

Exposure, Institutional Protection, and Household Climate Vulnerability in Peri-Urban Informal Settlements

Evelyn Lorenzo

eslorenzo@up.edu.ph

University of the Philippines Diliman

Brian Jason Ponce

University of the Philippines Diliman

Kristine Banalo

University of the Philippines Diliman

Ian Bernard Ines

University of the Philippines Diliman

Geomilie Tumamao-Guittap

University of the Philippines Diliman

April dela Cruz

University of the Philippines Diliman

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Lorenzo, Evelyn^{1*}; Ponce, Brian Jason¹; Banalo, Kristine¹; Ines Ian Bernard¹; Tumamao-Guittap, Geomilie¹;
Dela Cruz, April¹

*Corresponding author: Lorenzo, Evelyn eslorenzo@up.edu.ph

¹University of the Philippines, Quezon City, Philippines

ABSTRACT

We examine variation in household potential impact from climate-related hazards in peri-urban informal settlements in the Philippines. Using survey data from 382 households across seven organized communities, we construct indices of potential impact, exposure of service facilities, environmental risk perception, and autonomous adaptation from ordinal survey items using polychoric-correlation-based one-factor methods. We estimate a stepwise-selected ordinary least squares model with heteroskedasticity-robust standard errors. Among the three index predictors measured on a common 0–1 scale, the Exposed Service Facilities Index has the largest coefficient ($\beta = 0.2751$, $p < 0.001$), while environmental risk perception ($\beta = 0.1023$, $p = 0.019$) and autonomous adaptation ($\beta = 0.1680$, $p = 0.009$) are also positively associated with potential impact. Demographic composition displays age-specific associations: the female proportion within the 25–48 age group is positively associated with potential impact at the 5% level, while the corresponding measures for ages 60–65 and above 65 are positive at the 10% level, and that for ages 0–4 is negative at the 10% level. Having an own electricity supply for lighting is negatively associated with potential impact ($\beta = -0.0486$, $p = 0.039$). Government employment, solo-parent assistance, and PhilHealth assistance are positively associated with potential impact, while GSIS/SSS and HOA/CSO assistance are negatively associated. These results indicate that differential potential impact among peri-urban households is associated with overlapping spatial exposure, demographic composition, reactive household adaptation, and differentiated institutional linkages.

Keywords: climate vulnerability, social protection, gendered risk, climate adaptation

INTRODUCTION

Vulnerability to climate-related hazards is commonly understood as a function of exposure (the degree to which a system experiences climate stresses), sensitivity (the degree to which a system is affected by climate stimuli), and adaptive capacity (the ability to adjust to potential damage or take advantage of opportunities) (Thomas et al. 2019). This framework recognizes that vulnerability is not simply a product of physical exposure to hazards, but is socially constructed through economic, political, and institutional processes (Adams et al. 2023). Within informal settlements, the intersection of rapid urbanization, poverty, spatial marginalization, and weak governance shapes vulnerability (Williams et al. 2019). These settlements typically emerge on marginal lands—urban fringes, floodplains, steep slopes, and coastal zones—that are unsuitable for formal development and often exposed to natural hazards (Macarthy, 2012). Residents, thus, face multiple deprivations, namely inadequate housing, insecure tenure, limited access to water and sanitation, and exclusion from formal planning processes (Dlamini et al. 2025; Williams et al. 2019). Differential vulnerability, by contrast, emphasizes that within any population, certain groups face disproportionate risks because of their social, economic, and political positions (Thomas et al. 2019). This condition arises from structural inequalities along class, gender, age, ethnicity, migration status, and other axes of social differentiation (Gaisie et al. 2022; Adams, 2019), creating inequalities that shape both exposure to hazards (through residential location and housing quality) and capacity to respond (through access to resources, information, and decision-making power) (Adams et al. 2023).

Informal settlements face multiple climate-related hazards, with flooding being the most commonly studied (Rumbach and Shirgaokar 2017; Gaisie et al. 2022; Jozipovic 2015; Patankar 2015; John 2020; Williams et al. 2019; Hambrecht et al. 2022). In the Philippine and wider Southeast Asian context, these risks unfold alongside broader environmental pressures associated with economic growth, urbanization, and structural transformation (Ponce and Manlangit 2023; Ponce et al. 2022). This connection is important because macro-level environmental stressors are ultimately experienced through localized household exposure, infrastructure deficits, and unequal adaptive capacity. Flooding in informal settlements results from inadequate drainage infrastructure (Pandey et al. 2023), location in low-lying areas or floodplains, and the lack of solid waste management systems that block drainage channels (Siddiqui et al. 2022; John 2020; Macarthy 2012; Giri et al. 2021). Heat stress is an emerging concern, particularly in densely built settlements with poor ventilation, limited green space, and housing materials that absorb and retain heat (Alves and Santos 2025; Abdussalam 2020). Other hazards include landslides on steep slopes (Chikodzi and Khumalo 2021;

Macarthy 2012), coastal storms and sea-level rise (Ajibade 2013), and drought-related water scarcity (Borg et al. 2021). The impacts of these hazards on informal households are severe and multidimensional. Flooding causes direct damage to homes and possessions, disrupts livelihoods, increases disease risk through contaminated water, and creates psychological stress (Gaisie et al. 2021; Patankar 2015; John 2020). Heat stress leads to health problems, reduced labor productivity, and increased cooling costs (Alves and Santos 2025; Abdussalam 2020). These impacts are often compounded by limited access to healthcare, insurance, and social safety nets (Dlamini et al. 2025; Borg et al. 2021).

