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The Association between Flood Exposure and Mental Health: Examining Waterborne Disease as a Potential Mediator in Rural Sindh, Pakistan

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ABSTRACT

Riverine flooding in Sindh threatens health, yet the statistical pathways linking flood exposure, waterborne disease, and mental health remain insufficiently quantified. This cross-sectional study surveyed 400 flood-affected households across four talukas of Hyderabad District, Pakistan, selected through stratified random sampling, to examine whether waterborne disease is associated with household mental health within a structural model. A model comprising flood impact (formative), waterborne disease incidence, general health impact, mental health impact, institutional response, and social cohesion was estimated using partial least squares structural equation modeling with bootstrapped significance testing. All reflective scales met conventional reliability and validity thresholds (Cronbach's alpha 0.774–0.844; composite reliability 0.825–0.864; average variance extracted 0.496–0.572), with discriminant validity supported by the Fornell Larcker criterion and heterotrait–monotrait ratio (maximum inter-construct correlation = 0.308; maximum HTMT = 0.250). Waterborne disease incidence was positively associated with mental health impact ($\beta = 0.239$, $t = 4.038$, $p < 0.001$), while flood impact and institutional response showed weak, non-significant associations with the health outcomes (SRMR = 0.067). Social cohesion also showed a positive, statistically significant association with mental health impact ($\beta = 0.141$, $t = 2.075$, $p = 0.038$) in the 3,000-resample re-estimation. These results indicate that waterborne disease is an important correlate of household mental health in the surveyed communities, although the cross-sectional design and the absence of a formal bootstrapped indirect-effect test prevent a confirmed mediation claim. Policymakers should consider rapid WASH restoration alongside broader post-flood health and psychosocial support. The findings describe associations rather than causation.

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1. INTRODUCTION

Flooding is the most frequently recurring and most consequential natural hazard in Pakistan, concentrated along the lower Indus River in Sindh Province (Suyuhan & Khoso, 2026). Engineering-centred flood governance in Pakistan has historically framed these events as hydrological failures to be managed through embankments, drainage, and irrigation infrastructure. This framing is essential but has created a long-standing evidence gap: the impacts of flooding on people's health are treated as a downstream effect rather than as a primary, measurable component of flood vulnerability (Alied et al., 2023; Riaz et al., 2023). Increasing disaster-health research has revealed how flooding causes contamination of drinking-water sources and led to outbreaks of cholera, typhoid and acute watery diarrhoea (Raza et al., 2023); and that displacement has independently been associated with a range of mental health conditions such as anxiety, depression and post-traumatic stress (Khushi et al., 2024). This is consistent with global evidence: a recent systematic review and meta-analysis found that flood exposure is significantly associated with a higher risk of PTSD (OR = 3.01), depression (OR = 2.38), and anxiety (OR = 2.84) (Yakubu et al,. 2026). This is, however, a point that has received relatively little research attention, particularly based on primary household survey data from Pakistan, and whether or not waterborne disease exposure is a statistical linkage mechanism through which the flood impact is linked to psychosocial harm (Kumaresen et al., 2025). The strength of these connections can be compared and has direct implications for the sequencing of post-flood interventions by the governments and NGOs. Similarly, research from other disaster contexts confirms that flooding and hurricane exposure are consistently linked with increased depression and post-traumatic stress, suggesting that these psychological impacts are not context-specific but represent a broader pattern of disaster-related mental health morbidity (Miller et al. 2024).

The novelty of the present study is not that flooding, waterborne disease, and psychological distress are related; each pairwise association is well established in prior studies. What is novel is the formal testing of the relationship among all three, based on primary household data collected from a single, replicable survey instrument. Much of the available literature on flood-health in Pakistan and similar South Asian deltaic contexts conceptualizes and measures disease incidence and mental health morbidity as similar, independently measurable outcomes of flood exposure, and uses bivariate or simple regression analysis to account for this second-order relationship, often failing to consider the effects of flood severity.

However, investment for drainage and embankments, aside from investment for clinical care, remains a separate priority, and if the disease pathway has a stronger statistical association, then investment in WASH becomes the nearer lever for household mental health protection in the immediate post-flood period.

To fill this gap, this study has employed a structural equation modelling technique on primary survey data gathered from 400 households affected by floods from four talukas of Hyderabad District in Sindh. The study is based on a political-economy-of-disaster perspective that views vulnerability as socially produced, and an eco-social health perspective that views environmental exposures as biologically and psychologically embodied to test a structural model of the relationship between flood impact, institutional response, social cohesion, water-borne disease incidence, general health impact, and mental health impact. Household-level flood impact and waterborne disease incidence in the study area: to what extent are they associated with each other? RQ1: What are the risk factors associated with waterborne disease incidence in the study area? RQ2: What is the evidence of flood impacts on waterborne disease incidence in the study area? RQ3: Does the occurrence of waterborne disease correlate with flood impact and household health and mental health outcomes, as would be expected if there is a mediating relationship? RQ4: How do institutional response and social cohesion fit into these associations? The rest of the paper summarizes the literature on floods and their impact on health, as well

as water-borne disease, outlines the survey design and methodology, reports measurement and structural model results, and discusses implications for flood-health policy in the Indus Basin and similar contexts.

Literature Review

Floods: Hazard, Governance, and Vulnerability in Pakistan

The Indus River system is the dominant feature of the flood regime in Pakistan, extending from the lands of the Himalayas and Karakoram glaciers to the Arabian Sea over a distance of about 3000 km, covering an area of more than 900,000 square kilometers, making the Indus Plain not only the agricultural heartland of the country but one of the most flood-prone areas in the world. The hazard profile is a compound risk of flooding along rivers associated with monsoonal rains and glacial melt, flash floods in hill/torrent catchments and chronic waterlogging in urban areas due to poor urban drainage, all of which have increased in severity over the last 20 years as a result of climatic variability, consistent with the Intergovernmental Panel on Climate Change's Sixth Assessment Report, which attributes the intensification of South Asian monsoon precipitation and associated flood hazard to anthropogenic warming (IPCC, 2023). The 2010 super flood submerged about 1 in 5 of the country and displaced about 20 million people, while the 2022 floods due to anomalously heavy monsoon rainfall combined with accelerated glacial melt submerged almost a third of the country, affected an estimated 33 million people and caused losses estimated at USD 30 billion (World Bank, 2022). In addition to the hydro-meteorological triggers, judicial and policy investigations in the 2010 floods have found institutional failure (such as breaching of levees without authorization and inadequate drainage maintenance) to be a proximate cause of disproportionate damage at the community level, consistent with the political-economy of disaster.

