

Assessing the vulnerability and climate change impact on the marginalized communities in Dhaka division: a rasch score and mixed methods approach

Abstract

Bangladesh remains one of the most climate-vulnerable nations in the world, yet rigorous, community-disaggregated vulnerability measurement for its marginalized populations remains scarce. This study assesses climate and service-access vulnerability across four marginalized community types in Dhaka Division, namely Ethnic Minorities (Adivasi), Dalits, Disabled or Begging populations, and Urban Slum dwellers, covering three critical sectors: Health, Education, and Social Safety Net. A cross-sectional survey of $N = 295$ respondents was conducted using a multi-stage stratified random sampling design. The Rasch Item Response Theory (IRT) model was applied to dichotomized response matrices, while Principal Component Analysis (PCA) was performed on the polytomous Likert items to validate the latent dimensional structure. The Rasch model produced highly reliable vulnerability scales ($KR-20 = 0.826$ for Health, 0.919 for Education, 0.821 for Social Safety Net). PCA confirmed unidimensional pattern, with the first principal component explaining 34.2%, 53.3%, and 46.6% of total variance in the three sectors respectively. Convergent validity between Rasch and PCA scores was very high ($r = 0.943$ to 0.978 , $p < 0.001$). One-way ANOVA revealed statistically significant community-level vulnerability differentials in all sectors, most strongly in Education ($F = 26.48$, $p < 0.001$). Ethnic Minorities emerged as the most vulnerable overall (mean = -0.618 logits), followed by Dalits (-0.196). Sex-based analysis showed females as significantly more vulnerable than males in Education ($F = 21.66$, $p < 0.001$), while Third Gender respondents exhibited a distinctive mixed profile. Item-level analysis identified mental health services, specialist care, VGD/VGF registration, and housing assistance as the most inaccessible entitlements, pointing to priority areas for intersectional, community-sensitive climate adaptation and social protection policy.

Keywords: climate vulnerability, marginalized communities, rasch model, principal component analysis, social safety net, Bangladesh

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Introduction

Bangladesh is consistently ranked among the most climate-vulnerable countries in the world.¹ Located within the Ganges-Brahmaputra-Meghna delta, the country faces a uniquely intense combination of climate hazards (tropical cyclones, seasonal flooding, riverine erosion, salinity intrusion, and drought) that interact with deep-seated socio-economic inequalities.² The impacts of climate change are not distributed evenly across the population; rather, they are refracted through existing social hierarchies, concentrating risk and harm among communities that are already marginalized by ethnicity, caste, disability, gender identity, or urban poverty.^{3,4} Vulnerability is thus not a fixed attribute but emerges from the interplay of exposure, sensitivity, and adaptive capacity, all of which are shaped by political economy and social position. More than 7.1 million Bangladeshis were displaced by climate-related events in 2022 alone, and projections suggest the figure may rise to 13.3 million by 2050.⁵ The World Bank estimates that climate change could push an additional 3.8 million Bangladeshis into poverty by 2030.⁶

Dhaka Division, the administrative heartland of the country, presents a microcosm of these intersecting vulnerabilities. Despite being the economic hub, the division hosts millions of marginalized residents, Adivasi (ethnic minority) communities in the northern districts, Dalit sweeper communities in peri-urban Gazipur, disabled individuals and people engaged in begging in the central city, and vast populations of urban slum dwellers in Korail, Badda and other dense

enclaves. Each of these groups faces distinct but overlapping climate-related challenges, compounded by structural exclusion from basic services in health, education, and social protection.^{7,8} The poorest households are reported to lose up to 97% of their income during major disasters, compared to only 9.3% for the wealthiest, a disparity that renders climate adaptation fundamentally a question of social justice rather than purely an environmental concern.