A comparative review of selected empirical studies conducted across Africa, Asia, Latin America, and the Caribbean identified common factors that create differential vulnerability among informal households to climate-related hazards, particularly flooding, extreme weather events, and heat stress. The review yielded four primary categories of vulnerability factors: socio-economic (income, education, employment), physical and infrastructural (housing quality, location, access to services), social (gender, tenure security, social networks), and governance (land use planning, institutional capacity, policy enforcement) (Table 1). These studies reveal that lower-income households, female-headed households, recent migrants, and those living in structures made of temporary materials are significantly more vulnerable. Moreover, the studies indicate that vulnerability arises from complex interactions among poverty, spatial marginalization, inadequate infrastructure, insecure tenure, and weak governance systems.

Existing studies identify a common set of vulnerability correlates, but their relative importance varies across institutional and settlement contexts. This motivates a household-level analysis of within-settlement heterogeneity and the joint distribution of exposure, socio-economic conditions, adaptive behavior, and institutional access.

Table 1. Comparative Analysis of Vulnerability Factors Across Geographic Contexts

Study Location	Primary Hazard(s)	Factors of Vulnerability			
		Socio-economic	Physical	Social	Governance/Institution
Kolkata, India	Flooding, leaking	Income, financial stability	Housing materials, proximity to infrastructure	In situ births, length of residence	Infrastructure provision, tenure security
Accra, Ghana	Flooding	Income, employment	Housing quality, location	Gender, social networks	Service delivery
Bangladesh	Flooding, heat	Average income (\$96/month), informal employment, education	Housing materials (mud, thatch), inadequate services	Gender, lack of social networks, tenure insecurity	Weak labor rights, inadequate services
Cape Town, South Africa	Flooding	Poverty	Location, inadequate drainage	Tenure insecurity	Sanitation service delivery
Mumbai, India	Flooding	Poverty, lack of assets, no insurance	Location in flood-prone areas	Limited social protection	Inadequate infrastructure
Freetown, Sierra Leone	Flooding, landslides	Poverty, unemployment, and education	Location (hillsides, floodplains), housing quality (i.e., stick/iron sheet)	Gender (female-headed households), tenure insecurity	Poor planning enforcement, inadequate institutional capacity
Tanzania	Flooding	Income, employment	Housing materials, location	Tenure security	Infrastructure provision
Zimbabwe	Cyclones, flooding	Poverty, livelihood diversity	Location, housing quality	Social cohesion	Early warning systems, institutional response

Nepal	Flooding	Income, employment	Location, housing quality	Tenure security	Service provision	
Bhutan	Multiple hazards	Income, education, employment	Housing quality, access to services	Migration status, social networks	Government programs	support

Against this background, we examine the household-level correlates of potential climate impact within organized peri-urban informal settlements. The analysis focuses on within-settlement heterogeneity and estimates how service-facility exposure, environmental risk perception, autonomous adaptation, household composition, infrastructure access, employment, and institutional support co-vary with potential impact conditional on the other observed characteristics. This framing treats vulnerability as an allocation of risk across heterogeneous households rather than as a uniform condition attached to informal settlement status.

METHODOLOGY

A. Study Area and Community Selection

This study was conducted in seven informal communities in the Philippines' peri-urban areas. Peri-urban zones represent transitional spaces between urban cores and rural hinterlands, characterized by mixed land uses, rapid demographic change, incomplete infrastructure, and overlapping formal and informal governance structures. These areas are particularly vulnerable to climate-related hazards due to their location on marginal lands (floodplains, steep slopes, coastal zones), inadequate drainage and solid waste management systems, and limited access to formal disaster risk reduction programs. The Philippines context is especially relevant given the country's high exposure to multiple climate hazards (typhoons, flooding, landslides, storm surges, heat stress) and the concentration of informal settlements in peri-urban growth corridors around urbanizing areas.

We employed purposive sampling to select the seven organized informal settler families (Homeowner's Association or HOA) that are members to the Homeless People's Federation Philippines, Inc. (HPFPI) based on three criteria: (1) mixed-use peri-urban character, defined as settlements located at the urban-rural interface with a combination of residential, commercial, and agricultural land uses and incomplete integration into formal urban planning systems; (2) documented hazard exposure, including historical experience of flooding, landslides, or storm surge events based on local government disaster records and community reports; (3) community diversity, ensuring variation in settlement age, population size, tenure arrangements, and access to basic services to capture the heterogeneity of peri-urban informal settlements; (4) willingness of the HOA to participate; and (5) active membership and residency. This purposive approach allowed us to focus on communities that exemplify the vulnerability dynamics of peri-urban informal settlements while ensuring sufficient variation to support comparative analysis. The seven communities ranged in population from 632 households (excluding community enumerators) and had settlement histories spanning from recent (less than 5 years) to established (more than 10 years).

B. Household Survey and Sampling

We collected primary data through a semi-structured household survey administered to 382 households across the seven communities from December 2024 to February 2025. For the empirical analysis, we mapped the survey instrument to four analytical dimensions: exposure, potential impact, sensitivity, and adaptive capacity. The exposure component covered climate-related hazards and the reported exposure of critical service facilities. The potential-impact component measured the perceived likelihood of disruptions, damages, service interruptions, and threats to household functioning and safety. Sensitivity variables captured household demographics and gender–age composition, social norms, employment and economic conditions, housing and tenure, mobility and access, settlement conditions, environmental risks, and institutional or social-assistance linkages. Adaptive capacity distinguished between autonomous and planned adaptation. The Potential Impact Index served as the outcome variable in the regression. The broader candidate set included hazard indicators and composite measures of exposed service facilities, economic security, settlement amenities, environmental risk perception, autonomous adaptation, and planned adaptation, together with demographic, employment, housing, mobility, tenure, social-norm, and institutional variables. The final selected model retained the Exposed Service Facilities, Environmental Risk Perception, and Autonomous Adaptation indices; four gender–age composition measures; own electricity supply for lighting; government employment; and selected institutional-assistance indicators.

