (5) land subsidence, (6) mangrove loss, and (7) proportion of residential land cover within high-risk zones. Each indicator was scored on an ordinal scale of 1 to 5, where 1 indicates the lowest vulnerability and 5 indicates the highest, based on field observations, satellite-derived measurements, and secondary data. The scoring criteria are detailed in Table 1. The choice of a 1–5 scale follows established CVI literature (Gornitz, 1991) and allows differentiation across vulnerability gradients without implying precise interval-level measurement. The total CVI score (maximum = 35) was classified into four vulnerability levels: Low (<18), Moderate (18–24), High (25– 29), and Very High (30–35), as presented in Table 2.

It is acknowledged that this study uses an equal-weighting approach across indicators, reflecting a methodological decision to treat each dimension of coastal vulnerability as equally significant in the absence of locally calibrated empirical weights. Future research could explore indicator weighting through sensitivity analysis or expert elicitation to test the robustness of the CVI results.

2.6 Household Survey and Sampling Strategy

A structured household survey was administered to 150 respondents, with 50 households sampled in each of the three study villages. The sampling followed a stratified systematic approach: within each village, respondents were stratified by flood-risk zone (high, moderate, and low, as identified from the GEE risk map) and then selected systematically from household lists provided by local village administrations. This approach was adopted to ensure that

households across different risk levels within each village were proportionately represented. Inclusion criteria required that respondents be adult household heads (or their spouses) who had resided in the village for a minimum of two years and had direct experience of tidal flooding. While the sample of 50 households per village represents approximately 15–20 percent of total households in each village (based on BPS village data), the stratified design supports intra-village comparisons rather than strict statistical representativeness at the village population level. This limitation is acknowledged and future research could employ larger probabilistic samples to improve generalizability.

The survey instrument collected information on household demographics, income sources, housing tenure, flood experience, relocation preferences, and expectations regarding relocation assistance. Survey design was informed by prior studies on climate-induced relocation and livelihood vulnerability (Cernea, 2000; de Sherbinin et al., 2011) to ensure thematic relevance.

2.7 Analytical Framework

The analytical framework of this study links three key components: (1) tidal flood risk assessment, (2) coastal vulnerability analysis, and (3) household relocation preferences and impoverishment risks. Coastal vulnerability is positioned as a contextual mediating layer that amplifies or moderates the way physical flood hazards are experienced and responded to by households. That is, two villages with similar inundation frequencies may exhibit different household responses because their vulnerability contexts—shaped by factors such as mangrove loss, land subsidence, and infrastructure condition—differ in ways that affect the severity and permanence of flood impacts. The IRR framework is then applied at the household level to identify the specific socio-economic risks that would be triggered or exacerbated by relocation, providing a basis for evaluating the feasibility and design of relocation interventions. By linking these three components, the framework enables an examination of how environmental risk conditions interact with social and economic considerations to shape community adaptive responses.

3. RESULTS AND DISCUSSION

3.1 Spatial Distribution of Tidal Flood Risk

The spatial analysis conducted using Google Earth Engine reveals clear variations in tidal flood risk across the study villages. Based on inundation frequency, elevation, and tidal exposure, the study area is classified into low, moderate, high, and very high tidal flood risk zones. These variations reflect differences in local topography, proximity to the coastline, and exposure to tidal dynamics.

Villages with very high tidal flood risk experience persistent and daily inundation, which directly affects housing conditions, access to services, and daily mobility. In contrast, areas classified as high risk are subject to frequent but not daily flooding, though long-term exposure remains a growing concern due to ongoing sea-level rise and land subsidence. This spatial heterogeneity underscores that tidal flooding is not experienced uniformly across coastal settlements, even within the same regency.