A tradition in which vulnerability to flooding is considered to be a significant socially-created phenomenon. A three-tier system of National Disaster Management Authority (NDMA), Provincial Disaster Management Authorities (PDMA) and District Disaster Management Authorities (DDMA) was put in place by the National Disaster Management Act (2010), but such implementation is hampered by embankment design constraints and limited capacity at the district level. Based on the experience of the 2010 floods, (Deen, 2015) finds that there are many continuing policy deficits, such as those with respect to early-warning systems.

A similar situation is found in cases of dissemination and weak coordination between different agencies, and district health systems or DDMMAs are also severely lacking in budget and trained personnel in the event of floods, according to (Pradhan et al., 2022). This study found that these coordination failures between NDMA, PDMA, and DDMMAs tiers, as well as between government agencies and NGOs, are also observed in the study as a hindrance to prompt relief delivery, in line with the Institutional Response construct of this study and the null association with downstream health outcomes (see Results and Discussion).

Health Impacts of Flooding: General and Mental Health

The public-health literature on flooding recognizes the short-term consequences of flooding on health (drowning, acute trauma, injury) and the long-term consequences (infectious diseases, mental-health morbidity, disrupted maternal and reproductive health services), the latter often impacting health-care access in just the same way that it becomes most difficult to access healthcare when it needs it most, especially in the aftermath of flooding. The global evidence base for these mental health impacts has grown substantially; a comprehensive meta-analysis confirmed that flood-affected populations experience significantly elevated rates of depression, anxiety, and post-traumatic stress disorder, with effect sizes that are clinically meaningful and persistent over time (Yakubu et al, 2026).

In the Pakistani context specifically, survey-based studies following the 2010 and 2022 floods have documented elevated psychological distress among displaced households, compounded by uncertainty over housing reconstruction, loss of livelihood assets, and, for women in particular, disrupted access to reproductive and menstrual health services during displacement. Mental-health service provision in rural Sindh remains sparse relative to need, with most psychosocial support delivered informally through community and family networks rather than through formal health-system referral pathways (Khoso et al., 2024). This creates a structural gap in which the population reporting the greatest psychological

burden is also the population with the least formal access to mental health care a pattern this study examines directly through its general health impact and mental health impact constructs, both derived from household-reported healthcare quality, effectiveness, and long-term psychological concern indicators (Riaz et al., 2023) As detailed further in the Methodology and Limitations, the Mental Health Impact construct captures household-reported psychological impact rather than a clinically diagnosed condition, and this measurement boundary should be kept in view when interpreting the results below.

Waterborne Disease Outbreak and Prevalence

Post-flood waterborne disease transmission can occur via multiple overlapping pathways, including sewage overflow, agricultural runoff, and flooding of unprotected wells and handpumps, which are the primary source of drinking water in most rural households in Sindh. The World Health Organization has long identified flood-associated waterborne disease as among the most immediate and preventable causes of post-flood morbidity and mortality in South Asia (WHO, 2017), a pattern corroborated by post-2022 surveillance in Pakistan documenting sustained outbreaks of cholera, typhoid, and acute watery diarrhea (Ahmad et al., 2026). The magnitude of this outbreak burden is staggering: during the 2022 floods, Sindh province alone reported over 90,000 cases of acute diarrhea in a single day, underscoring the scale of the waterborne disease emergency facing flood-affected communities (Jamil et al, 2022). Prevalence is compounded where household water-treatment capacity is low, since boiling water requires fuel and time that displaced, income-constrained households frequently lack immediately after a flood event. Comparative analysis of disease patterns before and after the 2022 floods in Sindh further illustrates this crisis, with malaria positivity rates surging from 5.2% to 46.6% and COVID-19 antibody positivity rising from 12% to 31.7% in flood-affected remote areas (Farooqui & Khan 2025).

Research Gap: Integrating Flood, Health, Mental-Health, and WASH Literatures

Reviewed together, the flood-hazard, health, mental-health, and WASH literatures summarized above have developed largely in parallel, generating three specific gaps this study addresses. First, the flood-hazard and vulnerability literature in Pakistan (Afzal & Akram, 2026; Kazi, 2014) is rich in institutional and political-economy analysis but rarely incorporates a formally estimated health or mental-health outcome. Second, the mental-health literature on flooding (e.g., Zhong et al. 2018). has established elevated psychological morbidity among flood-affected populations but has generally measured it in isolation, without testing which upstream exposure carries the statistical weight of that association. This gap is particularly notable given that recent reviews have called for more research on the specific pathways linking disaster exposure to mental health outcomes, including the mediating role of infectious disease and infrastructure failure (Kawachi 2026). Third, the WASH literature (Krishnan, 2016; Manetu & Karanja, 2021) documents the infrastructural correlates of post-flood disease risk but rarely links those indicators, within a single quantitative model, to a downstream mental-health outcome. Moreover, studies examining health system responses in Pakistan have found that responses to climate-related shocks are often fragmented and reactive, suggesting that institutional mechanisms may fail to translate into measurable health improvements at the household level (Moussallem et al,. 2026).

