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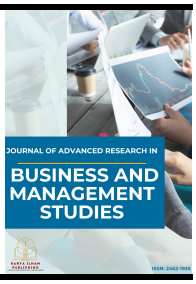

Spatially Uneven Coastal Risk in Port Dickson: Evidence from Shoreline Households

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ABSTRACT

This study develops a policy-facing, non-causal social profile of shoreline households in Port Dickson, Negeri Sembilan, by reading exposure, private recovery burden, perceived risk, public support, and stewardship behaviour together across three coastal spatial cells Lukut C1, Port Dickson Town C2, and Pasir Panjang C3. Using a household survey of 309 respondents and transparent comparative tables, we assess spatial heterogeneity and apply Pearson chi-square tests for key categorical outcomes. Results show marked within-district differences: C3 concentrates older and lower-income households, lower educational attainment, higher fishing dependence, and the highest reported hazard experience, especially storm surge and flooding. Repair and clean-up costs among affected households are often substantial and concern is widespread, with the highest high-concern share in C3. Support for shoreline protection is near-universal, and volunteering is high, with deepest engagement in the most exposed locality. Findings support vulnerability-sensitive coastal planning that prioritises high-burden hotspots while mobilising local stewardship capacity.

1. Introduction

Coastal shorelines are dynamic socio-ecological systems where recurrent hazards such as storm surge, flooding, and localized erosion translate into uneven risks for households living and working near the sea. For shoreline communities, hazard impacts are not limited to physical damage but are experienced as repeated disruptions, out-of-pocket recovery expenditures, and persistent concern about future events. Where livelihoods and daily routines depend directly on coastal space and resources, these pressures can also shape attitudes toward shoreline protection and motivate

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collective stewardship in the form of local participation, volunteering, and support for public interventions.

Coastal erosion is widely recognised as a critical environmental issue in Malaysia. National assessments report that about 1,347.6 km of shoreline is affected by erosion, roughly 15 percent of the national coastline, reflecting the combined influence of monsoon-driven hydrodynamics, climate-related sea level change, and human interventions that alter sediment supply and shoreline processes [13],[12]. In several coastal states, erosion can be rapid and economically consequential, placing settlements, tourism assets, and coastal infrastructure at risk and prompting the long-standing policy emphasis on both short-term protective works for critical areas and longer-term planning controls to reduce future exposure [14]. Beyond the immediate loss of land and property, erosion and related hazards can generate broader socio-economic disruption for coastal households and contribute to environmental degradation when protective ecosystems such as mangroves are compromised [14], [12].

Port Dickson in Negeri Sembilan provides a useful empirical setting to examine these coupled dimensions of coastal risk because settlement and livelihood contexts vary sharply across short distances along the same district coastline. Negeri Sembilan has a coastline length of 58 km, and shoreline monitoring linked to the National Coastal Erosion Study reports that 10.2 km, about 17.59 percent, was recorded as eroding in 2015, with sections classified as critical and medium in severity, underscoring the need to understand both the physical problem and its social implications for exposed communities [7]. Within Port Dickson, tourism-oriented waterfront development, long-established residential areas, and fishing-dependent settlements coexist, producing place-specific patterns of sensitivity, exposure, and expectations toward public action.

Against this background, this study examines shoreline households across three spatial cells along the Port Dickson coastline: Lukut as C1, Port Dickson Town as C2, and Pasir Panjang as C3. The objective is to document how household vulnerability and hazard experience are patterned across coastal space, and how these conditions relate to the lived dimensions of risk at household level, including private recovery burdens, perceived threat, and orientations toward shoreline protection and community stewardship. This emphasis responds to a practical policy need: shoreline management decisions depend not only on hazard diagnostics and engineering feasibility, but also on whether risks are socially concentrated, whether recovery costs are privately borne in ways that deepen vulnerability, and whether there is a credible local mandate and capacity to support resilience programmes through participation and shared responsibility [14], [13].

The remainder of the paper is structured as follows. The paper is structured as follows. Section 2 reviews literature. Section 3 explains the study's methodology and data. Section 4 presents the results and discussion. Section 5 concludes by summarising the main findings and contributions. Section 6 outlines policy implications and Section 7 discusses limitations and directions for future research.

2. Literature Review

2.1 Vulnerability and exposure

Coastal risk is widely framed as an interaction between hazard processes such as storm surge, coastal flooding, and shoreline change, exposure as the presence of people and assets in hazard-prone spaces, and vulnerability as the social and material conditions shaping sensitivity and the ability to prepare, respond, and recover [6]. This interaction produces spatially uneven impacts even within the same coastal district because shoreline morphology, settlement patterns, and socio-economic conditions vary across short distances, resulting in different risk configurations within a single

administrative boundary [6]. The IPCC AR6 framing for cities and settlements by the sea further emphasises that coastal risks are not determined by sea level rise or extremes alone, but mediated by development patterns and adaptation choices, and that the space for response depends on enabling conditions such as institutions, resources, and governance capacity [6]. This strengthens the case for household-facing evidence that can clarify how exposure and vulnerability are patterned within districts rather than assumed to be uniform [6].