We pre-tested the survey instrument with 14 households in a comparable peri-urban community, which were excluded from the final sample. The pre-test assessed question clarity, appropriateness of the response scale, sequencing, and interview duration. Based on the results, we refined the wording of selected items, simplified complex questions, and adjusted the survey flow to improve respondent comprehension and consistency across interviews. We converted the final instrument into a Kobo-based digital survey, which required approximately 45–60 minutes to complete.

The sampling frame consisted of 632 eligible households across the seven participating homeowners' associations. The initial field target was based on the conventional conservative proportion benchmark using a 95 percent confidence level and 5 percent margin of error, yielding approximately 383 households before allowance for non-response. The field target was subsequently increased by 20 percent to 460 households and allocated proportionally according to each community's share of the sampling frame.

Within each community, households were selected systematically from household lists provided by the HPFPI national office. Selection began at a random starting point and proceeded at a community-specific sampling interval; when necessary, selection continued from the beginning of the list using a circular systematic procedure. When a selected household was unavailable, ineligible, or declined participation, the next eligible household was approached. The final analytic sample comprised 382 completed household interviews, representing approximately 60.4 percent of the 632 eligible households. Because the available project records do not document an a priori regression-power calculation, we do not present a retrospective achieved-power claim as part of the sampling rationale.

A team of trained enumerators recruited from the seven study communities collected the data. All enumerators completed a two-day training workshop covering survey administration techniques, informed consent, ethical protocols, and data quality control. Enumerators administered surveys through face-to-face interviews in Filipino or the appropriate local language. Interviews were conducted in common community locations identified by the participating organizations. Technical coordinators reviewed completed survey forms for completeness and internal consistency. We verified missing or inconsistent responses through follow-up visits conducted within two weeks after the initial survey round. The study followed standard ethical procedures for human-subjects research, including informed consent, confidentiality, voluntary participation, and the right to withdraw from the interview.

C. Composite Index Construction

We constructed four composite indices from ordinal survey items using polychoric-correlation-based one-factor analysis. For each construct, we first estimated a polychoric correlation matrix to account for the ordered categorical nature of the component variables and then extracted a single common factor from that matrix. This approach is preferable to treating ordinal response categories as continuous and equally spaced when constructing latent socio-economic or behavioral measures (Kolenikov and Angeles 2009). The resulting factor-loading-weighted scores were subsequently rescaled to the 0–1 interval for comparability and interpretation.

The first index, the **Potential Impact Index**, captures the expected severity of household-level consequences from climate-related hazards. It combines indicators on damage to housing and community facilities, disruption of critical services, displacement, distress, fear of injury, and perceived threats to personal safety. The second index, the **Exposed Service Facilities Index**, measures household exposure by assessing proximity to critical service infrastructure, including markets, schools, health facilities, transport nodes, and other facilities in hazard-prone areas. The third index, the **Environmental Risk Perception Index**, captures household awareness and perceived severity of environmental hazards, including pollution-related risks, geologic hazards, and other non-climatic environmental stressors that may interact with climate-related threats. The fourth index, the **Autonomous Adaptation Index**, measures self-initiated household responses to risk, including social memory, risk information and perception, emergency readiness, coping mechanisms, recovery from impacts, and efforts to reduce future losses.

Each index was constructed from ordinal survey items by first estimating the corresponding polychoric correlation matrix and then extracting a single latent dimension. The Potential Impact Index was constructed from 11 items, the Exposed Service Facilities Index from 13 items, the Environmental Risk Perception Index from 10 items, and the Autonomous Adaptation Index from 28 items. The resulting composite scores were min–max rescaled to the 0–1 interval, with higher scores indicating greater potential impact, greater exposure of service facilities to disruption or damage, stronger environmental risk perception, or greater autonomous-adaptation activity. Table 2 reports the

number of items, the first-factor eigenvalue, the proportion of variance accounted for by the retained dimension, and the final score scale. These statistics are descriptive diagnostics of the one-factor representations rather than standalone evidence of construct validity.

Table 2. One-Factor Diagnostics for Composite Indices

Index	Number of Items	First-factor Eigenvalue	% Variance Explained	Score Scale
Potential Impact	11	4.6586	42.35	0-1
Exposed Service Facilities	13	6.4092	49.30	0-1
Environmental Risk Perception	10	4.7570	47.57	0-1
Autonomous Adaptation	28	8.0521	28.76	0-1

The retained one-factor representations account for 42.35% of the item variance for Potential Impact, 49.30% for Exposed Service Facilities, 47.57% for Environmental Risk Perception, and 28.76% for Autonomous Adaptation. The broader item content of the Autonomous Adaptation construct is reflected in its lower one-factor share relative to the other indices. We therefore use these diagnostics to describe the dimensional structure of the indices rather than imposing a common arbitrary variance-explained threshold across all four constructs.

We also constructed a Planned Adaptation Index capturing household-reported access to organized, anticipatory, or institutionally supported adaptation processes. Planned Adaptation was included in the broader candidate set considered in the model-selection exercises. In the separate LASSO-screened post-selection specification, Planned Adaptation was negatively associated with Potential Impact ($\beta = -0.1581$, $SE = 0.0848$, $p = 0.063$). However, the separate stepwise selection procedure used to obtain the main 14-predictor specification reported in Table 3 did not retain Planned Adaptation. We treat the LASSO estimate as an alternative-specification result rather than combining coefficients generated by different selection procedures.