Table 1. Coastal Vulnerability Index of Study Area

CVI Indicator	Kartika Jaya	Mororejo	Karangsari	Brief Description
Elevation	5	5	4	Kartika Jaya and Mororejo dominated by areas below 2 m above sea level
Tidal flood frequency	5	5	4	Daily tidal flooding in Kartika Jaya and Mororejo; periodic flooding in Karangsari
Inundation duration	5	5	3	Prolonged inundation (>5 hours) in Kartika Jaya and Mororejo; shorter duration in Karangsari
Coastal abrasion / erosion rate	4	5	4	Severe shoreline erosion observed particularly in Mororejo
Land subsidence	5	5	4	Significant subsidence in Kartika Jaya and Mororejo
Mangrove loss	5	5	3	Extensive mangrove degradation; nearly absent in Kartika Jaya and Mororejo
Residential land cover in high-risk zones	5	5	4	Majority of housing units located within high-risk (red) zones
Total CVI Score	34	35	26	Maximum possible score = 35
CVI Risk Level	Very High	Very High	High	—

Source: *Author, 2025*

Table 2. Classification of CVI Score Ranges and Tidal Flood Risk Levels

CVI Score Range	Tidal Flood Risk Level	Interpretation
30–35	Very High	Persistent tidal inundation, severe environmental degradation, and high socio-economic vulnerability
25–29	High	Frequent tidal flooding with significant impacts on housing and livelihoods
18–24	Moderate	Periodic flooding with manageable but increasing risks
< 18	Low	Limited tidal flooding and relatively stable environmental conditions

Source: *Adapted from Gornitz (1991); Abuodha & Woodroffe (2010); modified by authors, 2025*

Table 3. Summary of Tidal Flood Risk Levels by Study Village

Village	Subdistrict	Dominant Risk Level	Key Spatial Characteristics
Mororejo	Kaliwungu	Very High	Very low elevation, persistent inundation, tidal basin formation
Karangsari	Kendal	High	Mixed elevation, increasing inundation frequency, transitional risk profile
Kartika Jaya	Patebon	Very High	Very low elevation, fully exposed coastline, persistent inundation

Source: *Author, 2025*

The GEE-based analysis applied to Mororejo, Karangsari, and Kartika Jaya reveals that these three coastal settlements represent some of the most critical areas with respect to tidal flood vulnerability in Kendal Regency. The assessment integrates digital elevation models (DEM), tidal flood inundation frequency over a ten-year period (2014–2024), residential land-use coverage, and observed trends in coastal environmental change. This unified analytical

framework ensures methodological consistency across the three villages, enabling comparative interpretation of risk conditions.

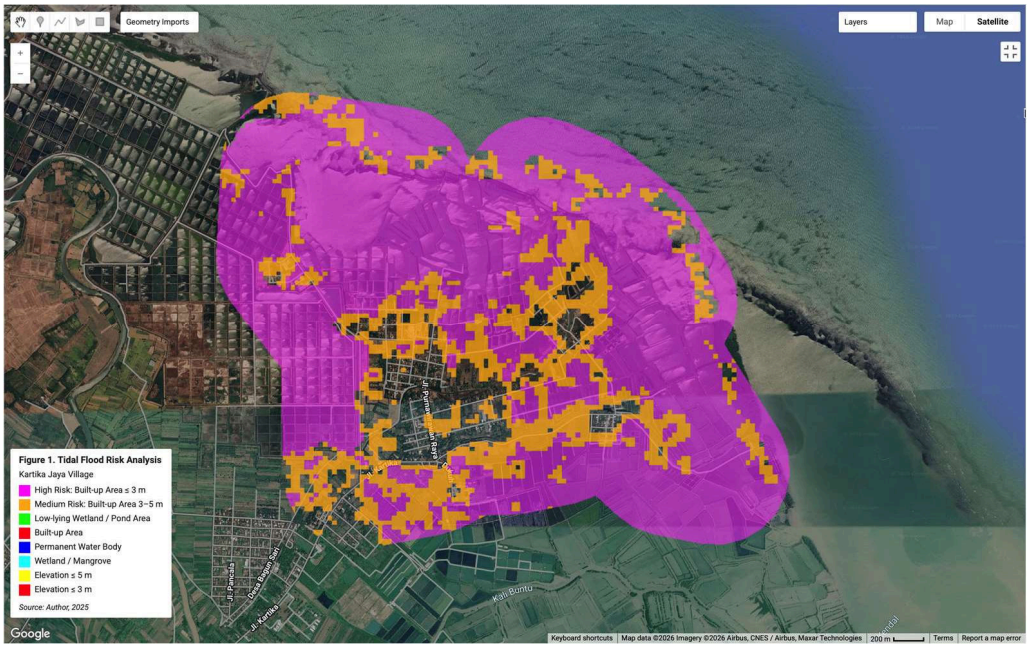


Figure 1. Spatial distribution of tidal flood-prone areas in Kartika Jaya Village based on elevation, land cover, built-up areas, wetlands, and surface water occurrence.
Source: *Author, 2025*