At the empirical level, household vulnerability research often operationalises vulnerability through exposure, sensitivity, and adaptive capacity, and Malaysia-based work has applied this household-scale integrative approach in coastal settings [4]. In Selangor's west-coast evidence, distributions show how vulnerability can be concentrated through limited capacity rather than extreme exposure alone: about 96 per cent of households were classified as moderate exposure and 4 per cent as high exposure, sensitivity was reported as moderate for all households, and adaptive capacity was predominantly low with 76 per cent classified as low, 17 per cent moderate, and 7 per cent high [4]. This kind of household distribution is consistent with multi-hazard coastal environments where households experience more than one hazard type across time and where exposure varies sharply across short distances due to settlement layout and infrastructure placement [8], [6].

Malaysia-based coastal evidence also shows that awareness and perceived risk are socially patterned, reinforcing why within-district heterogeneity should be expected. Along the Pahang coast, household survey work with 498 households across 11 locations reports that awareness and adaptation strategy profiles vary by socio-economic characteristics, including higher mean awareness scores among older respondents, respondents with prior experience, those with higher education, those reporting better health, and those with stronger socio-economic status [8]. Taken together, these strands suggest that even within one district, some localities may concentrate older households, lower-income households, livelihood dependence on climate-sensitive activities, or less robust housing types, and that risk intensifies when such characteristics overlap with higher exposure, aligning with the IPCC emphasis that outcomes depend on how exposure and vulnerability are configured in place and on whether enabling measures exist [6].

2.2 *Private burden and responsibility*

A second major strand concerns what happens after exposure, particularly how recovery and adaptation costs are distributed between households and the public sector. Coastal hazards generate direct damage to housing and contents, indirect losses through disrupted work, transport, and schooling, and time-intensive recovery tasks such as clean-up and temporary repairs, and recovery research shows these burdens can be unevenly distributed and not always mitigated by assistance mechanisms in equitable ways [2]. Policy analyses similarly emphasise that many disaster costs manifest as household-level repairs, replacement of damaged property, relocation expenses, and lost income, meaning the private burden is a key pathway through which hazards translate into longer-term welfare impacts, especially where households have limited buffers [10].

A policy-economics perspective also argues that risk reduction spending can reduce future losses but raises persistent questions about who pays upfront and how costs are distributed. A widely cited public finance benchmark from the United States reports average flood damages of around 46 billion US dollars per year over the past decade in 2023 dollars and estimates that future damages could be reduced by about 2 to 3 dollars for every 1 dollar spent on flood adaptations, highlighting that private burden and public investment are linked through both welfare and fiscal channels [3]. While figures differ across countries, the broader implication remains relevant for equity-sensitive

coastal planning: repeated household out-of-pocket burdens can compound vulnerability when cost responsibilities drift toward households least able to absorb them, consistent with climate-resilient development concerns highlighted in the IPCC synthesis [6].

Malaysia's west-coast household evidence also positions private burden alongside perception and participation as practical drivers of adaptation preferences. Survey findings report that 66.9 per cent of households expressed willingness to pay for planned adaptation measures, with willingness aligning with exposure, awareness, risk perception, and community participation indicators, implying that household coping capacity and perceived fairness or feasibility shape support for planned interventions [5]. For shoreline household studies, these insights justify treating repair costs not only as monetary outcomes but also as indicators of exposure intensity, dwelling condition, and the ability to mobilise funds or external support, motivating transparent descriptive reporting even when inferential power is limited for affected subsamples.

2.3 *Stewardship and support*

A third strand focuses on collective response through public support for protective measures and stewardship behaviours such as volunteering, monitoring, and participation in clean-ups and conservation activities. This matters because adaptation implementation depends on social legitimacy and local capacity, not only on technical design, and the IPCC framing emphasises that response choices and enabling conditions are key determinants of viable adaptation pathways [6].

Environmental stewardship research shows that volunteering can be structured, multi-scalar, and connected to broader civic ecology functions. A content analysis of 50 groups involved in volunteer beach clean-ups reports coordination across five geographic scales from local to global and documents that many groups conduct additional stewardship activities beyond clean-ups, including education, advocacy, research, and monitoring, indicating that volunteering can build durable engagement infrastructures rather than one-off actions [9]. Regional syntheses in Southeast Asia similarly stress that sustained clean-up initiatives, community participation, and structured approaches including marine citizen science can strengthen marine debris management and public education outcomes [16].