Existing vulnerability assessments in Bangladesh have relied predominantly on composite indices constructed from national-level indicators^{9,10} limiting their ability to capture the granular, community-specific dimensions of vulnerability. Most studies treat marginalized communities as monolithic categories, obscuring important heterogeneity within and between groups. The Health, Education, and Social Safety Net sectors, which form three pillars of the government's whole-of-government approach to climate resilience, have rarely been evaluated simultaneously using a common measurement framework that allows valid cross-sector and cross-community comparison. A further methodological gap concerns measurement error and item-level properties. Conventional methods that sum Likert-scale responses assign equal weight to all items regardless of their empirical difficulty or discriminatory power. The Rasch model addresses this limitation by estimating person ability and item difficulty on a common logit scale, yielding theoretically grounded, interval-level measures.^{11,12}

The present study responds to these gaps by deploying the Rasch IRT framework alongside Principal Component Analysis (PCA) to produce reliable, quantitatively comparable vulnerability scores

for 295 respondents drawn from four marginalized community types in Dhaka Division. The specific objectives are: (i) to describe the socio-demographic profile and basic service access patterns of the target communities; (ii) to compute and compare Rasch-based vulnerability scores across the Health, Education, and Social Safety Net sectors; (iii) to validate and cross-check the Rasch scores using PCA; (iv) to analyze vulnerability differentials by sex (Male, Female, Third Gender) and community type; (v) to identify the most and least difficult service-access items using item difficulty parameters; and (vi) to formulate evidence-based policy recommendations. By disaggregating findings across four community types and three sex categories, including the often-overlooked Third Gender population, the study generates intersectional insights that can directly inform inclusive climate adaptation and social protection policy.

Methodology

Study design and study area

The study adopted a cross-sectional, mixed-methods design combining a structured household survey with qualitative key-informant interviews. A multi-stage stratified random sampling was used for sampling design, and the field survey was done during November 17- 30, 2025, including training sessions, and pilot survey. Quantitative data were used for Rasch and PCA modelling, while qualitative inputs informed questionnaire design and contextual interpretation. The study was carried out in three districts of Dhaka Division: Mymensingh (Adivasi communities in Haluaghat and Dhobaura upazilas), Gazipur (Dalit sweeper and leather-worker communities in Tongi and Gazipur Sadar), and Dhaka (Disabled, begging, and urban slum populations in Korail, Badda, and adjoining areas). The three sites were selected purposively to capture distinct community profiles within a common administrative division.

Sampling strategy

A multi-stage stratified random sampling design was used, with community type as the primary stratification variable. The target sample size was determined using Cochran's¹³ formula for proportions with a 95% confidence level and a ±5% margin of error, yielding a minimum of 270 respondents; the realized sample was N = 295. Within each community stratum, households were selected using systematic random sampling from enumeration lists maintained by local NGOs and union parishad records. Inclusion criteria required respondents to be aged 18 years or above and to have resided in the study area for at least the preceding 12 months. Written informed consent was obtained prior to interviewing, and all protocols followed standard research ethics guidelines on anonymity and secure data storage.

Data collection instruments

Data were collected using a semi-structured questionnaire comprising three sector-specific modules. The Health module contained 15 Likert-scale items (scored 1- 4) capturing perceptions and experiences of health service access, quality, and climate-related health shocks. The Education module contained 11 Likert-scale items (scored 1- 4) covering school access, educational quality, and climate-related disruptions to schooling. The Social Safety Net module contained 11 items (scored 1- 3) assessing awareness of, registration in, and receipt of major social protection programs (VGD/VGF, old-age allowance, widow's allowance, disability allowance, food assistance, and housing support). Parallel dichotomized versions of each module were constructed by coding responses above the midpoint as 1 (adequate access / positive experience) and those at or below the midpoint as 0. These binary matrices served as the input for

the Rasch IRT analysis. The questionnaire was administered in Bangladesh by trained field surveyors following a one-day training workshop. Data were captured using KoBoToolbox and cleaned in Stata 17.