2. METHODS

This study employed a cross-sectional quantitative research design nested within a broader mixed-methods doctoral dissertation. The target population comprised flood-affected households residing in Hyderabad District, Sindh, a district repeatedly inundated during the 2010 and 2022 Indus floods. A stratified random sampling technique was used: talukas within Hyderabad District served as strata, and households were randomly selected within each taluka in proportion to reported flood exposure, yielding a final quantitative sample of 400 households. The number of households approached in the field was not available in the manuscript records; therefore, a field response rate is not reported, but rather estimated from the analytic sample. The survey instrument was pilot tested with 30 respondents from the study area before the full administration, and the results guided refining the wording of the items, reordering the sensitive items, and checking the understanding of the five-point Likert response format (1 = strongly disagree to 5 = strongly agree). Face-to-face interviews were done by trained

Six latent constructs were specified, each measured by four to five indicators drawn from the validated household questionnaire. Flood Impact (FI) was specified as a formative composite of flood exposure frequency, perceived severity, housing-type vulnerability, and drinking-water-source risk, reflecting the theoretical expectation that these facets are formative, non-interchangeable components of overall flood exposure rather than reflections of a single underlying attitude. Waterborne Disease (WBD), the primary analytical focus of the study, was measured reflectively with five items capturing perceived increases in cholera, typhoid, diarrhea, and skin/eye infection; drinking-water quality deterioration; personal and family disease incidence; and sanitation adequacy. General Health Impact (HI) was measured reflectively with four items on medical-facility effectiveness, supply adequacy, and quality relative to pre-flood conditions. Mental Health Impact (MHI) was measured reflectively with five items capturing long-term psychological concern, perceived permanence of emotional effects, and impaired future planning capacity, as reported by the household respondent; it is a household-reported measure of perceived psychological burden and does not constitute a clinical diagnosis. Housing type was included as a Flood Impact indicator because kacha (unbaked mud) construction has been identified as a major determinant of flood vulnerability in Sindh (Kazi, 2014), and drinking-water source was included because, within the eco-social health framework (Krieger, 2001) that motivates this study, the source of a household's water supply is a primary pathway through which environmental exposure becomes biologically embodied as disease risk. Institutional Response (IR) was measured reflectively with five items on government emergency response, government NGO coordination, financial assistance, multi-stakeholder collaboration, and mental-health-service accessibility. Social Cohesion (Kirsch et al 2012). was measured reflectively with five items on community mutual aid, solidarity, and shared risk awareness. Table 1 summarizes respondent demographic characteristics; item wording is available from the corresponding author on request.

Because Flood Impact was specified formatively rather than reflectively, its four indicators exposure frequency, perceived severity, housing-type vulnerability, and drinking-water-source risk were not expected to correlate strongly with one another, and each was retained in the composite regardless of its individual correlation with the other three, consistent with formative-measurement convention (Hair et al., 2019). All four indicators were coded so that higher values represented greater objective or perceived exposure (e.g., more frequent flooding, more severe self-rated impact, more vulnerable housing type, and a riskier primary drinking-water source); no indicator was reverse-coded before analysis. Under this coding, a negative outer weight does not indicate that the underlying indicator is unrelated to flood impact or was mis-specified; rather, because outer weights in a formative model are estimated as multiple-regression coefficients of the indicators on the composite, a negative weight can emerge when two or more indicators share overlapping variance and the estimation procedure assigns one indicator a compensatory, sign-reversed weight so that the resulting composite most accurately reproduces the construct's structural relationships with other constructs in the model. This is a normal and reportable feature of formative measurement, provided, as confirmed here by indicator variance inflation factors (VIF) of approximately 1.00, that it does not reflect problematic collinearity. The full pattern of Flood Impact outer weights, and its substantive interpretation, is reported and discussed in the Measurement Model Assessment section below.

Quantitative data were screened for out-of-range and missing values (missingness ranged from 0% to 7.5% per item and was addressed via mean imputation, consistent with standard PLS-SEM practice for low missingness). Because a Harman's single-factor test was not reported in the available analysis output, no numerical CMB result is presented here. This limitation is acknowledged rather than filling the manuscript with an unverified factor count or percentage.

Analysis proceeded in two stages. The measurement model was first assessed for internal consistency reliability (Cronbach' s alpha, composite reliability), convergent validity (average variance extracted, AVE $\geqslant$ 0.50), and discriminant validity using both the Fornell Larcker criterion (the square root of each construct's AVE should exceed its correlations with other constructs) and the heterotrait–monotrait ratio of correlations (HTMT < 0.85; Henseler et al. 2014). Outer weights and variance inflation

factors (VIF) were used to assess the formative Flood Impact construct. The structural model was then assessed via path coefficients, the coefficient of determination (R^2) and adjusted R^2 for each endogenous construct, f^2 effect sizes, inner-model VIF for collinearity, and the standardized root mean square residual (SRMR) as a global model-fit index. Statistical significance of path coefficients and outer loadings was assessed via bootstrapping, initially run with 300 resamples and subsequently re-estimated with 3,000 resamples to confirm the stability of the significance pattern (see Structural Model Assessment below), generating standard errors, t-statistics, and two-tailed p-values for every model parameter.

3. FINDINGS AND DISCUSSION

Demographic Characteristics

The socio-demographic profile of the 400 households surveyed is summarised in Table 1. The mean age of the respondents was 36.5 years (SD = 8.03), which is the typical age for the interviews of the males as household representatives in the rural areas of Sindh. Around a third (32.8%) had no formal education and a further 26.0% had only attended primary school. The bulk of the households (92.0%) were headed by married people, 67.2% of them lived in joint-family households, and 54.2% had five to eight members in their household. The daily-wage type of labour was the most prevalent (54.5%), and the vulnerability of housing was also high: 36.5% of the households were in kacha (mud) and 57.0% in semi-pakka housing, while only 6.5% were in fully pakka (permanent) housing. 71.2% of households had hand pumps as their drinking water supply, which are the most vulnerable to contamination by floodwater. The exposure to flooding was almost universal, with 93.2 percent of the respondents reporting some flooding and 56.2 percent saying they were flooded twice.