Empirical work also demonstrates that willingness to participate can be measured as an outcome shaped by resilience attributes and engagement design. In Bali, Indonesia, evidence based on 647 valid survey samples examines how community resilience dimensions relate to willingness to participate in beach clean-up initiatives under different engagement conditions, reinforcing the idea that stewardship potential is not uniform across communities [17]. In ecosystem-based protection, household evidence from the Mahakam Delta reports that over 80 per cent of respondents perceived mangrove benefits as essential to livelihoods and presents cost-benefit estimates based on willingness-to-pay values, including an estimated cost-benefit ratio of about 2.34 under a five-year project life assumption, supporting the view that livelihood-linked ecosystem measures can generate both protective and welfare-relevant rationales for support [18].

On the support side, the literature consistently highlights that preferences for protective measures depend on perceived exposure, trust, and perceived fairness, and that perceptions can diverge from technical risk models. In the Philippines, survey evidence from 1,093 households finds that more than half of households located within modelled inundation zones either did not know their exposure or believed they were not exposed to storm surge heights of 2 metres and above, showing a substantial perception-model gap for larger events and reinforcing the need to treat concern, support, and stewardship as empirically meaningful dimensions for policy design [15]. Malaysia-based research likewise emphasises that public perception, preparedness, and capacity are

linked in policy-relevant ways, including evidence from Greater Kuala Lumpur reporting adaptive capacity at a mean of 3.97 with a standard deviation of 0.64 and highlighting positive relationships between risk perception, preparedness, and adaptive capacity, supporting people-centred resilience interventions [11]. Complementary governance-focused evidence from Malaysia also highlights participation conditions, including work based on 20 in-depth stakeholder interviews that foreground public participation and implementation challenges for community-based mitigation [1].

For shoreline household research, these insights together suggest a practical conceptual sequence in which households experience hazards through exposure, manage immediate recovery through private resources and coping, develop forward-looking concerns about future events, and then express preferences for protective measures while participating in collective action through volunteering and stewardship. The literature does not require these elements to align perfectly across contexts, but it provides a coherent basis for organising descriptive empirical reporting around exposure, private burden, perceived concern, support, and stewardship potential, and for reading spatial differences as evidence of heterogeneity in risk experience and readiness without making causal claims.

3. Methodology

3.1 Study Design and Analytic Stance

This paper adopts a descriptive, policy-facing approach to document how shoreline household conditions vary within a single coastal district. The analysis is intentionally non-causal and is designed to support planning-oriented interpretation rather than model-based prediction. Results are presented as transparent place-based co-variation across spatial cells, using comparative descriptive tables and Pearson chi-square tests for selected categorical outcomes. The organising sequence guiding reporting follows exposure and hazard experience, private burden of recovery, perceived concern about future events, and orientations toward support and stewardship.

3.2 Study Setting, Spatial Cells, and Sample

The study was conducted in Port Dickson, Negeri Sembilan, Malaysia, a west-coast district where shoreline households face recurrent coastal hazards and shoreline change pressures. The target population comprised shoreline households located near the coast and routinely interacting with shoreline conditions through residence, daily routines, or livelihoods. To make within-district spatial heterogeneity visible, survey locations were grouped into three shoreline cells reflecting settlement clustering and coastline context. A structured household survey was administered to 309 respondents across the three spatial cells. Cell C1 represents Lukut with 108 respondents, Cell C2 represents Port Dickson Town with 111 respondents, and Cell C3 represents Pasir Panjang with 90 respondents. The cell-based structure functions as the central comparative lens, enabling interpretation across places that share the same district-level governance while potentially differing in exposure, household resources, and readiness. The sample is treated as an empirical social profile of the surveyed shoreline households in the selected cells, suitable for transparent descriptive comparison and association testing, but not used to make causal or predictive claims.

3.3 Survey Instrument, Data Collection, and Operational Definitions

Data were collected through a structured household questionnaire administered to shoreline residents across the three spatial cells. The instrument was designed for policy-facing readability and

comparative analysis across place, using predominantly closed-ended response options recorded in categorical formats suitable for frequency tabulation and chi-square testing. Items captured socio-demographic context and a set of constructs used to organise reporting in a transparent, non-causal way. Exposure refers to household-reported experience of coastal hazards and shoreline impacts. Private burden refers to household-reported recovery demands, captured primarily through repair and recovery cost categories and related disruption indicators. Perceived risk refers to forward-looking concern about future shoreline events. Support refers to household preferences for protective measures and planned interventions. Stewardship refers to willingness to participate in collective actions such as volunteering or shoreline-related community activities. These constructs guide how results are tabulated and discussed by spatial cell without implying causal direction.

3.4 Statistical Analysis

Analysis proceeds in two steps. First, descriptive analysis presents frequency and percentage distributions by spatial cell for each indicator, forming the core evidence base for place-based comparison. Second, Pearson chi-square tests are used to assess whether selected categorical outcomes differ across spatial cells. The chi-square results are interpreted as associations rather than causal effects and are used to highlight outcomes where spatial variation is statistically distinguishable within the sample. Where useful, effect size can be reported using Cramér's V to indicate the strength of association alongside statistical significance. Interpretation emphasises pattern consistency and practical relevance, especially for outcomes measured on affected subsamples such as repair costs, where smaller bases can reduce statistical power.