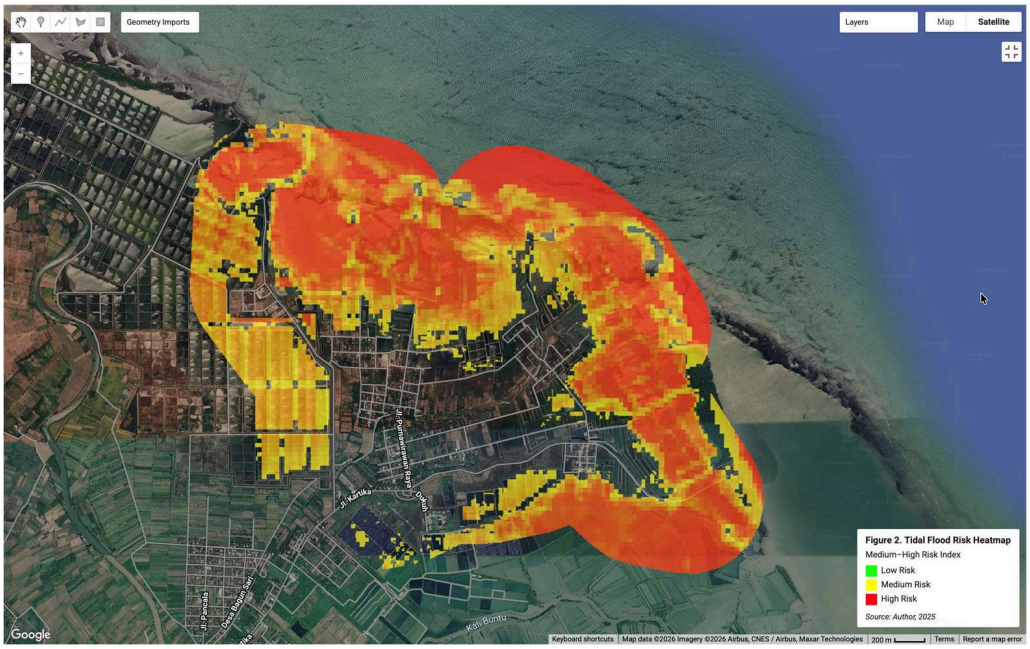


Figure 2. Medium–high tidal flood risk heatmap of Kartika Jaya Village generated from normalized elevation, water occurrence, and land-cover risk index.
Source: *Author, 2025*

Kartika Jaya Village is currently in a fully exposed coastline condition due to extensive loss of coastal vegetation and long-term mangrove conversion. Tidal wave energy is no longer attenuated by natural buffers, allowing tidal flooding to directly impact residential areas. GEE

heatmap analysis indicates that all housing units fall within high-risk zones. Community-led adaptation measures such as floor elevation have become increasingly ineffective as inundation depth and persistence have grown beyond adaptive thresholds. Impacts extend to critical infrastructure: village roads remain inundated throughout the year, household wells have become brackish to saline, septic systems are no longer functional, and aquaculture ponds

suffer repeated damage from saltwater intrusion. These cumulative conditions align with findings on prolonged coastal flooding's effect on long-term habitability (Wong et al., 2014). The physical evidence from Kartika Jaya suggests that the settlement has exceeded its adaptive threshold under current conditions; however, whether planned relocation is the appropriate response—and under what governance and financial arrangements it could be implemented requires further policy analysis beyond the scope of this study.