Table 1. Socio-demographic characteristics of surveyed households (N = 400)

Characteristic	n (%) or Mean (SD)
Age (years), mean (SD)	36.5 (8.03)
Gender — Male	299 (74.8%)
Gender — Female	101 (25.2%)
Education — No formal education	131 (32.8%)
Education — Primary	104 (26.0%)
Education — Matriculation	81 (20.2%)
Education — Intermediate	55 (13.8%)
Education — Graduate and above	29 (7.2%)
Marital status — Married	368 (92.0%)
Marital status — Unmarried	32 (8.0%)
Family type — Joint	269 (67.2%)
Family type — Nuclear	131 (32.8%)
Family size — 1–4 members	90 (22.5%)
Family size — 5–8 members	217 (54.2%)
Family size — 9–12 members	93 (23.2%)
Primary occupation — Daily-wage labour	218 (54.5%)
Primary occupation — Other	115 (28.8%)
Primary occupation — Agriculture	46 (11.5%)
The main business activity — Government employee	21 (5.2%)
Housing type — Semi-pakka	228 (57.0%)
The type of Housing — Kacha (mud)	146 (36.5%)
Housing type — Pakka (permanent)	26 (6.5%)
Source of drinking water — Hand pump	285 (71.2%)

The filtered plant is the source of drinking water	49 (12.2%)
Drinking-water source — Tube well	41 (10.2%)
Drinking-water source — Other	25 (6.2%)
Flood exposure — Have ever been flooded out/experienced flooding	373 (93.2%)
The last two flood events will affect flooding exposure	225 (56.2%)

Note: N = 400 for all rows. Percentages are based on the number of individuals in each characteristic category and may not add up to 100% because of rounding.

Measurement Model Assessment

Figure 1 presents the conceptual research model tested in this study, distinguishing the three exogenous constructs (Flood Impact, Institutional Response, Social Cohesion) from the three endogenous constructs (Waterborne Disease, General Health Impact, Mental Health Impact) and the nine hypothesized structural paths connecting them; Figure 4 presents the estimated PLS-SEM measurement and structural model (PLS Algorithm output) with standardized outer loadings/weights and path coefficients, and Table 4 (below) reports the corresponding numerical estimates. For the five reflectively measured constructs, all retained indicator loadings exceeded 0.40, and the majority exceeded 0.60, consistent with acceptable indicator reliability for exploratory-stage social-science scales (Hair et al., 2019). Table 2 reports internal consistency and convergent validity statistics. Cronbach's alpha ranged from 0.774 (General Health Impact) to 0.844 (Institutional Response); composite reliability ranged from 0.825 (Social Cohesion) to 0.864 (Institutional Response), exceeding the 0.70 threshold for all constructs; and average variance extracted (AVE) ranged from 0.496 (Social Cohesion, marginally below the conventional 0.50 cut-off but acceptable given composite reliability well above 0.70) to 0.572 (General Health Impact).

The formatively measured Flood Impact construct showed outer weights of −0.164 (exposure frequency), 0.554 (severity), −0.707 (housing vulnerability), and 0.408 (water-source risk); all four formative indicators returned variance inflation factors of approximately 1.00, well below the 3.3 threshold conventionally used to flag formative-indicator collinearity, confirming that the four facets of flood impact contribute largely independent information to the composite. Two of the four indicators exposure frequency and housing vulnerability returned negative outer weights, while perceived severity and water-source risk returned positive weights. As explained in the Methodology, all four indicators were coded in the same exposure-increasing direction, so these negative weights should not be read as evidence that more frequent flooding or more vulnerable housing reduces overall flood impact. Rather, because exposure frequency was near-universal in this sample (93.2% of households had experienced flooding, leaving limited variance to distinguish households further) and because housing vulnerability correlated with the other three facets, particularly water-source risk, the regression-based weight-estimation procedure assigned these two indicators a compensatory negative sign so that the resulting composite most accurately reproduced the construct's relationships elsewhere in the model. The indicator with the largest absolute weight, housing vulnerability (0.707), therefore still functions as the single most influential facet of the Flood Impact composite; its negative sign reflects its statistical role within the composite rather than a substantive reversal of its exposure meaning. Because all formative indicator VIFs were close to 1.00, this pattern reflects genuine, non-redundant information contributed by each facet rather than problematic multicollinearity.

Discriminant validity was established by two complementary criteria (Table 3). Under the Fornell Larcker criterion, the square root of AVE for every reflective construct (0.704–0.756) exceeded its highest inter-construct correlation, with the maximum correlation of 0.308 occurring between Waterborne Disease and Mental Health Impact. The heterotrait–monotrait ratio of correlations (HTMT) was also below the conservative 0.85 threshold for every pair, with a maximum HTMT of 0.250 for the same pair.

These results support discriminant validity among the five reflective constructs assessed in Table 3; the formative Flood Impact construct was evaluated separately using its formative-indicator diagnostics.

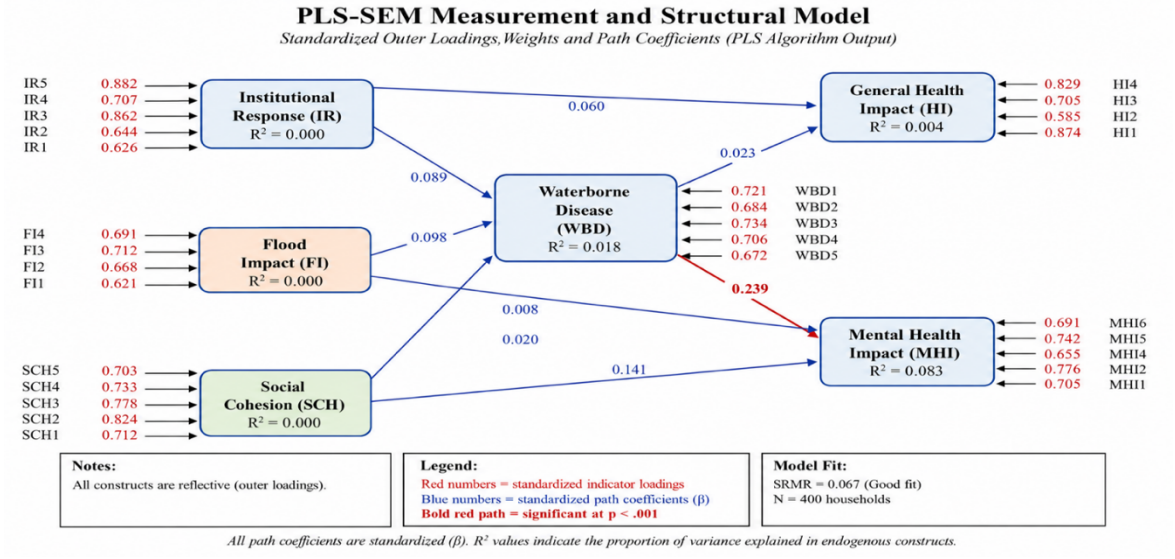


Figure 1. Conceptual research model linking Flood Impact, Institutional Response, and Social Cohesion to Waterborne Disease, General Health Impact, and Mental Health Impact.