4. Results and Discussions

4.1 Household Characteristics and Coastal Hazard Exposure (Results & Discussion with Linked Literature)

Table 1 summarises the demographic profile and recent coastal hazard exposure of shoreline households across the three spatial cells. A clear spatial gradient is evident, reinforcing the literature's core point that coastal risk is configured through the place-specific interaction of hazard processes, exposure, and socially patterned vulnerability—so outcomes can vary sharply even within a single district [6]. In Port Dickson, Pasir Panjang (C3) concentrates multiple vulnerability markers: older households (≥55 years) are highest in C3 (18.8%) relative to C1 (8.3%) and C2 (10.8%), low-income households (<RM2,000/month) are also highest in C3 (56.7%), and fishing as a primary livelihood is substantially more common in C3 (16.7%) than in C1–C2 (0.0–1.8%). Post-secondary education shows the reverse gradient, with C3 lowest (25.6%) compared to C1 (54.6%) and C2 (50.5%). This co-location of age, income constraints, livelihood dependence, and lower education is consistent with household-scale vulnerability evidence emphasising that sensitivity and adaptive capacity often cluster spatially rather than being evenly distributed [4], [6].

These socio-economic contrasts align with pronounced disparities in recent hazard experience. More than half of C3 households (55.6%) report experiencing at least one coastal hazard in the past two years, compared with 38.7% in C2 and 25.0% in C1. Storm surge is the dominant reported hazard across the cells and is particularly elevated in C3 (45.6%), while flooding is also higher in C3 (25.6%) than in C1–C2 (11.1–12.6%). This pattern is consistent with the multi-hazard framing in the literature, where households in coastal environments encounter more than one hazard type

across time and where local settlement and infrastructure placement can generate sharp within-district exposure differences [8], [6]). It also aligns with Malaysia-based evidence that hazard awareness and adaptation profiles vary by socio-economic characteristics and experience, implying that high-exposure localities may also display systematically different risk perceptions and response capacities [8].

Reported coastal erosion remains low in all three cells (2.8–7.2%) relative to storm surge and flooding. This should not be read as evidence that shoreline change is unimportant; rather, it may reflect differences in hazard salience and how households classify "events" in survey recall, where episodic surge and flood disruptions are more readily reported than gradual shoreline processes. This measurement caution reinforces why descriptive, household-facing evidence is valuable for policy: it clarifies how risk is experienced and reported, not only how it is modelled technically [6].

Overall, Table 1 indicates a strong spatial overlap between social vulnerability and hazard experience: Pasir Panjang (C3) combines lower socio-economic buffers and higher livelihood sensitivity with the highest reported storm surge and flooding exposure. This is the type of within-district heterogeneity anticipated in the IPCC framing, where risk outcomes depend on how exposure and vulnerability are configured in place and on enabling conditions for response [6]. The next sections therefore examine whether this same cell also shows higher private recovery burdens and stronger expressed demand for support and stewardship engagement—domains that the literature identifies as central to equity-sensitive coastal planning and community-based mitigation [2], [10], [1], [6].

Table 1
Household characteristics and coastal hazard exposure by spatial cell (%)
Cells: C1 Lukut (n=108), C2 Port Dickson (n=111), C3 Pasir Panjang (n=90)

	C1: Lukut	C2: Port Dickson	C3: Pasir Panjang
Older households (≥55 years)	8.3	10.8	18.8
Low-income households (<RM2,000/month)	46.3	51.3	56.7
Fishing as primary livelihood	0.0	1.8	16.7
Post-secondary education	54.6	50.5	25.6
Experienced any coastal hazard (past 2 years)	25.0	38.7	55.6
of which: Coastal erosion (%)	2.8	7.2	4.4
of which: Storm surge (%)	17.6	24.3	45.6
of which: Flooding (%)	11.1	12.6	25.6

Note: *Hazard categories are not mutually exclusive; households may report more than one hazard.*

4.2 Private Repair Costs and Concern About Future Coastal Hazards

Table 2 reports the distribution of out-of-pocket repair and clean-up costs following recent coastal hazard events (Panel A), together with households' concern about future coastal risks over the next five years (Panel B). Read together, the results extend the spatial vulnerability pattern in Table 1 by showing how hazard experience translates into a substantial private burden and heightened forward-looking concern—two domains the literature identifies as central to equity-sensitive coastal planning [2], [10], [6].

Private repair burden (Panel A). Among households that reported experiencing at least one coastal hazard in the past two years, repair and clean-up costs are widespread and often substantial. Pasir Panjang (C3) shows the heaviest burden at mid-to-high cost levels: 44.0% of affected households report spending RM2,000–4,999 on their most recent event, and a further 14.0% report ≥RM5,000. This pattern is particularly consequential given C3's higher concentration of low-income households, implying a greater likelihood that recovery costs must be absorbed with limited financial

buffers. Port Dickson Town (C2) also exhibits a pronounced high-cost tail, with 23.3% of affected households reporting ≥RM5,000—consistent with the possibility that urban beachfront assets and housing values increase repair outlays when events occur, even if overall exposure is lower than in C3. Lukut (C1) reports comparatively lower costs, with 40.7% of affected households spending <RM500, aligning with its lower hazard incidence in Table 1.