Rasch model analysis

The dichotomous Rasch model was estimated separately for each sector using Joint Maximum Likelihood Estimation (JMLE). The probability that respondent i endorses item j is modelled as:

$$P(X_{ij} = 1 | \theta_i, \delta_j) = \exp(\theta_i - \delta_j) / [1 + \exp(\theta_i - \delta_j)]$$

where θ_i is person ability (here, latent vulnerability) and δ_j is item difficulty, both expressed on a common logit scale. The iterative algorithm was run to a convergence criterion of a maximum parameter change < 0.001 logits. Extreme person scores (raw = 0 or raw = maximum) were anchored at ±4.0 logits to avoid infinite estimates. Item fit was evaluated using weighted (infit) and unweighted (outfit) mean-square statistics; values in the range 0.7–1.3 were treated as strong evidence of fit, while the more permissive band 0.6–1.4 was also reported.¹⁴ Reliability was quantified using the Kuder-Richardson 20 (KR-20) coefficient, the dichotomous analogue of Cronbach's alpha, and item-total correlations (point-biserial r) were computed for each item.

Principal component analysis

PCA was performed on the mean-centered polytomous Likert matrices for each sector. Eigenvalues greater than 1.0 (Kaiser criterion) were retained as the primary extraction rule, supplemented by inspection of scree plots. Factor loadings on the first two principal components were examined to assess item-level contributions to the dominant dimensions. Scores on the first principal component (PC1) were extracted for each respondent and correlated with the corresponding Rasch ability estimate (Pearson's r) to provide convergent validity evidence.

Statistical testing

Community-level differences in Rasch ability scores were assessed by one-way Analysis of Variance (ANOVA), with community type (four levels) as the factor. Sex-based differences (Male, Female, Third Gender) were tested analogously. Where omnibus F-tests were significant, Tukey's Honestly Significant Difference (HSD) was applied for pairwise comparison at $\alpha = 0.05$. All analyses were executed in Python 3.11 (NumPy, SciPy, scikit-learn) and cross-verified in Stata 17.

Analysis and results

Sample characteristics

Of the 295 respondents, 30.5% (n = 90) were from Disabled/Begging populations, 25.8% (n = 76) Ethnic Minority (Adivasi), 24.1% (n = 71) Urban Slum, and 19.7% (n = 58) Dalit. By sex, females constituted 49.8% (n = 147), males 39.7% (n = 117), and Third Gender respondents 10.5% (n = 31). All Third Gender respondents resided in urban slum settlements, reflecting the geographic concentration of the hijra community in central Dhaka's informal housing.

Rasch model reliability and item fit

Reliability was strong in all three sectors. KR-20 coefficients were 0.826 for Health, 0.919 for Education, and 0.821 for Social Safety Net. The item infit and outfit mean-squares for all 37 items

fell within the acceptable 0.7–1.4 range, confirming adequate model–data fit across sectors and despite the considerable heterogeneity of the sample. Item difficulty parameters spanned approximately –2.6 to +2.1 logits, indicating a broad difficulty hierarchy well-targeted to the respondent population.

Table 1 summarizes item difficulty parameters for the five most difficult (i.e. rarest) items per , those that mark the frontier of service access for marginalized communities.

Table 1 Most difficult (rarest-achieved) service-access items per sector (Rasch δ , logits)

Sector	Description	δ (logits)	Interpretation
Health	Mental health services access	2.08	Hardest
Health	Specialist / hospital care	1.72	Very difficult
Education	Climate disruption to school calendar	1.37	Hardest
Education	Vocational / skills training	1.13	Very difficult
Social Safety Net	VGD/VGF registration	2.11	Hardest
Social Safety Net	Widow / distressed women's registration	2.01	Very difficult
Social Safety Net	Housing / shelter assistance	1.81	Very difficult

By contrast, the easiest items across sectors were Frequency of health facility visits, ($\delta = -2.52$), Primary school access, ($\delta = -1.59$), and Food assistance access, ($\delta = -2.49$), indicating that routine, low-barrier services are broadly reached even among the most marginalized. The item-difficulty gap between routine and gateway services is thus both wide and policy-actionable.