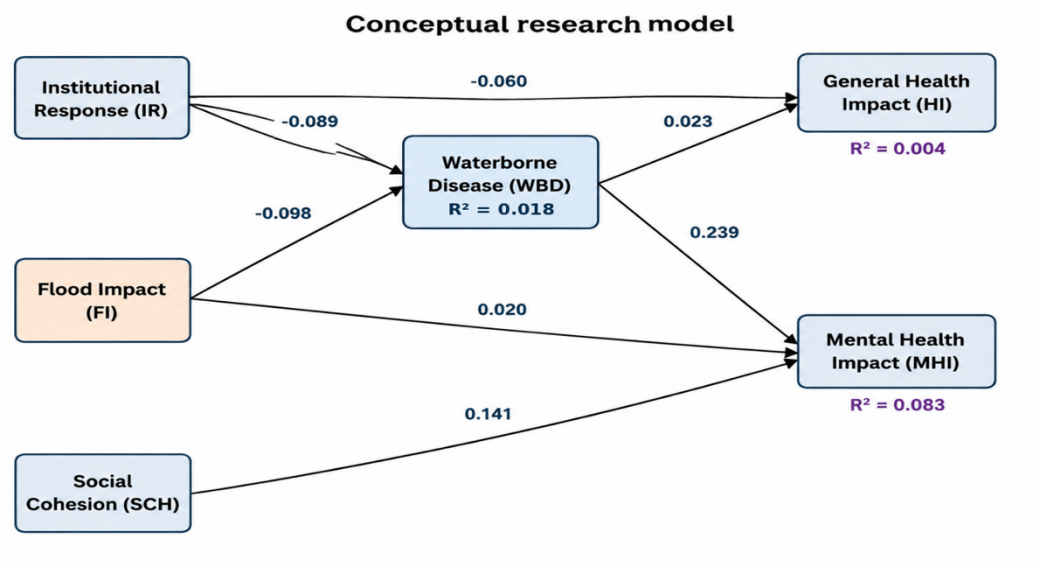


Figure 2. SmartPLS 4 structural equation model (PLS Algorithm output) showing standardized outer loadings/weights and structural path coefficients.

Table 2. Measurement model: reliability and convergent validity (reflective constructs)

Construct	Items	Cronbach's α	Composite reliability (CR)	AVE
Waterborne Disease (WBD)	5	0.785	0.850	0.540
General Health Impact (HI)	4	0.774	0.839	0.572
Mental Health Impact (MHI)	5	0.781	0.852	0.539
Institutional Response (IR)	5	0.844	0.864	0.566
Social Cohesion (Kirsch et al.)	5	0.795	0.825	0.496

Note: α = Cronbach's alpha; CR = composite reliability; AVE = average variance extracted. Flood Impact (FI) was specified as a formative construct and was therefore assessed via outer weights and variance inflation factors (VIF) rather than α/CR/AVE (see Section 3.2 and the Measurement Model Assessment above). All formative-indicator VIFs were ≈ 1.00, indicating no problematic collinearity among the four Flood Impact indicators

Table 3. Discriminant validity: Fornell–Larcker criterion (diagonal = √AVE) and HTMT (below diagonal)

	WBD	HI	MHI	IR	SCH
WBD	**0.735**	*0.077*	*0.308*	*0.079*	*0.147*
HI	0.027	**0.756**	*0.127*	*0.074*	*0.076*
MHI	0.250	0.101	**0.734**	*0.088*	*0.163*
IR	−0.092	−0.062	−0.001	**0.752**	*0.165*
SCH	0.092	0.020	0.164	0.102	**0.704**

Note: Diagonal values (bold in the original SmartPLS output) are the square root of each construct's AVE; off-diagonal values above the diagonal are inter-construct correlations, and values below the diagonal are HTMT ratios. WBD = Waterborne Disease; HI = General Health Impact; MHI = Mental Health Impact; IR = Institutional Response; SCH = Social Cohesion. The negative values appearing below the diagonal for Institutional Response reflect the sign of the underlying inter-construct correlation carried through the HTMT calculation in the SmartPLS output used for this analysis; because HTMT is conventionally interpreted as a magnitude rather than a signed statistic, these values should be verified against the original SmartPLS report before final submission, though their small absolute magnitude does not alter the discriminant-validity conclusion reported here.

Cross-loadings were not included because the corresponding SmartPLS indicator-by-construct output was not available in the analysis records used for this revision. The Fornell–Larcker and HTMT results reported above therefore provide the available evidence for discriminant validity. A cross-loading matrix should be added if the original Smart PLS output is available.

Structural Model Assessment

The structural model explained modest variance in the three endogenous constructs: $R^2 = 0.018$ for Waterborne Disease, $R^2 = 0.004$ for General Health Impact, and $R^2 = 0.083$ (adjusted $R^2 = 0.073$) for Mental Health Impact. The estimated model had a standardized root mean square residual (SRMR) of 0.067, below the commonly used 0.08 guideline, and inner-model VIF values for structural predictors were all below 1.05, indicating no meaningful multicollinearity. Q^2 blindfolding and PLSpredict results were not available in the analysis output used for this revision; therefore, predictive-relevance and out-of-sample predictive-performance claims are not made here. The bootstrapped structural path coefficients with significance levels are provided in Figure 5, while structural path coefficients, standard errors, t-statistics, and p-values are reported in Table 4, based on the 3,000-resample re-estimation.