Concern about future hazards (Panel B). Concern levels are high across all cells, and are most intense where recent exposure is greatest. In Pasir Panjang (C3), 88.9% of households report being worried or extremely worried, including 60.0% who are extremely worried. Port Dickson Town (C2) also shows elevated concern, with 63.9% worried or extremely worried. Even in Lukut (C1), where recent hazard experience is comparatively lower, half of households (50.0%) report being worried or extremely worried, indicating that perceived risk may extend beyond direct recent experience and can diffuse through shared coastal narratives, visible shoreline change, and anticipation of future events. This reinforces the literature's emphasis that risk and response are mediated by social and institutional conditions, not hazard metrics alone (Glavovic *et al.* [6]), and is consistent with Malaysia-based evidence that awareness and perceived risk vary by socio-economic characteristics and experience [8].

Overall, Table 2 highlights a dual household burden: direct private expenditures for repairs and clean-up, and sustained concern about future hazards. The pattern is most acute in Pasir Panjang, where higher exposure and higher concern coincide with weaker socio-economic buffers. This aligns with policy-facing work showing that disaster impacts materialise as household-level repair and recovery burdens that can compound vulnerability when repeated and insufficiently offset by support mechanisms [2], [10]. In a non-causal but planning-relevant sense, the findings strengthen the local economic case for proactive coastal protection and targeted assistance—particularly in high-exposure, lower-income shoreline communities—because reducing event frequency and severity would directly reduce avoidable household losses and stress [6]

Table 2
Private repair costs and concern about future coastal hazards by spatial cell

Panel A. Reported repair and clean-up costs among affected households
(experienced ≥1 coastal hazard in past 2 years; C1 n=27; C2 n=43; C3 n=50)

Repair / clean-up cost (RM)	C1: Lukut	C2: Port Dickson	C3: Pasir Panjang
< RM500	40.7	32.6	28.0
RM500–1,999	33.3	27.9	14.0
RM2,000–4,999	22.2	18.6	44.0
≥ RM5,000	3.7	23.3	14.0

Panel B. Household concern about future coastal hazards (next 5 years)
(within-cell percentages; C1 n=108; C2 n=111; C3 n=90)

Level of concern	C1: Lukut	C2: Port Dickson	C3: Pasir Panjang
Not worried	5.6	9.0	3.3
Somewhat worried	31.5	27.0	11.1
Neutral	13.0	17.1	7.8
Worried	33.3	36.9	28.9
Extremely worried	16.7	27.0	60.0

Notes: *Values are percentages (%). Panel A percentages are calculated* ***among affected households*** *only (defined as reporting ≥1 coastal hazard experience in the past two years; affected counts derived from Table 1). Panel B percentages are calculated* ***within each spatial cell****. Cells correspond to Lukut (C1), Port Dickson Town (C2), and Pasir Panjang (C3).*

4.3 From Private Losses and Risk Concern to Public Support

Tables 2 and Table 3 below show a coherent spatial pattern linking lived hazard experience, private recovery burden, forward-looking concern, and public support for shoreline protection. Consistent with the IPCC framing that risk outcomes and response choices are shaped by how exposure and vulnerability are configured in place [6], cells with higher reported hazard experience and greater concern also express stronger support for protective intervention.

In Pasir Panjang (C3), where Table 2 indicates the highest concentration of mid-to-high repair costs among affected households and the most intense concern about future hazards, support for shoreline protection is near-universal. Almost all households report supporting or strongly supporting protection measures (98.9%), and the dominant response is **strong support** (67.8%). This alignment suggests that concern is grounded in lived experience and tangible household consequences rather than abstract risk perceptions, matching evidence that support for protective measures often rises with perceived exposure and the salience of losses [6], [15].

Port Dickson Town (C2) shows similarly high support but with a more moderate intensity profile: most households support shoreline protection (64.0%), while a smaller share strongly support it (21.6%), and a non-trivial neutral group remains (12.6%). This distribution implies broad legitimacy for protection measures, though with less urgency than C3. The pattern is compatible with governance-oriented findings that support and participation can vary across communities depending on perceived immediacy, perceived fairness, and implementation conditions [1], even when general concern remains elevated.

In Lukut (C1), the least exposed cell in Table 1 and the lowest-cost profile in Table 2 Panel A, support remains the majority position (65.7% support or strongly support), but neutrality is noticeably higher (27.8%) and outright non-support is observed only here (4.6%). This reinforces the descriptive logic that the social mandate for intervention tends to be strongest where households have already experienced losses and anticipate future disruption—consistent with the broader literature that private burden is a key pathway through which hazards translate into welfare impacts and policy preferences [2], [10].