D. Vulnerability Classification

For descriptive analysis, we grouped the continuous Potential Impact Index into five equal-width intervals on its 0–1 scale: Level 1 (very low), 0.00–<0.20; Level 2 (low), 0.20–<0.40; Level 3 (moderate), 0.40–<0.60; Level 4 (high), 0.60–<0.80; and Level 5 (very high), 0.80–1.00. These cutoffs are researcher-defined descriptive categories used to summarize how household characteristics vary across the distribution of potential impact. They are not intended as externally validated or administratively fixed vulnerability thresholds, and the continuous Potential Impact Index remains the outcome used in the regression analysis. The classification yields 18 households in Level 1, 52 in Level 2, 109 in Level 3, 113 in Level 4, and 90 in Level 5.

This classification was used as a descriptive device to examine how household characteristics, exposure, risk perception, adaptation behavior, and institutional affiliations vary across the distribution of potential impact. Equal-width intervals provide a transparent, reproducible basis for comparing vulnerability tiers because each category spans the same range of index values. The five-tier structure also offers sufficient differentiation across households without imposing externally defined thresholds that may not suit peri-urban informal settlements in the Philippine context. The resulting categories are therefore interpreted as relative vulnerability groups within the study sample rather than as universal or administratively fixed cutoffs.

E. Regression Analysis

We modeled the Potential Impact Index as the dependent variable. The initial specification contained 60 candidate explanatory variables spanning hazard exposure; exposed service facilities; economic security and settlement amenities; environmental risk perception; autonomous and planned adaptation; household demographics and gender–age composition; social norms; income and employment; housing and tenure; mobility and access; and institutional or social-assistance indicators.

As an exploratory model-selection exercise, we estimated a linear LASSO specification, selecting the penalty through cross-validation (Tibshirani 1996). Separately, we applied stepwise backward elimination to the broader candidate set using a $p > 0.10$ removal criterion. The stepwise procedure retained 14 predictors: the Exposed Service Facilities,

Environmental Risk Perception, and Autonomous Adaptation indices; four gender–age composition measures; own electricity supply for lighting; government employment; and five institutional-assistance indicators. We entered continuous index scores and demographic ratios on their original 0–1 scale, while entering employment, housing, and institutional indicators as binary variables.

We estimated the resulting OLS model with heteroskedasticity-robust standard errors and used all 382 observations. The model is jointly statistically significant ($F(14,367) = 11.18$, $p < 0.001$), with $R^2 = 0.2600$ and a root mean squared error of 0.1947. Because model selection is data-dependent, conventional post-selection standard errors and p-values are conditional on the selected specification and do not incorporate uncertainty arising from the selection process itself. We therefore interpret the coefficients as conditional associations rather than causal effects and emphasize their direction, magnitude, and substantive interpretation alongside statistical significance.

F. Focus Group Discussions

To complement the quantitative survey data and provide a deeper contextual understanding of household vulnerability dynamics, we conducted focus group discussions (FGDs) across the seven study communities. These helped validate emerging quantitative patterns, probe counterintuitive findings, and surface lived experiences and community perspectives that the structured survey instrument may not have fully captured.

We purposively selected participants for each FGD to ensure diversity in household vulnerability levels, gender, and organizational roles. In total, 99 community members participated across the eight FGDs, with 9–12 participants per session. The largest community hosted two FGDs to capture variation within larger, more heterogeneous settlements, while the remaining six communities each hosted one FGD.

Each FGD followed a semi-structured discussion guide organized into four thematic modules aligned with the survey domains: (1) **hazard exposure and impacts** (experiences of past climate-related disasters, perceived changes in hazard frequency and severity, impacts on housing, livelihoods, and community life); (2) **risk perception and awareness** (sources of climate information, factors shaping risk perception, barriers to awareness); (3) **adaptation behaviors and strategies** (autonomous household-level risk reduction measures, barriers to adaptation, role of community organizations); and (4) **institutional support and social protection** (experiences with government assistance programs, social insurance, and community-based organizations, perceived effectiveness and gaps in support). The discussion guide included open-ended questions, probing prompts, and hypothetical scenarios to elicit rich, detailed responses and encourage dialogue among participants.

Trained moderators fluent in the local language (Tagalog or regional dialects) co-facilitated the FGDs, which lasted approximately 120–180 minutes. All discussions were audio-recorded with participant consent and supplemented by detailed note-taking by a research assistant. Audio recordings were transcribed verbatim and translated into English for analysis. We employed thematic coding through NVivo to identify recurring patterns, divergent perspectives, and illustrative examples across the FGD transcripts. We developed codes iteratively through deductive coding (based on the survey domains and theoretical framework) and inductive coding (emerging themes identified through close reading of transcripts).

The FGD data served three functions in the mixed-methods design. First, they contextualized and triangulated patterns observed in the quantitative analysis. Second, they provided qualitative evidence on plausible mechanisms underlying otherwise counterintuitive associations, including the positive coefficient on Autonomous Adaptation. Third, they highlighted contextual nuances and structural constraints (e.g., gaps in social protection programs, gendered caregiving burdens, and institutional barriers to formal adaptation support) that enriched interpretation of the regression results and informed policy recommendations. Throughout the Results and Discussion section, we integrate FGD insights to triangulate quantitative findings and illustrate vulnerability dynamics.

RESULTS AND DISCUSSION

A. Correlates of Household Potential Impact

Table 3 reports the post-selection OLS estimates for household potential impact. The model is jointly statistically significant and accounts for 26 percent of the observed cross-sectional variation in the Potential Impact Index. Given

the observational, cross-sectional design and data-dependent model selection, the coefficients are interpreted as conditional associations rather than causal effects. Among the three composite index predictors measured on the same 0–1 scale, the Exposed Service Facilities Index has the largest estimated coefficient, followed by Autonomous Adaptation and Environmental Risk Perception.