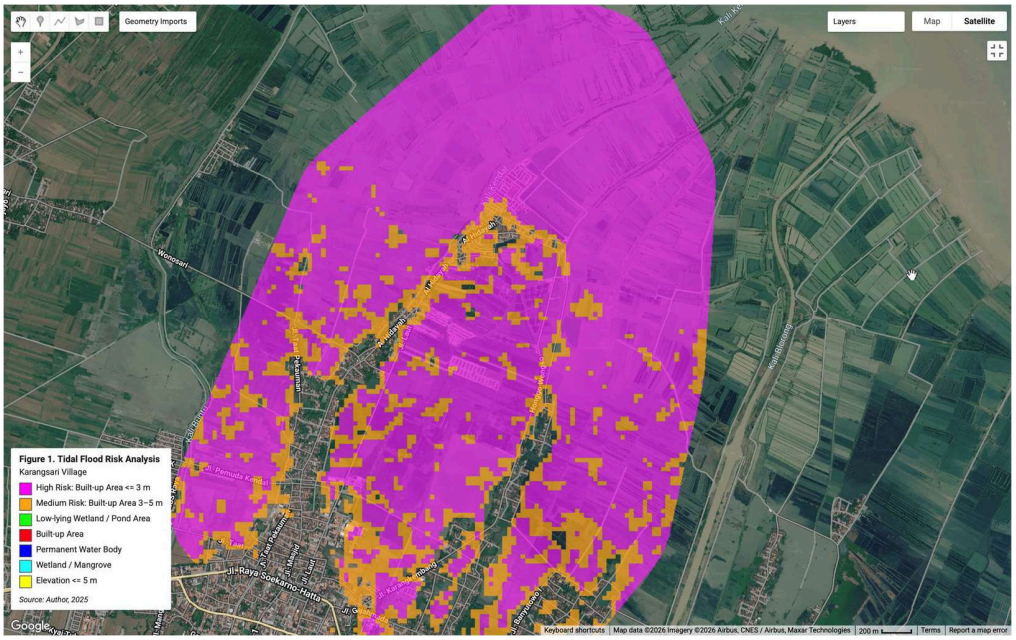


Figure 3. Spatial distribution of tidal flood-prone areas in Karangsari Village based on elevation, land cover, built-up areas, wetlands, and surface water occurrence.
Source: *Author, 2025*

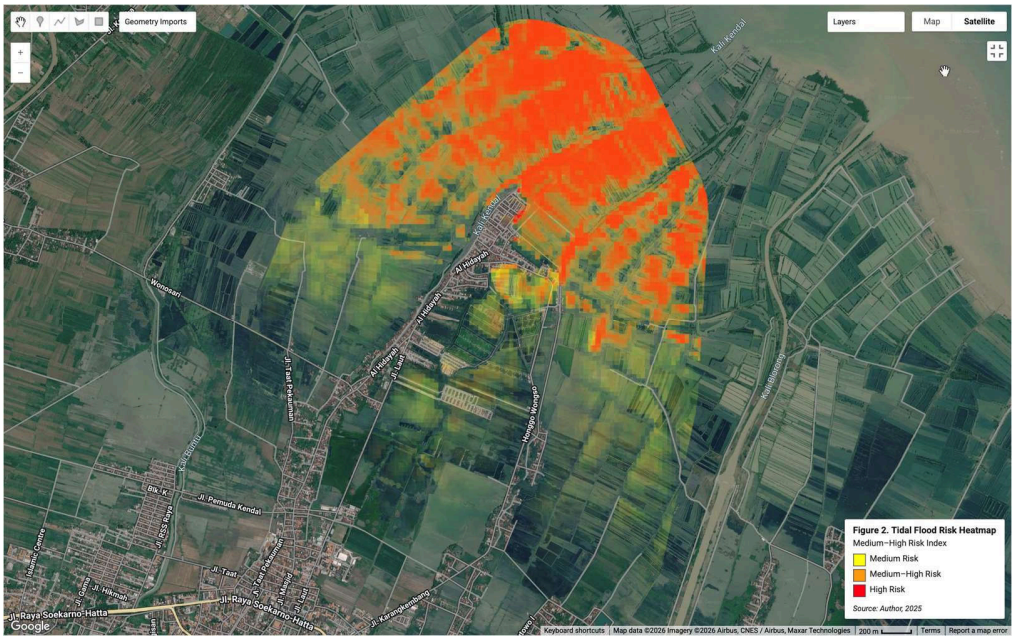


Figure 4. Medium–high tidal flood risk heatmap of Karangsari Village derived from normalized elevation, surface water occurrence, and land-cover risk index.
Source: *Author, 2025*

Karangsari Village exhibits a dynamic risk profile in which tidal flooding does not occur daily but has increased in frequency over time, indicating a gradual transition from episodic toward semi-permanent inundation. Residential areas extend from moderate-risk zones toward lowerrisk areas, with critical water supply and sanitation systems partly dependent on currently lowrisk zones. This spatial dependency creates instability in service provision when tidal flooding affects connecting infrastructure. Early signs of saline intrusion in household wells and repeated damage to aquaculture embankments are evident, collectively signaling emerging environmental and infrastructure stress.