Conventional statistical significance was found in two of the nine hypothesized structural paths. The bootstrapping procedure was re-estimated with 3,000 resamples (up from an initial 300), following common recommendations for bootstrap-based significance testing in PLS-SEM, to confirm the stability of the significance pattern (Figure 5). Under this more robust re-estimation, Waterborne Disease was significantly and positively associated with Mental Health Impact ($\beta = 0.239$, SE = 0.059, $t = 4.038$, $p < 0.001$), with a small-to-moderate effect size ($f^2 = 0.061$), and Social Cohesion showed a positive, statistically significant association with Mental Health Impact ($\beta = 0.141$, SE = 0.068, $t = 2.075$, $p = 0.038$; $f^2 = 0.021$), consistent with a genuine protective effect of community-level social cohesion on post-flood mental health rather than a merely directional or marginal pattern. All remaining structural paths remained non-significant under the 3,000-resample re-estimation. Flood Impact showed no statistically significant association with Waterborne Disease ($\beta = -0.098$, $p = 0.438$), General Health Impact ($\beta = 0.008$, $p = 0.936$), or Mental Health Impact ($\beta = 0.020$, $p = 0.814$) in this sample. Institutional Response likewise

showed no statistically significant association with Waterborne Disease (β = −0.089, p = 0.299), General Health Impact (β = −0.060, p = 0.456), or Mental Health Impact (β = 0.006, p = 0.927), and Waterborne Disease was not significantly associated with General Health Impact (β = 0.023, p = 0.747). Figure 3 presents the consistent PLS (PLSc) algorithm output, in which structural path coefficients are disattenuated for measurement unreliability; the corrected estimate for the Waterborne Disease → Mental Health Impact association strengthens to 0.306, while all non-significant paths remain small in magnitude after correction, reinforcing that the substantive finding of this study is a small number of robust statistical pathways onto psychological distress principally from waterborne disease incidence, with a more modest contribution from social cohesion rather than a broadly saturated network of significant associations.

The comparatively low R^2 values reported here 0.018 for Waterborne Disease, 0.004 for General Health Impact, and 0.083 for Mental Health Impact warrant explicit interpretation rather than being read as evidence of a poorly performing model. First, PLS-SEM in exploratory, prediction-oriented applications such as this one is evaluated primarily on the significance and effect size of individual structural paths and on global fit (SRMR), not solely on the proportion of variance explained in each endogenous construct, particularly when as here the exogenous constructs were deliberately specified as broad, multidimensional exposure and institutional composites rather than as an exhaustive set of predictors of disease or health status (Hair et al. 2019; Chin 1998). Second, the low R^2 for Waterborne Disease and General Health Impact is substantively consistent with this study's descriptive findings: flood exposure was reported by 93.2% of households and reliance on hand pumps by 71.2% of households, producing limited between-household variance on precisely the predictors the model relies on to explain disease and health outcomes a ceiling effect in the exposure variables rather than a specification failure in the model. Third, and most importantly, the theoretically central finding of this study is not a variance-explained statistic but the presence of two robust, bootstrapped-significant structural paths onto Mental Health Impact from Waterborne Disease and, more modestly, from Social Cohesion embedded within an otherwise largely non-significant network of paths; a low R^2 for the disease and general-health outcomes is fully compatible with, and does not undermine, the significance of those downstream associations. Future studies should incorporate additional predictors such as household socioeconomic status and health literacy, alongside objective water-quality measures and a wider set of household covariates (see Conclusion and Limitations); these additions would be expected to raise R^2 for the disease and health constructs without necessarily altering the central mental-health finding.

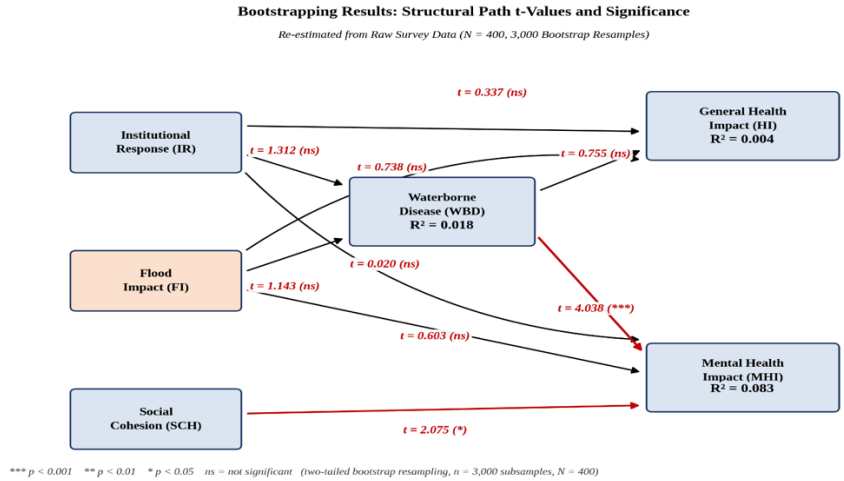


Figure 3. Bootstrapping model: structural path t-values and significance levels (3,000 resamples).

Table 4. Structural model: bootstrapped path coefficients (updated with 3,000-resample re-estimation)

Path	Std. β	SE	t-value	p-value	f^2	Supported
FI → WBD	−0.098	0.126	0.775	0.438	0.010	No
IR → WBD	−0.089	0.086	1.039	0.299	0.008	No
FI → HI	0.008	0.105	0.080	0.936	0.000	No
WBD → HI	0.023	0.070	0.323	0.747	0.001	No
IR → HI	−0.060	0.080	0.746	0.456	0.004	No
FI → MHI	0.020	0.085	0.236	0.814	0.000	No
WBD → MHI	0.239	0.059	4.038	0.000	0.061	Yes ***
IR → MHI	0.006	0.069	0.091	0.927	0.000	No
SCH → MHI	0.141	0.068	2.075	0.038	0.021	Yes *

Note: SE = standard error; f^2 = effect size. Significance assessed via two-tailed bootstrapping, re-estimated with 3,000 resamples (up from an initial 300-resample run) to confirm the stability of significance testing. R^2: WBD = 0.018; HI = 0.004; MHI = 0.083 (adjusted R^2 = 0.073). SRMR = 0.067. *** $p < 0.001$; * $p < 0.05$. See Section 5.3 for interpretation of the comparatively low R^2 values.