Table 3. Factors affecting the potential impact of climate hazards on households

FACTOR	COEFFICIENT	SE
Outcome: Potential Impact (Index; 0.0000-1.0000)		
Exposed Service Facilities (Index; 0.0000-1.0000)	0.2751***	0.0384
Environmental Risk Perception (Index; 0.0000-1.0000)	0.1023**	0.0434
Autonomous Adaptation (Index; 0.0000-1.0000)	0.1680***	0.0643
HH Female Intensity: > 65 (ratio)	0.0623*	0.0353
HH Female Intensity: 60-65 (ratio)	0.0564*	0.0290
HH Female Intensity: 25-48 (ratio)	0.0617**	0.0305
HH Female Intensity: 0-4 (ratio)	-0.0629*	0.0361
HH utilizes electricity (dummy)	-0.0486*	0.0235
HH Employment: Government (dummy)	0.0734***	0.0273
Social Assistance: Solo Parents (dummy)	0.0860**	0.0350
Social Assistance: GSIS/SSS (dummy)	-0.0491*	0.0262
Social Assistance: PhilHealth (dummy)	0.0775***	0.0249
Social Assistance: PAG-IBIG (dummy)	0.0502*	0.0261
Social Assistance: HOAs (dummy)	-0.0411*	0.0209
Constant	0.2458***	0.0542

n = 382 households

Prob > *F* = 0.0000

*R*² = 0.2600

Root MSE = 0.1947

***, **, and * denote significance at $\alpha = 0.01$, 0.05, and 0.10, respectively

Note: The constant represents the predicted Potential Impact Index when all continuous predictors equal zero, and all binary indicators are in their reference categories. Because this combination is not necessarily representative of an observed or substantively typical household, the intercept is retained for model completeness and is not interpreted as an independent vulnerability effect.

Among the three composite index predictors measured on the same 0–1 scale, the Exposed Service Facilities Index has the largest estimated coefficient. A 0.10 increase in the index is associated with a 0.0275-point higher Potential Impact Index, holding the other retained covariates constant. This association is consistent with service dependence becoming an additional source of vulnerability when critical facilities themselves are exposed to hazard-related disruption. Because facility exposure and household potential impact are observed contemporaneously, however, the coefficient does not identify a causal effect of facility proximity, location, or infrastructure placement.

Environmental risk perception is positively associated with potential impact. A 0.10 increase in the Environmental Risk Perception Index corresponds to a 0.0102-point higher Potential Impact Index, conditional on the other retained covariates. The result is consistent with risk perception incorporating information from prior hazard exposure, experienced disruption, and the surrounding risk environment. In this sense, perceived risk functions as an informational margin through which households register accumulated environmental stress.

Autonomous Adaptation is positively associated with potential impact. A 0.10 increase in the Autonomous Adaptation Index corresponds to a 0.0168-point higher Potential Impact Index, conditional on the other retained covariates. The pattern is consistent with state-dependent self-protection: households facing higher perceived or realized losses devote more effort to private adaptation. Autonomous adaptation therefore appears to operate as a compensatory household response to elevated risk rather than as a simple marker of low vulnerability.

Household composition adds another layer of heterogeneity. The female proportion among household members aged 25–48 has a coefficient of 0.0617 and is statistically significant at the 5 percent level, while the corresponding coefficients for ages 60–65 and above 65 are 0.0564 and 0.0623 and are significant at the 10 percent level. These age-specific gradients are consistent with differences in household labor allocation, dependency, care intensity, and mobility across the life cycle.

The female proportion among household members aged 0–4 is negatively associated with potential impact ($\beta = -0.0629$, $p = 0.082$). The sign reversal relative to the working-age and older groups reinforces the importance of household life-cycle composition. Very young dependents may alter household mobility, precautionary behavior, time allocation, and access to informal care networks, producing a different vulnerability profile from that associated with working-age and elderly household members.

Access to a household's own electricity source is negatively associated with potential impact ($\beta = -0.0486$, $p = 0.039$). Electricity access captures an important infrastructural endowment: it supports information access, communication, lighting, food storage, and continuity of basic household functions during disruptions. Its negative coefficient is consistent with basic infrastructure expanding the household's short-run capacity to absorb and manage climate-related shocks.

Government employment is positively associated with potential impact ($\beta = 0.0734$, $p = 0.007$), conditional on the other retained covariates. The result indicates that formal employment status alone is not a sufficient proxy for household resilience. Government employment may be correlated with unobserved differences in residential location, commuting patterns, service dependence, household expenditure commitments, or other characteristics not fully captured by the model. More generally, employment formality and climate resilience represent distinct margins of household welfare: stable employment may improve income security without necessarily reducing physical exposure or increasing short-run liquidity for preparedness and recovery (Tuaño et al., 2025).

Institutional linkages exhibit heterogeneous associations with potential impact. GSIS/SSS assistance or coverage is negatively associated with the Potential Impact Index ($\beta = -0.0491$, $p = 0.062$), as is HOA/CSO assistance ($\beta = -0.0411$, $p = 0.050$). These institutions operate through different economic channels: formal social insurance can strengthen income smoothing and access to employment-linked benefits, while community organizations can reduce information and coordination costs, facilitate collective action, and improve access to external assistance.

By contrast, solo-parent assistance ($\beta = 0.0860$, $p = 0.014$), PhilHealth ($\beta = 0.0775$, $p = 0.002$), and PAG-IBIG ($\beta = 0.0502$, $p = 0.056$) are positively associated with potential impact. The pattern is consistent with non-random selection into institutional programs: eligibility, formal-sector attachment, prior need, and household disadvantage jointly shape program participation. Institutional affiliation therefore carries information about both access to protection and the underlying characteristics that determine eligibility and demand for support.