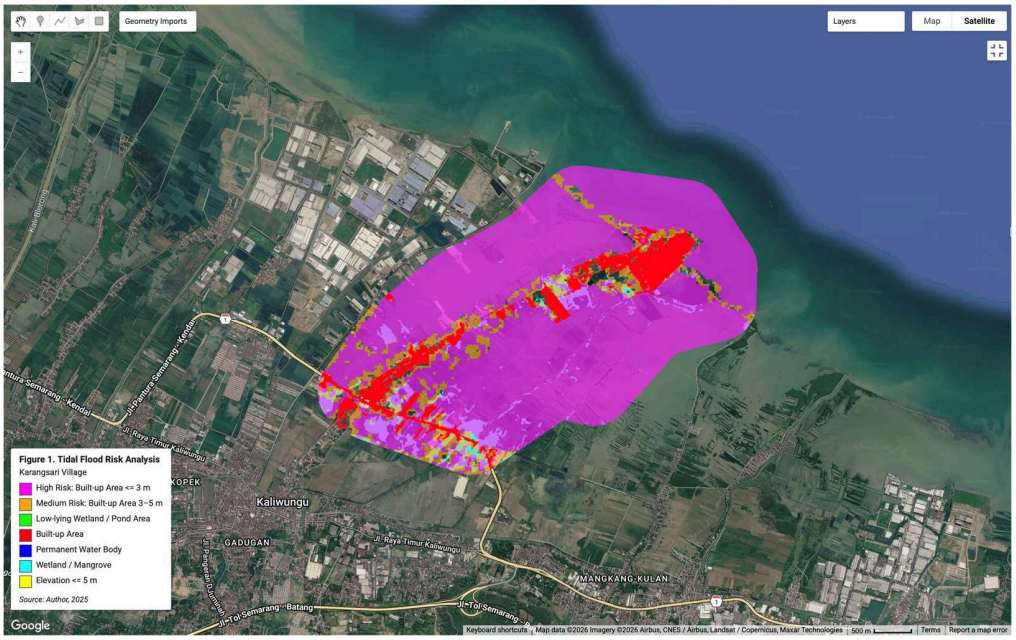


Figure 5. Spatial distribution of tidal flood-prone areas in Karangsari Village based on elevation, land cover, built-up areas, wetlands, and surface water occurrence.
Source: *Author, 2025*