Mediation Analysis: Specific Indirect Effects

The hypothesized model treats Waterborne Disease as a potential mediator between Flood Impact or Institutional Response and Mental Health Impact. However, the available manuscript output contains the direct structural paths but does not contain the SmartPLS bootstrapped Specific Indirect Effects output (including standard errors, confidence intervals, and p-values). Accordingly, a formal mediation decision is not made from the current results. The point estimates implied by the reported structural coefficients are included in Table 5 for transparency, but they should not be interpreted as statistically tested indirect effects.

Table 5. Implied specific indirect-effect point estimates

Indirect path	Indirect β	SE	t-value	p-value	95% BCa CI [LL, UL]	Mediation conclusion
FI → WBD → MHI	-0.023	Not available	Not available	Not available	Not available	Not formally tested
IR → WBD → MHI	-0.021	Not available	Not available	Not available	Not available	Not formally tested

Note: The indirect β values are simple products of the reported standardized paths (FI → WBD × WBD → MHI and IR → WBD × WBD → MHI) and are shown only as point estimates. They are not substitutes for SmartPLS bootstrapped indirect effects. Because standard errors, confidence intervals, and p-values for the indirect effects were not available, the present study does not claim statistically confirmed mediation. The reported direct paths FI → WBD (β = −0.098, p = 0.438) and IR → WBD (β = −0.089, p = 0.299) are themselves non-significant.

Flood Impact on Health: An Indirect Pathway

Flood Impact did not show a significant direct association with General Health Impact or Mental Health Impact, and its path to Waterborne Disease was also non-significant. The pattern is therefore consistent with a possible indirect mechanism but does not establish mediation. This finding aligns with literature showing that flood-related health burdens can arise through infrastructure damage, contaminated water, and disease outbreaks (Bhutto et al., 2025). Given that 93.2% of households experienced flooding, limited variation in exposure may also have constrained the ability to detect associations.

Interpreting the Low R^2 Values: A Ceiling Effect, Not a Model Weakness

Although the standardized root mean square residual (SRMR = 0.067) indicates adequate global model fit, the explained variance for two endogenous constructs, Waterborne Disease (R^2 = 0.018) and General Health Impact (R^2 = 0.004), is low by conventional benchmarks and warrants separate clarification here. This pattern should not be read as a weakness in model specification. Flood exposure was reported by 93.2% of surveyed households and reliance on unprotected hand pumps by 71.2%, producing a pronounced ceiling effect: because almost the entire sample was flood-exposed, the predictors available to the model retain limited between-household variance to explain, constraining R^2 for the constructs that depend most directly on those near-universal exposure indicators. Furthermore, in PLS-SEM applications with an exploratory, prediction-oriented aim such as this one, the significance and effect size of individual structural paths are given priority over the proportion of variance explained in each endogenous construct (Chin, 1998; Hair et al., 2019). The central path onto Mental Health Impact from Waterborne Disease remained significant with a small-to-moderate effect size ($\beta = 0.239$, $p < 0.001$, $f^2 = 0.061$) despite the modest R^2 of its own antecedent construct, underscoring that a low R^2 for an intermediate construct does not undermine the substantive, theoretically central finding of this study.

Waterborne Disease as the Primary Correlate of Psychological Distress

Waterborne Disease showed the strongest significant correlation with Mental Health Impact (β = 0.239, $p < 0.001$; PLSc β = 0.306). The result is in line with findings of (Azizullah et al., 2011) which reported that groundwater contamination is the major cause for post-flood disease. Safe water was seen as socially mediated outcome, since households knew how to properly boil the water, but they didn't have the means to get fuel and money; a similar observation has been made by (Andrade et al., 2018; Gowrisankar et al., 2017). This association is similar to results found internationally (Zhong et al., 2018), furthering the evidence by formally quantifying the pathway between disease and distress, based on data at the household level. The strength of this pathway is consistent with the broader meta-analytic evidence that flood-related health burdens, particularly infectious disease, are significant drivers of subsequent psychological morbidity **(**Yakubu et al,. 2026).

WASH Interventions: Implications for Post-Flood Response

The results confirmed the priority to be given to WASH interventions rather than general relief. The three implications are: (1) Rapid hand-pump decontamination should be a priority since 71.2% of people use hand pumps (Acharya & Silori, 2025; Ahmed et al., 2024); (2) Sanitation adequacy should be given due attention because broken handpumps increase the risk of contamination (Ali et al., 2026; Gautam et al., 2017); (3) Point of use treatment materials (chlorine tablets, filters) should be provided directly, and not solely through health education, due to economic barriers to boiling water (Mhd Noor et al., 2022). They are cost-effective (USD 0.50/month for chlorine tablets) and suitable for (World Bank, 2022) recommendations on integrated WASH-mental health programming .The urgency of these interventions is underscored by the documented reality that during the 2022 floods, Sindh province alone recorded over 90,000 cases of acute diarrhea in a single day, highlighting the scale of the WASH crisis that must be addressed **(**Jamil et al,. 2022).

Social Cohesion: A Significant Protective Association

Social Cohesion showed a statistically significant protective association with Mental Health Impact (β = 0.141, t = 2.075, p = 0.038, confirmed under a 3,000-resample bootstrap re-estimation), notwithstanding some measurement limitations (AVE = 0.496). This aligns with (Akhter et al., 2026; Patel, 2022), who found that informal networks provide accessible support; this significant association suggests that social cohesion may also function indirectly, by enabling access to other protective resources (Jamshed et al., 2019; Wisner, 2019). The protective role of social cohesion is increasingly recognized in the disaster literature; recent reviews have concluded that there is sufficient evidence to suggest that social cohesion plays a vital role in building community resilience and protecting mental

health following disasters **(**Kawachi, 2026). Seminal work in this field has consistently demonstrated that communities with stronger social networks recover more effectively from disasters, with measurable improvements in both psychological and physical health outcomes (Aldrich 2012). Given this significant, protective association, preserving and strengthening neighborhood networks during relief operations should be treated as an evidence-supported psychosocial protection measure rather than a purely speculative one, though replication in larger samples remains valuable.