Taken together, the selected covariates reveal that variation in household potential impact is associated with spatial, demographic, behavioral, and institutional conditions. Among the same-scale index predictors, exposure of service facilities has the largest estimated coefficient, while environmental risk perception and autonomous adaptation are also positively associated with potential impact. The latter relationships are consistent with the possibility that perception and household responses are partly endogenous to prior exposure, although the data do not establish temporal ordering. The institutional coefficients likewise vary in sign and may reflect both differences in access to protection and selection into programs. Overall, the results point to substantial heterogeneity within peri-urban informal settlements that income or poverty status alone cannot capture.

B. Patterns Across Potential Impact Tiers

For descriptive purposes, the tier classification shows how the retained household characteristics are distributed across the Potential Impact Index. Of the 382 households, 312, or 81.7 percent, fall within the moderate-to-very-high tiers. Because these tiers are constructed directly from the dependent variable, do not interpret the comparisons in Table 4 as independent tests of determinants or as causal gradients. Rather, they describe how the retained covariates co-vary with households' positions in the observed potential-impact distribution.

The Exposed Service Facilities Index rises from 0.4585 in Level 1 to 0.7287 in Level 5, with generally higher values in the upper potential-impact tiers. This descriptive pattern is consistent with the regression result showing a positive conditional association between exposure of critical service facilities and potential impact. It does not, however, identify whether facility proximity, infrastructure siting, household location, or another correlated spatial characteristic drives the relationship. Complementing this structural dimension, Environmental Risk Perception is generally higher in the upper potential-impact tiers. However, the pattern is not monotonic: the mean falls from 0.5243 in Level 1 to 0.4496 in Level 2 before increasing to 0.5781 in Level 5. The tiered distribution therefore supports a positive overall association without implying a uniform gradient across all groups. However, the focus discussions clarified that the variability within tiers shows that, even among similarly exposed households, risk perception differs, suggesting the influence of prior experience, education, and access to information.

Autonomous adaptation, by contrast, shows a clear distributional pattern. Level 3 households record a mean index score of 0.6339, while Level 5 households report the highest mean (0.7179) and the lowest dispersion ($SD = 0.1361$). The concentration of adaptation effort in the upper potential-impact tier is consistent with state-dependent household investment in self-protection: expected or experienced losses increase the demand for precautionary action.

The gender–age composition measures also vary across potential-impact tiers, although they do not follow uniform monotonic patterns. Female intensity among ages 25–48 is highest in Level 5, while the age 60–65 measure peaks in Level 4, and the remaining age-group measures vary across the distribution. These descriptive differences are consistent with heterogeneity in household composition across potential-impact levels, but Table 4 does not itself estimate nonlinear or interaction effects. Caregiving, mobility, and labor-allocation mechanisms therefore remain plausible interpretations.

Electricity access is lower in Level 5 than in Level 1 (67.78 percent versus 83.33 percent), while government employment is most prevalent in Level 5. Together, these patterns illustrate that income formality and infrastructural security capture different dimensions of household resilience. The focus-group evidence further points to limited financial buffers and dependence on exposed services, suggesting that stable employment does not necessarily translate into sufficient liquidity or asset protection when shocks occur.

Institutional affiliation also varies systematically across the potential-impact distribution. PhilHealth and PAG-IBIG participation become more prevalent in the upper tiers, while HOA-related support remains widespread but declines among the highest-potential-impact households. This pattern reflects both program targeting and household selection into different forms of protection. The contrasting regression coefficients further suggest that institutional linkages differ in how much they provide income smoothing, risk pooling, collective support, and access to services.

The qualitative evidence helps interpret this institutional pattern. Focus group discussions indicate that households often experience social programs as partial, delayed, administratively burdensome, or poorly matched to disaster-related needs. Assistance may be too small to cover actual recovery costs, too slow to address urgent losses, or too narrowly designed to respond to overlapping vulnerabilities. Membership-based programs may also require stable employment and regular contributions, which many informal households lack. For some households, contributions are perceived as a deduction from already constrained income rather than as an immediately usable safety net. Limited knowledge of eligibility rules and program procedures further weakens the protective value of institutional affiliation. These accounts help explain why program participation can coexist with high measured vulnerability.

Taken together, the tiered analysis shows that higher potential impact tends to co-occur with greater service-facility exposure, stronger risk perception and autonomous adaptation, particular household-composition profiles, weaker access to some basic infrastructure, and differentiated institutional linkages. These patterns do not establish that the characteristics statistically interact or jointly cause vulnerability, since this analysis estimates no interaction effects. Instead, they show that different combinations of observed constraints and institutional connections characterize households occupying different parts of the potential-impact distribution.

The results favor a portfolio approach to adaptation policy. Household preparedness, resilient service infrastructure, basic utilities, social protection, and community institutions address different margins of vulnerability and are therefore complementary, not interchangeable. The concentration of autonomous adaptation among higher-potential-impact households also points to substantial private expenditure of effort on self-protection. Public adaptation can

raise the returns to these private efforts by reducing exposure, improving service continuity, and expanding access to risk-pooling mechanisms.