Rasch vulnerability scores by community

Table 2 reports mean Rasch ability scores by community across the three sectors and the composite. Higher (more positive) scores indicate better service access; more negative scores imply greater vulnerability.

Table 2 Mean rasch vulnerability scores (logits) by community type

Community	n	Health	Education	Social safety net	Overall	Rank
Ethnic Minority (Adivasi)	76	-0.258	-0.865	-0.732	-0.618	1 (most vulnerable)
Dalit	58	0.513	-1.690	0.59	-0.196	2
Disabled / Begging	90	-0.157	0.494	0.396	0.244	3
Urban Slum	71	0.056	1.681	-0.200	0.512	4 (least vulnerable)

One-way ANOVA confirmed statistically significant community-level differences in all four composites: Health ($F(3, 291) = 2.684, p = 0.047$), Education ($F(3, 291) = 26.481, p < 0.001$), Social Safety Net ($F(3, 291) = 4.824, p = 0.003$), and Overall ($F(3, 291) = 7.510, p < 0.001$). The Education sector displayed by far the strongest community effect. Tukey HSD pairwise comparisons revealed that Urban Slum dwellers had significantly higher education scores than all other groups, with the largest gap relative to Dalits (mean difference = 3.371 logits, $p < 0.001$). The Ethnic Minority–Dalit difference in education was not significant ($p = 0.18$), implying that these two rural and peri-urban communities face broadly comparable educational barriers. Ethnic Minorities emerged as the most overall-vulnerable community (-0.618 logits), driven by their weak Education and Social Safety Net performance, while Dalits showed the single most severe sector

deficit anywhere in the study (Education at -1.690 logits), consistent with persistent caste-based exclusion in school environments.

Rasch vulnerability scores by sex

Table 3 presents Rasch scores disaggregated by sex. Sex-based ANOVA revealed highly significant differences in Education ($F(2, 292) = 21.66, p < 0.001$), significant differences in Social Safety Net ($F(2, 292) = 3.45, p = 0.033$) and Overall vulnerability ($F(2, 292) = 4.98, p = 0.007$), while Health differences were not statistically significant ($F(2, 292) = 1.68, p = 0.188$). Female respondents scored approximately 0.5 logits lower than males both in Education and overall, consistent with broader Bangladesh literature on gender gaps in secondary and tertiary education linked to early marriage, domestic labour demands, and safety concerns.

Table 3 Mean rasch vulnerability scores (logits) by sex

Sex	n	Health	Education	Social safety net	Overall
Male	117	0.082	0.578	0.148	0.269
Female	147	-0.139	-0.628	-0.005	-0.257
Third Gender	31	-0.051	-0.411	0.32	-0.047

Third Gender respondents (all urban-slum residents) displayed a distinctive profile: a relatively positive Social Safety Net score (+0.320 logits), likely reflecting targeted NGO and hijra-community-specific interventions in Dhaka, but a clearly negative Education score (-0.411 logits), consistent with documented harassment and institutional

exclusion of gender-non-conforming individuals from schooling. The near-zero overall score (-0.047) therefore masks substantial within-individual unevenness, underscoring the importance of sector-specific rather than aggregate vulnerability measurement for gender minorities.

Principal component analysis and convergent validity

PCA of the polytomous Likert matrices confirmed a dominant first component in every sector. PC1 explained 34.2% of total variance in Health, 53.3% in Education, and 46.6% in Social Safety Net. All items loaded positively on their sector's PC1, supporting the interpretation of a general latent vulnerability dimension underlying each module. Secondary components with eigenvalues above unity (most noticeably in Health) suggest meaningful sub-dimensions (for example, awareness versus utilization, and community-based versus facility-based care), but do not contradict the essential unidimensional pattern required by the Rasch framework, since PC1 consistently dominated and item fit statistics remained within acceptable bounds.