Overall, Table 3 indicates that public support for shoreline protection is not evenly distributed across the district, but closely tracks the geography of exposure, private repair burden, and future concern. For policy-facing coastal planning, this provides a clear legitimacy signal: the areas bearing the greatest household-level costs and stress also express the strongest demand for protection, aligning with people-centred adaptation framing and the enabling-conditions emphasis in coastal risk governance [6].

Table3

Public support for shoreline protection by spatial cell (%)

Cells: C1 Lukut (n=108), C2 Port Dickson Town (n=111), C3 Pasir Panjang (n=90).

Level of support (Likert 1–5)	C1: Lukut	C2: Port Dickson	C3: Pasir Panjang
1 – Do not support	4.6	0.0	0.0
2 – Somewhat support	1.9	1.8	1.1
3 – Neutral	27.8	12.6	0.0
4 – Support	47.2	64.0	31.1
5 – Strongly support	18.5	21.6	67.8

4.4 Volunteering and Community Stewardship Behaviour

Table 4 reports household participation in coastal volunteering and the intensity of engagement measured by monthly volunteer hours. Overall, stewardship is high across the district, but the depth of participation varies clearly by spatial cell. This matter because the literature emphasises that adaptation implementation depends not only on technical design but also on local legitimacy and the practical capacity for sustained community action [6], and that volunteering can function as a durable engagement infrastructure rather than a one-off activity [9], [16].

Participation (Panel A). Most households report some involvement in coastal activities, with participation highest in Pasir Panjang (C3) at 93.3% and Port Dickson Town (C2) at 91.0%. Lukut (C1) remains majority-participating (80.6%), but has the highest non-participation share (19.4%). The near-universal participation in C2–C3 suggests that volunteering is normalised as a community practice in the more coastal-facing localities.

Intensity (Panel B). Spatial differences are stronger when engagement intensity is considered. In Pasir Panjang, volunteering is not only widespread but sustained: 68.8% of households report contributing three or more hours per month (3–5 hours: 34.4%; >5 hours: 34.4%). In C2, participation is high but more moderate in intensity, with the largest share contributing 1–2 hours per month (34.2%) and a smaller high-intensity segment (>5 hours: 14.4%). Lukut shows a more uneven profile, with a larger zero-hours group (19.4%) and a smaller middle-intensity segment (3–5 hours: 16.7%). These distributions are consistent with evidence that willingness to participate and sustained engagement can vary across communities, reflecting differences in resilience attributes, local organisation, and engagement conditions rather than a uniform “environmental attitude” [17].

Read alongside Tables 1–2, the stewardship pattern aligns with the broader descriptive sequence motivating this paper: cells with higher hazard exposure, higher private repair burden among affected households, and stronger forward-looking concern also show stronger and deeper volunteering engagement. Importantly, the Pasir Panjang profile suggests that high exposure does not necessarily map to disengagement; instead, where risk and livelihood dependence are concentrated, stewardship may be more embedded as a practical response capacity. This resonates with the stewardship literature showing that coastal volunteering often extends beyond clean-ups to include monitoring, education, and other civic ecology functions that can support longer-term management [9], [16]. For policy-facing shoreline planning, Table 4 therefore indicates that high-exposure communities may also represent high-engagement partners for locally grounded protection and maintenance efforts, reinforcing the IPCC emphasis on enabling conditions and community capacity in viable adaptation pathways [6].

Table 4
Household participation in coastal volunteering by spatial cell (%)
Cells: C1 Lukut (n=108), C2 Port Dickson Town (n=111), C3 Pasir Panjang (n=90).

Panel A. Participation in coastal volunteering

Volunteering participation	**C1: Lukut**	**C2: Port Dickson**	**C3: Pasir Panjang**
No volunteering	19.4	9.0	6.7
Any volunteering	80.6	91.0	93.3

Panel B. Monthly volunteering hours for coastal activities

Volunteering hours per month	**C1: Lukut**	**C2: Port Dickson**	**C3: Pasir Panjang**
0 hours	19.4	9.0	6.7

<1 hour	11.1	21.6	7.8
1–2 hours	29.6	34.2	16.7
3–5 hours	16.7	20.7	34.4
>5 hours	23.1	14.4	34.4

Notes: Volunteering refers to unpaid participation in coastal activities such as beach clean-ups, mangrove planting, monitoring, or environmental awareness programmes. Percentages are calculated within each spatial cell.

4.5 Chi-square Results

Pearson chi-square tests showed in Table 5 indicate that key outcomes vary across spatial cells. The distribution of any coastal hazard experience differs significantly by place ($p < 0.001$), confirming the descriptive gradient in Table 1 where Pasir Panjang (C3) records the highest exposure (50/90; 55.6%), followed by Port Dickson Town (C2) (43/111; 38.7%), and Lukut (C1) the lowest (27/108; 25.0%). This reinforces the central descriptive claim of within-district heterogeneity in shoreline risk experience.