Table 4. Variations in vulnerability determinants across levels

DETERMINANT	VULNERABILITY LEVEL											
	1 Very Low		2 Low		3 Moderate		4 High		5 Very High		TOTAL	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
Exposed Service Facilities	0.4585	0.2910	0.4618	0.2711	0.5404	0.2598	0.6407	0.2609	0.7287	0.2413	0.5999	0.2745
Environmental Risk Perception	0.5243	0.1910	0.4496	0.2358	0.5318	0.2274	0.5489	0.2421	0.5781	0.2751	0.5362	0.2452
Autonomous Adaptation	0.6716	0.2072	0.6570	0.1882	0.6339	0.1693	0.6823	0.1401	0.7179	0.1361	0.6729	0.1608
HH Female Intensity: > 65	0.0833	0.2572	0.1058	0.2682	0.1193	0.2797	0.1283	0.3258	0.1222	0.3119	0.1191	0.2980
HH Female Intensity: 60-65	0.1389	0.3346	0.1058	0.2859	0.1514	0.3368	0.1947	0.3805	0.1389	0.3182	0.1545	0.3394
HH Female Intensity: 25-48	0.3241	0.3405	0.4510	0.3026	0.3384	0.3231	0.4139	0.3386	0.4773	0.3272	0.4081	0.3299
HH Female Intensity: 0-4	0.0556	0.2357	0.1715	0.3632	0.1009	0.2949	0.1062	0.3095	0.0963	0.2826	0.1089	0.3038
HH utilizes electricity	0.8333	0.3835	0.7308	0.4479	0.7890	0.4099	0.7168	0.4526	0.6778	0.4699	0.7356	0.4416
Government employment	0.1111	0.3234	0.0577	0.2354	0.1284	0.3361	0.1593	0.3676	0.2111	0.4104	0.1466	0.3542
Assistance to Solo Parents	0.0000	0.0000	0.0577	0.2354	0.0550	0.2291	0.0442	0.2066	0.0778	0.2693	0.0550	0.2282
Social Security (GSIS/SSS)	0.5556	0.5113	0.5192	0.5045	0.6422	0.4816	0.6637	0.4745	0.6222	0.4875	0.6230	0.4853
Social Protection (PhilHealth)	0.3889	0.5016	0.5000	0.5049	0.6239	0.4867	0.6726	0.4714	0.7444	0.4386	0.6387	0.4810
Shelter financing and social assistance (PAG-IBIG)	0.2778	0.4609	0.4038	0.4955	0.4495	0.4997	0.5310	0.5013	0.5667	0.4983	0.4869	0.5005
Assistance from HOAs	0.7222	0.4609	0.6346	0.4862	0.6697	0.4725	0.6637	0.4745	0.6222	0.4875	0.6545	0.4762
HH Distribution	18 (4.71%)		52 (13.62%)		109 (28.53%)		113 (29.58%)		90 (23.56%)		382 (100%)	

CONCLUSION

Synthesis: Vulnerability as Overlapping Risk and Response

The results show that household potential impact is associated with several overlapping dimensions of peri-urban vulnerability. Greater exposure of service facilities, stronger environmental risk perception, autonomous adaptation, selected demographic characteristics, infrastructure access, employment, and institutional linkages remain associated with potential impact after conditioning on the other variables retained in the model. The positive association between autonomous adaptation and potential impact is particularly consistent with a setting in which household responses partly emerge after exposure and disruption. However, the cross-sectional data cannot directly establish that temporal mechanism.

The evidence reveals substantial within-settlement heterogeneity in household potential impact. Households sharing broadly similar peri-urban conditions occupy different positions in the vulnerability distribution because they differ in service exposure, demographic composition, infrastructure, adaptation behavior, employment, and institutional access. This heterogeneity has direct implications for targeting efficiency: area-based interventions can be improved by incorporating household-level information on exposure, adaptive capacity, and access to formal and informal risk-sharing mechanisms.

Limitations

Several limitations should be considered when interpreting the findings. First, the final model explains 26% of the observed cross-sectional variation in the Potential Impact Index ($R^2 = 0.2600$). The remaining variation should not be interpreted as a direct estimate of omitted determinants; it may reflect unmeasured household and community characteristics, measurement and reporting variation, idiosyncratic shocks, and model specification. Second, the cross-sectional design does not establish temporal ordering or causal effects. This is particularly important for environmental risk perception and autonomous adaptation, because prior exposure or losses may simultaneously increase perceived potential impact and induce household responses. Institutional-assistance indicators may likewise reflect eligibility, prior need, or selection into programs rather than treatment effects. Third, the final specification is data-dependent because variables were screened through regularization and stepwise selection; coefficient magnitudes and conventional significance levels may therefore be sensitive to alternative specifications. Fourth, several key constructs are derived from self-reported ordinal responses and may capture reporting heterogeneity alongside underlying risk and response. Finally, the seven communities were purposively selected from organized peri-urban settlements, which limits the extent to which the findings can be generalized to informal settlements more broadly in the Philippines. The results are therefore interpreted as conditional associations within the study population.

Policy Implications

The findings identify several opportunities to improve climate-adaptation targeting. First, the strong association between exposure of service facilities and potential impact places infrastructure reliability at the center of household resilience. Investments in drainage, safe access routes, hazard-resistant facilities, and continuity of essential services can reduce the expected losses associated with dependence on exposed service networks.

Second, the positive associations of environmental risk perception ($\beta = 0.1023$, $p = 0.019$) and autonomous adaptation ($\beta = 0.1680$, $p = 0.009$) indicate that demand for self-protection is highest where perceived and experienced risk is greatest. This creates a strong case for complementing private adaptation with anticipatory public investments that lower exposure and reduce household preparedness costs.

Third, the institutional coefficients reveal substantial heterogeneity in program reach and household selection. GSIS/SSS ($\beta = -0.0491$, $p = 0.062$) and HOA/CSO assistance ($\beta = -0.0411$, $p = 0.050$) are negatively associated with potential impact. In contrast, solo-parent assistance ($\beta = 0.0860$, $p = 0.014$), PhilHealth ($\beta = 0.0775$, $p = 0.002$), and PAG-IBIG ($\beta = 0.0502$, $p = 0.056$) are positively associated. Eligibility, employment formality, household need, and benefit design generate different selection patterns across programs. A stronger social-protection response therefore requires attention to benefit adequacy, timing, accessibility, and programs' capacity to provide liquidity and risk pooling when climate shocks occur.