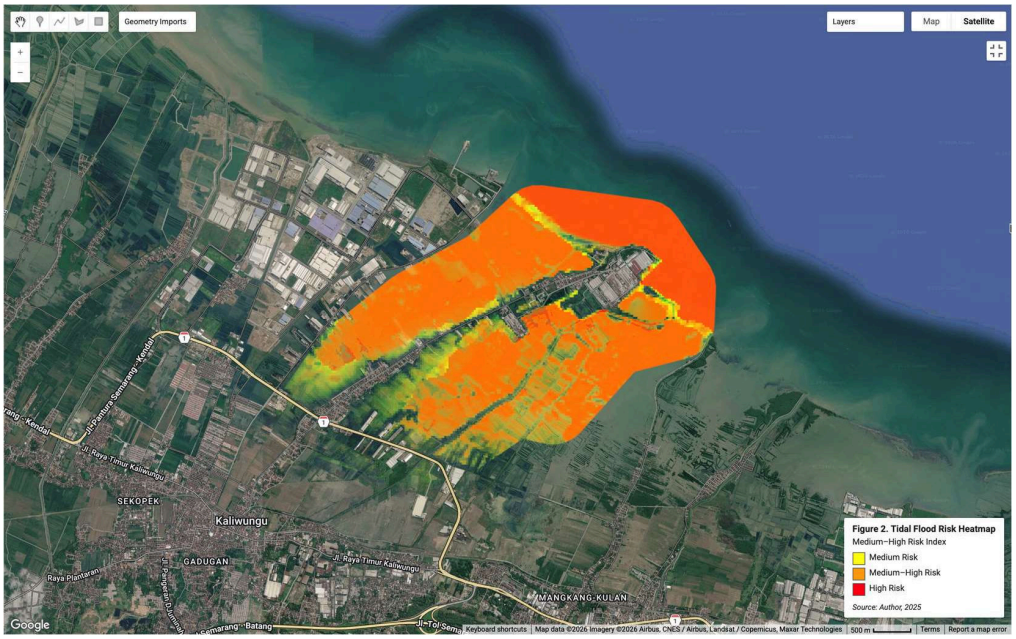


Figure 6. Medium–high tidal flood risk heatmap of Mororejo Village derived from normalized elevation, surface water occurrence, and land-cover risk index.
Source: *Author, 2025*

Mororejo Village has effectively transformed into a tidal flood basin, with nearly the entire village functioning as a persistent inundation zone. Loss of mangrove vegetation and conversion of aquaculture ponds have created open pathways for seawater to penetrate inland, while ongoing land subsidence has lowered surface elevations and prevented natural drainage. Spatial overlay between built-up areas and GEE risk heatmaps confirms that most settlements are located within high to very high risk zones. Evacuation routes toward southern areas

traverse moderate-risk zones, frequently disrupting transport during high-tide events. Household adaptations such as floor elevation have become increasingly ineffective. Severe environmental and infrastructure impacts including road inundation, septic system collapse, groundwater salinization, and aquaculture failure collectively indicate that Mororejo has entered a phase of progressive socio-environmental decline.

3.2 Coastal Vulnerability Index Assessment

The CVI analysis provides additional insight into how physical flood exposure translates into vulnerability at the settlement level. Areas with similar flood frequencies may exhibit different vulnerability levels depending on environmental sensitivity and spatial configuration. High vulnerability zones are characterized not only by frequent flooding but also by prolonged water retention, which exacerbates damage to housing structures and public infrastructure. The CVI therefore functions as a contextual mediating layer: it captures the broader environmental conditions that determine whether similar levels of physical exposure produce similar or divergent impacts across villages.

Kartika Jaya Village, with a CVI score of 34 out of 35, exhibits characteristics of a fully exposed coastline, consistent with the absence of natural buffers documented in the literature (Gornitz, 1991; Abuodha & Woodroffe, 2010). The combination of very low elevation, proximity to the shoreline, complete mangrove loss, and persistent inundation duration places it in the highest vulnerability category. Mororejo, with a CVI score of 35, scores highest across nearly all indicators, reflecting its transformation into a tidal basin with no effective natural or structural protection. Karangsari, with a score of 26, falls within the High category but its relatively better mangrove cover and shorter inundation duration suggest greater remaining adaptive capacity compared to the other two villages.

3.3 Household Socio-Economic Conditions and Impoverishment Risks

Household survey results indicate that tidal flooding has significant socio-economic implications for coastal residents. The majority of surveyed households depend on livelihoods closely tied to coastal environments, including fisheries, aquaculture, and small-scale trading (Table 5). Recurrent flooding disrupts income-generating activities, damages housing assets, and increases maintenance costs, progressively heightening vulnerability over time.

Table 5. Descriptive Statistics of Survey Respondents by Village

Variable	Kartika Jaya (n=50)	Mororejo (n=50)	Karangsari (n=50)	Total (n=150)
Mean household size (persons)	4.6	4.8	4.3	4.6
Households dependent on coastal livelihoods (%)	72	76	64	71
Home ownership (%)	68	70	74	71
Households experiencing flooding ≥ once/week (%)	82	86	48	72
Households reporting income disruption due to flooding (%)	78	80	56	71
Preference for collective relocation (%)	62	66	54	61

Source: *Author Survey, 2025*

Applying the IRR framework reveals five key risk dimensions that would be activated or intensified by relocation if not proactively managed (Table 6). The most prominent are livelihood disruption and social network fragmentation, both of which are closely tied to the coastal livelihoods and community structures that have developed over generations. Housing instability is already severe in Kartika Jaya and Mororejo, where recurrent damage has progressively reduced housing quality below functional thresholds. The risk of marginalization—where the poorest households with informal tenure arrangements may be excluded from formal relocation programs—is a particularly important concern that relocation program design must address explicitly.