Concern paragraph. Spatial differences are also statistically significant for high concern about future hazards ($p < 0.001$; Table 5). High concern is most concentrated in Pasir Panjang (C3), where worried/extremely worried responses dominate, followed by Port Dickson Town (C2), with Lukut (C1) showing the largest neutral or lower-concern share. In descriptive terms, perceived risk is patterned geographically in a way that aligns with the exposure gradient, supporting the paper's organising sequence linking recent hazard experience to forward-looking concern.

Repair cost paragraph. In contrast, the distribution of repair and clean-up cost categories among affected households does not differ significantly across cells at conventional thresholds ($p = 0.12$; Table 5), despite an apparent descriptive gradient in Table 2 Panel A (e.g., higher-cost categories appearing more frequently in C3 and a high-cost tail in C2). This non-significant result likely reflects within-cell variability in damage severity and repair decisions, alongside the smaller affected subsample used for Panel A analysis, which reduces statistical power. The pattern therefore remains descriptively meaningful for policy discussion but should not be interpreted as evidence of systematic cost differences across cells.

Table 5
Spatial differences across key outcomes (Pearson chi-square tests)

Outcome (by spatial cell)	Test	p-value
Any coastal hazard experience (past 2 years; 0/1)	Pearson χ^2	<0.001
High concern about future hazards (worried/extremely worried vs others)	Pearson χ^2	<0.001
Repair/clean-up cost category among affected households	Pearson χ^2	0.12

Notes: *P-values compare distributions across C1 (Lukut), C2 (Port Dickson Town), and C3 (Pasir Panjang).* ***High concern*** *is defined as* ***worried or extremely worried*** *(Likert 4–5). Repair/clean-up costs are analysed* ***among affected households only****.*

5. Conclusion

This paper set out to provide a policy-facing, non-causal social profile of shoreline households in Port Dickson by reading exposure, private burden, perceived risk, public support, and stewardship behaviour together across three spatial cells. The descriptive results show clear within-district heterogeneity. Pasir Panjang C3 concentrates multiple vulnerability markers, including older households, lower incomes, lower educational attainment, and higher livelihood dependence on fishing. At the same time, it records the highest reported hazard experience, particularly storm surge

and flooding. Port Dickson Town C2 occupies an intermediate position. Lukut C1 shows comparatively stronger socio-economic buffers and lower reported hazard exposure.

Across cells, coastal hazards translate into meaningful household-level consequences. Among affected households, repair and clean-up expenditures are often substantial. Concern about future hazards is widespread and is most intense in C3. Public support for shoreline protection is strong across the district. Support is near-universal, and the dominant response in C3 is strongly support. Volunteering and coastal stewardship are also high overall. Participation is highest and engagement is deepest in the most exposed locality. Chi-square tests confirm significant spatial differences in hazard experience and high concern. Differences in repair-cost category distributions are not statistically significant, likely because of within-cell variability and the smaller affected subsample.
Taken together, the findings indicate that shoreline risk in Port Dickson is not uniform. The places carrying the greatest exposure and social vulnerability also report the strongest concern, the strongest mandate for protection, and the highest stewardship engagement. This integrated descriptive picture supports vulnerability-sensitive coastal planning by clarifying where household burdens are greatest and where community capacity for participation is strongest.

6. Policy implications

6.1 Targeted, Vulnerability-Sensitive Protection Prioritisation

The spatial concentration of exposure and socio-economic vulnerability in Pasir Panjang implies that equal investment across the coastline may not be equitable. Planning should prioritise high-exposure, lower-buffer areas for protective actions and maintenance because these communities face the largest combined burden. That combined burden reflects hazard experience, private recovery costs, and high concern. A practical approach is to treat C3 as a priority zone for near-term risk reduction. At the same time, planning should maintain proportional, preventive measures in C2 and C1 to avoid risk transfer and future escalation.

6.2 Reduce Household Private Burden Through Clear Support Channels

Repair and clean-up costs among affected households demonstrate that a meaningful share of disaster impacts occurs as out-of-pocket household expenditure. Policy can reduce welfare losses by improving the accessibility and timeliness of support mechanisms after events. Policy can also lower the cost of prevention before events. Options include standardised post-event assistance pathways that are easy to understand at household level. Options also include targeted support for lower-income households facing repeated events. A third option is prevention-oriented subsidies or co-financing for household-level protective improvements, such as flood-proofing, drainage improvements, and elevation of key household assets, where appropriate. Even when large-scale engineering is planned, bridging support that reduces repeated small-to-medium household losses can mitigate vulnerability accumulation.

6.3 Align Protection Communication with Lived Hazard Experience

Concern is high across the district and is especially intense in C3. This suggests that risk communication should be designed around the hazards people actually report, especially storm surge and flooding, and the practical disruptions they experience, including clean-up, repairs, and access interruptions. Communication that connects protective measures to expected household-level benefits will likely be more credible than abstract messages about long-run change. Those benefits

include reduced damage frequency, reduced clean-up time, and reduced repair spending. Importantly, risk communication should acknowledge uncertainty and avoid overpromising, because trust affects support and participation in implementation.