Role of Government Institutions and NGOs: Targeting Mismatch

Institutional Response had no significant correlation with any of the factors, which is in line with the targeting mismatch; current relief is more focused on shelter and food, than on WASH specific interventions. This is reiterating the conclusion of (Pradhan et al., 2022) who found that there are policy gaps in Pakistan's disaster response. The null finding could also be due to timing problems (assistance already received), recall bias or aggregation of different types of assistance masking the effect of WASH. This will help to re-weight relief packages with a focus on water-quality restoration (Khan & Ali, 2014 Glago, 2021). The absence of a significant association between institutional response and health outcomes is consistent with broader evidence that health system responses to climate-related shocks in lower-middle-income countries are often fragmented, reactive, and insufficiently targeted to the specific needs of affected populations, particularly with respect to water, sanitation, and hygiene interventions **(**Moussallem et al,. 2026).

Synthesis and Policy Implications

The results point to one policy-relevant conclusion: waterborne disease shows a stronger statistical association with mental health impact than flood impact or institutional response in this sample. This pattern suggests that environmental exposures may become embodied in health through structural conditions, consistent with vulnerability and eco-social perspectives. The study therefore supports consideration of WASH restoration as a component of post-flood health protection, while avoiding a causal or mediation claim that cannot be established from the cross-sectional data.

4. CONCLUSION

This study used primary household survey data from 400 flood-affected families in Hyderabad District, Sindh, to test a structural model linking flood impact, waterborne disease incidence, general health impact, mental health impact, institutional response, and social cohesion. The primary result is that waterborne disease incidence ($\beta = 0.239$, $p<0.001$; PLSc corrected, but not flood severity) is the strongest statistically significant correlate with the impact of floods on the mental health of the households, with social cohesion ($\beta = 0.141$, $p = 0.038$) emerging as a second, more modest but statistically significant protective correlate.

This is a result that is consistent for the composite (PLS) and disattenuated (PLSc) algorithm output, and is robust to bootstrapped significance testing, with $\beta = 0.306$. The model had adequate global fit (SRMR = 0.067) and, although the model explained only a modest amount of variance (R^2) for Waterborne Disease and General Health Impact (which is likely related to the near-universal waterborne disease and hand-pump exposure as experienced by this sample and not to model misspecification), the model is considered to be reliable and valid.

Theoretically, the study contributes to political-economy-of-disaster and eco-social health perspectives by providing household-level structural evidence that waterborne disease is significantly associated with mental health impact in a flood-affected South Asian setting. Because the available output does not include a formal bootstrapped indirect-effect test, the findings should be interpreted as evidence for an important statistical pathway rather than confirmed mediation.

Maintain that environmental exposures do not just happen, but are mediated by the structures of biology and society and are traceable.

Practically, the findings argue for repositioning water-quality and sanitation restoration as front-line psychosocial protection measures in post-flood response, and for testing whether social-cohesion-

preserving relief modalities, such as neighborhood-based rather than dispersed sheltering, measurably improve mental-health outcomes.

This study has several limitations. The cross-sectional design precludes causal inference and cannot rule out reverse or reciprocal relationships between disease incidence and psychological distress; the associations reported here should accordingly be interpreted as a hypothesized statistical pathway rather than a demonstrated causal sequence, pending confirmation in longitudinal or intervention research. The Mental Health Impact construct, while reliable and valid as a measurement scale, represents household-reported psychological impact the respondent's own assessment of long-term psychological concern, perceived permanence of emotional effects, and impaired future planning capacity rather than a clinical diagnosis of anxiety, depression, or post-traumatic stress disorder established through standardized clinical instruments or professional assessment; references to "mental health impact" throughout this paper should be read with this measurement boundary in mind. The sample, while randomly stratified within Hyderabad District, may not generalize to other Indus Basin districts with different water infrastructure or institutional capacity. The sample also skewed toward male respondents (74.8%), reflecting the household-representative interview convention in rural Sindh; consequently, the model likely underestimates the true psychological burden for women, as previous studies indicate that women report significantly higher post-flood anxiety than men. The gender limitation is particularly significant given that recent research explicitly identifies women in South Asia as the most vulnerable demographic during climate-related disasters, facing compounded risks from disrupted healthcare access, increased caregiving burdens, and heightened psychological distress. Several constructs, particularly Flood Impact and General Health Impact, explained limited variance in their respective endogenous outcomes (R^2 = 0.018 and 0.004, respectively); as discussed in Section 5.3, this is consistent with the near-universal flood exposure and hand-pump reliance in this sample rather than necessarily indicating model misspecification, but it nonetheless suggests that unmeasured household- and community-level factors such as pre-flood asset ownership, distance to functioning health facilities, or prior disaster experience warrant inclusion in future models. As with most applied PLS-SEM studies of this kind, findings were not cross-validated against a covariance-based SEM estimator, which would additionally yield absolute fit indices (e.g., CFI, RMSEA); this remains a useful robustness check for future replications of this model. Missing values (0–7.5% per item) were addressed via mean imputation rather than multiple imputation or full-information maximum likelihood; while consistent with common PLS-SEM practice at this level of missingness, more conservative missing-data techniques could be applied in future work. Future research should pursue longitudinal or panel designs capable of testing the direction of the disease–distress association, incorporate objective water-quality testing and, where feasible, validated clinical mental-health screening instruments alongside self-reported disease incidence and household-reported psychological impact, and test the Institutional Response construct's apparent null association through intervention or quasi-experimental designs that vary the WASH content of relief packages directly.

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