Table 6. Key Impoverishment Risks Identified among Surveyed Households

IRR Dimension	Observed Risk Characteristics	Implication for Relocation Planning
Livelihood security	Disrupted income from aquaculture and coastal trade; reduced workdays	Relocation sites must maintain access to coastal or equivalent livelihood sources
Housing stability	Recurrent structural damage, declining habitability, progressive inundation	Replacement housing must meet minimum habitability standards above flood elevation
Social network cohesion	Risk of fragmentation under individual/dispersed relocation schemes	Collective relocation approach can preserve community-based mutual support systems
Access to basic services	Limited access to clean water, sanitation, and health services during prolonged inundation	Relocation sites must ensure adequate infrastructure provision from the outset
Marginalization risk	Households with low asset base and informal tenure may face exclusion from formal relocation programs	Targeted assistance and inclusive eligibility criteria are essential

Source: *Author Survey, 2025*



Figure 7. Physical Condition of Houses Affected by Tidal Flooding
Source: *Author Survey, 2025*

3.4 Community Relocation Preferences

The analysis of household relocation preferences reveals a strong and consistent inclination toward collective rather than individual relocation across all three villages (Table 7). More than 60 percent of surveyed households overall expressed a preference for relocating together with their community, with the highest share in Mororejo (66%) and the lowest in Karangsari (54%). This pattern is consistent with the gradient of tidal flood risk across villages: households facing more severe and persistent flooding are more inclined to support relocation, and they do so with a strong preference for collective rather than dispersed arrangements.

The preference for collective relocation reflects multiple overlapping motivations that go beyond simple risk aversion. From a livelihood perspective, collective relocation enables the maintenance of occupation-based social clusters fishing communities, for instance, need to remain near the sea and near each other to sustain crew-based fishing operations. From a social

capital perspective, community-based mutual support networks, which provide informal financial assistance, childcare, and disaster response, are functionally inseparable from geographic proximity. These networks are difficult if not impossible to reconstruct after dispersed relocation (Cernea, 2000; de Sherbinin et al., 2011). From a risk perception perspective, the preference for collectivity may also reflect distrust of individual household relocation as a process that exposes households to isolation and greater vulnerability during the transition period. This interpretation is supported by the strong preference for cash-based transitional assistance, which suggests households want flexibility to manage the transition on their own terms within a shared community framework.

The preference pattern also has important implications for relocation governance. Collective relocation is significantly more complex and resource-intensive than individual household resettlement, requiring coordinated land acquisition, infrastructure provision, and community consultation processes. The Indonesian regulatory and fiscal context for managed retreat at this scale remains underdeveloped, and the gap between expressed community preference and available government capacity to implement collective relocation represents a critical governance challenge that future research and policy development must address.

Table 7. Summary of Community Relocation Preferences

Relocation Option	General Preference Trend	Key Motivating Factors
Collective relocation	Predominant (>50% across all villages)	Preservation of social cohesion, shared livelihood access, mutual support networks
Individual relocation	Limited (<20%)	Concern over loss of community ties and economic interdependence
Cash-based transitional assistance	Strongly preferred	Flexibility in managing logistics, household expenses, and resettlement transition
In-kind assistance only	Less preferred	Perceived as less flexible for diverse household needs

Source: *Author Survey, 2025*

3.5 Linking Risk, Vulnerability, and Relocation Preferences

The integrated analysis demonstrates that community relocation preferences are shaped by the combined influence of tidal flood risk, coastal vulnerability, and socio-economic conditions, operating at different levels and through different mechanisms. Spatial risk assessments identify where flooding is most severe, but they do not fully explain why communities respond differently to similar levels of exposure. The CVI layer adds context by showing how environmental sensitivity captured through indicators such as mangrove loss, land subsidence, and inundation duration amplifies flood impacts in ways that go beyond inundation frequency alone. The IRR analysis then identifies the specific socio-economic risks that would be triggered by relocation, transforming the analysis from a hazard mapping exercise into a socially grounded assessment of adaptive options.