6.4 Use Existing Stewardship Capacity as an Implementation Asset

Volunteering participation is high, and the deepest engagement is concentrated in the most exposed community. Rather than treating volunteering as symbolic, agencies can formalise and support community stewardship as part of shoreline management. This can be done by establishing regular, predictable programmes such as clean-ups, monitoring days, and reporting channels. It can also be done by providing basic resources, including equipment, safety guidance, and structured roles. A third step is to link community activities to municipal maintenance schedules and reporting systems. Where community capacity is strongest, co-design and citizen monitoring can improve maintenance and enable earlier identification of shoreline stressors.

6.5 Keep Cross-Cell Coordination to Avoid Adaptation Gaps

Although C3 emerges as the priority hotspot, C2 and C1 still show substantial concern and meaningful exposure. Policies should therefore combine prioritised investment in hotspots with district-wide coordination. This approach helps ensure that protective actions in one area do not shift erosion or flooding pressures to adjacent stretches. It also helps ensure that inland-adjacent households in C2 are not excluded from preparedness and information channels. A district shoreline plan that explicitly recognises cell differences while maintaining shared standards for protection, response, and participation can reduce uneven outcomes.

7. Limitations

7.1 Cross-Sectional Design and Non-Causal Interpretation

The study is intentionally descriptive and is based on a cross-sectional household survey. This limits inference about causality or directionality among exposure, private burden, concern, support, and volunteering. The patterns are interpreted as co-variation across place rather than causal effects. Longitudinal data or repeated surveys would be needed to assess how changing hazards or interventions alter household outcomes over time.

7.2 Self-Reported Measures and Recall and Salience Effects

Hazard experience, repair costs, concern, and volunteering are self-reported and may be affected by recall bias and salience. Episodic hazards such as storm surge and flooding may be more readily reported than gradual processes such as erosion. This may understate chronic shoreline change in survey responses. Repair and clean-up costs may also be approximate or rounded. They can vary depending on whether households include labour, materials, or opportunity costs in their estimates.

7.3 Denominator Differences and Affected-Household Subsamples

Some outcomes are measured for all households, including concern, support, and volunteering. Repair and clean-up costs are analysed only among affected households. This reduces

sample size and statistical power for cost comparisons. It also makes cost distributions sensitive to within-cell variability and missingness among affected respondents. As a result, non-significant chi-square results for repair-cost distributions should not be treated as evidence of no differences. Instead, they should be read as limited evidence given subsample constraints.

7.4 Spatial-Cell Definition and Within-Cell Heterogeneity

The three spatial cells provide a useful planning lens, but each cell likely contains internal variation in micro-exposure. That micro-exposure may reflect distance to shoreline, elevation, drainage, housing quality, and proximity to protective structures. Aggregation to cell level can therefore mask important neighbourhood-level differences. Future work could integrate simple geospatial indicators, such as distance-to-coast bands and elevation classes, to sharpen within-cell targeting without shifting into causal modelling.

7.5 Limited Hazard Scope and Missing Contextual Drivers

The hazard categories reflect those captured in the survey instrument and may not include all relevant coastal stressors. These stressors may include compound events, longer-term shoreline retreat, infrastructure failure pathways, or cascading livelihood disruptions. In addition, several contextual drivers that shape recovery and adaptation choices are not measured directly here. These drivers include insurance coverage, access to formal assistance, tenancy status, social networks, and trust in institutions. They may influence private burden, concern, and support.

7.6 External Validity Beyond Port Dickson

The results are directly informative for Port Dickson's shoreline communities and similar west-coast settings, but generalisation to other Malaysian coastal districts should be done cautiously. Coastal morphology, settlement density, governance arrangements, and livelihood structures differ across regions. These differences can alter the configuration of exposure and vulnerability and can affect the feasibility of particular protection options.

Taken together, the study provides a grounded, household-facing profile of how shoreline risk is experienced and interpreted across Port Dickson's coastal cells, while remaining explicitly descriptive and non-causal. The results indicate that the areas facing the highest reported exposure and the weakest socio-economic buffers also carry the greatest private recovery burden and the highest forward-looking concern. These same areas also show the strongest mandate for public protection, alongside high stewardship engagement that can be mobilised as an implementation asset. These findings support a practical planning approach that prioritises vulnerability-sensitive investment and targeted support in high-burden localities, while maintaining district-wide coordination to avoid uneven coverage or risk transfer. At the same time, the evidence should be read with appropriate caution given the cross-sectional design, reliance on self-reported measures, and denominators that vary across outcomes. These limitations motivate future work that combines repeated household measurement with finer-grained spatial indicators and clearer accounting of assistance access, tenure, and recovery constraints.

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