The convergent validity between Rasch ability scores and PCA PC1 scores was very strong: $r = 0.952$ for Health, $r = 0.978$ for Education, and $r = 0.943$ for Social Safety Net (all $p < 0.001$, $N = 295$). These near-unity correlations demonstrate that the two methods, despite differing in input format (binary vs. Likert) and mathematical logic (IRT vs. eigen-decomposition), recover the same underlying construct. This provides robust psychometric validation for the use of Rasch logits as interval-level vulnerability measures in subsequent policy analysis.

Item-level insights for program design

The item-difficulty hierarchy carries direct programmatic implications. In the Health sector, the two most difficult items, namely mental health services and specialist/hospital care, identify secondary and tertiary care as essentially unreachable for the surveyed communities, pointing toward mobile specialist outreach, telemedicine, and structured referral systems as priority investments. In Social Safety Net, the highest difficulties are concentrated on registration rather than awareness, with VGD/VGF registration and widow's allowance registration emerging as the principal bottlenecks. This pattern is consistent with reports of documentary complexity, elite capture of beneficiary lists, and administrative opacity impeding conversion of eligibility into enrolment. Awareness campaigns alone are therefore insufficient: simplified documentation, registration-facilitation desks, and community-based intermediaries are required. In Education, the hardest-to-reach experiences were climate-disruption resilience of the school calendar and vocational/skills training, pinpointing the intersection of climate adaptation and human-capital investment as a critical policy frontier.

Conclusion

This study applied the Rasch IRT model and PCA to assess, compare, and validate the vulnerability of 295 marginalized respondents across four community types and three service sectors in Dhaka Division, Bangladesh. The Rasch framework yielded highly reliable vulnerability scales ($KR-20 = 0.821-0.919$), and the convergent validity with PCA-based composites ($r = 0.943-0.978$) was near-unity, establishing both the internal consistency and construct validity of the vulnerability measures. Ethnic Minorities (Adivasi) emerged as the most vulnerable community overall (mean Rasch = -0.618 logits), followed by Dalits (-0.196), while Urban Slum dwellers, despite their income poverty, registered the highest service-access scores, reflecting the distinctive character of urban poverty as one of access alongside precarity rather than simple absence of services. Educational vulnerability exhibited the largest community effect ($F = 26.48$, $p < 0.001$), with Dalits facing the most severe barrier of any group in any sector. Sex-based analysis confirmed that females are significantly more educationally vulnerable than males, while

Third Gender respondents presented a distinctive mixed profile with stronger social-protection access but weaker educational inclusion.

Beyond aggregate rankings, the item-level results identify the specific entitlements that constitute the main access frontier for marginalized communities: mental health services, specialist care, VGD/VGF and widow's-allowance registration, and housing assistance. Policy responses should therefore move from undifferentiated awareness campaigns toward registration facilitation, mobile specialist outreach, anti-discrimination protocols in Dalit-receiving schools, mother-tongue multilingual education for Adivasi children, physical-accessibility standards in health facilities, and targeted social-protection instruments for Third Gender individuals. Methodologically, the study establishes the Rasch model as a rigorous, replicable, and policy-actionable framework for multi-sector vulnerability measurement in South Asia, one that moves beyond composite indices to identify precisely which services fail which communities, and by how much.

Several limitations are acknowledged. The cross-sectional design precludes causal inference; the sample size within specific sex-by-community cells (particularly Third Gender) is modest; and the absence of Third Gender respondents in rural strata constrains generalizability for that subgroup. A longitudinal follow-up at 24-month intervals, expanded geographic coverage beyond Dhaka Division, and deeper qualitative exploration of caste-based and gender-based exclusion mechanisms constitute priority directions for future research. Notwithstanding these limitations, the study demonstrates that rigorous, intersectional, publication-quality vulnerability measurement is feasible within modest research budgets, and offers a replicable template for evidence generation in resource-constrained settings.

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Conflicts of interest

The author declares that there is no conflict of interest.

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