Finally, the gender–age composition estimates point to heterogeneity across life-cycle groups but should be interpreted cautiously. The female proportion aged 25–48 is positively associated with potential impact at the 5 percent level ($\beta = 0.0617$, $p = 0.044$), while the corresponding coefficients for ages 60–65 ($\beta = 0.0564$, $p = 0.053$), above 65 ($\beta = 0.0623$, $p = 0.078$), and 0–4 ($\beta = -0.0629$, $p = 0.082$) are supported only at the 10 percent level. These associations are consistent with differences in caregiving responsibilities, mobility, and economic roles, but the present analysis does not directly estimate those mechanisms. Gender-responsive adaptation policy is therefore better motivated by the broader pattern of household constraints than by treating individual demographic coefficients as causal effects. Own electricity access is negatively associated with potential impact ($\beta = -0.0486$, $p = 0.039$), reinforcing the broader importance of reliable basic infrastructure while similarly stopping short of a causal interpretation.

Future Research Directions

Future research can extend this analysis in four directions. First, longitudinal household panel data would allow researchers to trace how hazard exposure, adaptation behavior, institutional support, and vulnerability evolve. This would help distinguish whether autonomous adaptation reduces subsequent losses or mainly reflects compensatory responses after repeated shocks. Second, future studies should combine household survey data with spatially explicit measures of exposure, including flood depth, drainage and service-infrastructure maps, housing quality, health outcomes, and geocoded hazard histories. Linking reported household conditions with observable environmental and infrastructure measures would improve the precision of vulnerability assessment and strengthen empirical inference. Third, comparative research across peri-urban and informal settlements in the Philippines, Southeast Asia, and other climate-exposed regions could identify which vulnerability mechanisms are context-specific and which are more generalizable. Such comparisons should account for differences in tenure arrangements, settlement organization, local governance, social protection, and hazard exposure. Fourth, planned adaptation and institutional risk governance should be examined more directly as distinct channels for reducing vulnerability. Future work could evaluate interventions such as service-corridor upgrading, anticipatory social protection, community-based early warning systems, and participatory settlement planning to assess which policy instruments most effectively reduce household exposure, strengthen adaptive capacity, and shift households from reactive coping toward sustained risk reduction.

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Author Information

Authors and Affiliations

University of the Philippines – School of Urban Regional Planning (SURP), Diliman, Quezon City, Philippines

Lorenzo, Evelyn

Ponce, Brian Jason

Banalo, Kristine

Ines, Ian Bernard

Tumamao-Guittap, Geomilie Sardan

Dela Cruz, April

Contributions **Based on CRediT Roles and Example Research Tasks That Could be Attributed to Them (<https://zenodo.org/records/18421449>)*

Evelyn Lorenzo: Supervision, conceptualization, methodology, writing – original draft, writing – review and editing, formal analysis, investigation, validation (<https://orcid.org/0009-0007-2560-1143>)

Brian Jason Ponce: Methodology, formal analysis, software, data curation, writing – original draft, writing – review and editing (<https://orcid.org/0000-0002-8349-1065>)

Kristine Banalo: Data gathering, data curation, formal analysis, investigation, validation (<https://orcid.org/0009-0004-6446-0193>)

Ian Bernard Ines: Data gathering, data curation, investigation, validation (<https://orcid.org/0009-0006-9827-8159>)

Geomilie Sardan Tumamao-Guittap: Data gathering, project administration, funding acquisition, validation (<https://orcid.org/0009-0007-1917-4368>)

April dela Cruz: Data gathering, project administration, funding acquisition, validation (<https://orcid.org/0009-0008-3096-7315>)

Corresponding Author

Correspondence to Evelyn Lorenzo

Data Availability

The primary data supporting this study's findings are not publicly available. The household survey microdata, focus group discussion (FGD) transcripts, and documentation were collected from community residents in peri-urban informal settlements under written informed consent that included strict confidentiality assurances and did not include provisions for public data release. Public release of these materials would risk identifying individual participants given the small, spatially bounded nature of the study communities. De-identified and aggregated survey data that underpin the statistical findings reported in this article may be made available by the corresponding author (Evelyn S. Lorenzo) upon reasonable request and subject to review by the research team to ensure compliance with participant confidentiality and the data governance requirements of the RURBANISE project under the Climate Adaptation and Resilience (CLARE) Programme (FCDO/IDRC, Grant No. 109999-001). FGD transcripts cannot be shared owing to participant anonymity commitments.

Ethics declarations

Formal institutional ethical review board approval was not sought for this study. Instead, ethical oversight was managed through a rigorous, multi-institutional review process. The survey instruments, informed consent documentation, and interview guides were formally submitted to and vetted by the project's local and international partner institutions—including the Technical Assistance Movement for People and Environment, Inc. (TAMPEI), the Homeless People's Federation Philippines, Inc. (HPFPI), the Philippine Alliance (PACSII), and the University of Sheffield—prior to the commencement of fieldwork. The research framework aligns with these partner organizations' ethical standards and the funding requirements of the Climate Adaptation and Resilience Program (CLARE), jointly supported by Canada's International Development Research Center (IDRC) and the UK's Foreign, Commonwealth & Development Office (FCDO). We obtained explicit, written informed consent from all community participants before administering the survey, and we treated all data with strict confidentiality.

Prior Public Presentation

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Competing Interests

The authors declare no competing interests.