From a policy standpoint, the results suggest that relocation planning in tidal flood–prone coastal regions of Indonesia cannot be based on hazard indicators alone. Risk-informed

strategies must be complemented by mechanisms that address impoverishment risks, preserve social cohesion, and incorporate community preferences into program design. The findings also highlight the importance of distinguishing between villages at different stages of vulnerability progression: Kartika Jaya and Mororejo appear to have exceeded adaptive thresholds under current physical conditions, while Karangsari may still have a window for insitu risk reduction measures before conditions deteriorate to a similar level. This differentiation has direct implications for prioritization and resource allocation in coastal risk management.

It is important to note that this analysis identifies the need for adaptive interventions and documents community preferences for collective relocation, but does not prescribe relocation as the only or inevitable response. The social costs of relocation including potential impoverishment, community fragmentation, and loss of place identity are real and must be weighed carefully against the risks of continued exposure. Effective adaptation will require a governance framework that engages communities as active participants rather than subjects of technical decisions.

4. CONCLUSION

This study demonstrates that tidal flood risk and community relocation preferences in coastal Kendal are shaped by the interplay of physical exposure, environmental vulnerability, and socio-economic conditions rather than by hazard exposure alone. Three principal findings emerge. First, tidal flood risk varies substantially across the study villages, with Kartika Jaya and Mororejo classified as Very High risk (CVI scores 34 and 35) and Karangsari as High risk (CVI score 26), reflecting differences in elevation, mangrove cover, land subsidence, and inundation persistence. Second, a majority of affected households over 60 percent across all villages prefer collective relocation with cash-based transitional assistance, driven by concerns over livelihood continuity, social cohesion, and housing security. Third, the application of the IRR framework identifies five key impoverishment risk dimensions livelihood disruption, housing instability, social network fragmentation, service access reduction, and marginalization that must be explicitly addressed in relocation program design to prevent relocation from generating new forms of vulnerability.

The findings suggest that relocation policies in tidal flood–prone coastal areas cannot rely on physical risk indicators alone. Effective strategies must integrate spatial risk assessment with socio-economic analysis and community engagement to ensure that relocation is both technically justified and socially feasible. The strong preference for collective relocation implies that program designs must account for community-scale land acquisition, coordinated infrastructure provision, and mechanisms to preserve social and livelihood networks. Cashbased transitional assistance is a critical component of acceptable relocation programs, and its inclusion should be treated as a design standard rather than an optional element.

This study has several limitations. The household survey captures relocation preferences at a single point in time and within three specific coastal villages; both environmental conditions

and community attitudes continue to evolve. The sample of 50 households per village, while representative of risk strata, does not provide full statistical representativeness at the village population level. The CVI uses equal weighting across indicators, which may not fully reflect the relative importance of different vulnerability drivers in this specific context.

Regarding the GEE-based risk assessment, the use of JRC Global Surface Water as a proxy for tidal inundation frequency captures long-term surface water occurrence rather than tidal-specific flooding events, and may therefore underrepresent areas that experience frequent but brief tidal inundation not captured in the 30 m satellite record. The SRTM DEM, acquired in 2000, does not reflect current land subsidence, which is ongoing in the study area and may mean that current flood-prone areas are more extensive than the elevation data suggests. The ESA WorldCover 2020 land cover classification at 10 m resolution may misclassify mixed-use or transitional land cover common in small-scale coastal settlements. These data limitations should be considered when interpreting spatial risk outputs. Additionally, this study documents preferences and risks but does not evaluate the governance, legal, and fiscal feasibility of the relocation interventions implied by its findings.

Future research could extend this work by: (1) conducting longitudinal surveys to track how relocation preferences evolve as physical conditions change; (2) applying weighted CVI approaches through expert elicitation or sensitivity analysis to test index robustness; (3) comparing relocation preference patterns across different coastal contexts in Indonesia to improve the generalizability of findings; and (4) examining the governance, legal, and budgetary conditions under which collective relocation at the scale identified in this study could be practically implemented.

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