INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

IFPRI

IFPRI Discussion Paper 2441

September 2026

Exposure to Multiple Shocks and Fragility

Distinct but Connected Dimensions of Vulnerability in Polycrisis Contexts

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Notices

Abstract

Households in low- and middle-income countries increasingly face overlapping and intersecting risks, yet empirical approaches analyze shock exposure or fragility in isolation. We bring these two dimensions together by examining exposures to multiple shocks and fragility as distinct but connected dimensions relevant to polycrisis contexts at the household level. Using panel data from the HORTINLEA survey (2014–2016) conducted in Kenya in rural and peri-urban areas, we combine a nonparametric multi-shock index (MSI), which captures exposure to economic, climatic, and health shocks, with a fragility exposure index (FEI), which measures experiences of human insecurity, economic exclusion, and social cohesion. We find that the MSI and FEI are weakly correlated, consistent with limited empirical overlap between the two indexes in this sample. Contemporaneous, earlier, and three-wave average shock exposures are not significantly associated with aggregate fragility. In contrast, fragility exposure is robustly associated with food security outcomes. A 10-percentage-point higher FEI is associated with 0.11–0.14 fewer food groups in household dietary diversity and 0.18–0.27 fewer months of adequate household food provisioning. Domain-specific results reveal heterogeneous associations, with exposure to multiple shocks positively associated with greater fragility in the social cohesion domain. The findings highlight the value of distinguishing shock exposure from underlying fragility when assessing household vulnerability in contexts affected by multiple overlapping pressures.

Acknowledgments

The survey data used in this study were collected as part of the HORTINLEA project, funded by the German Federal Ministry of Education and Research (BMBF) under Grant No. FKZ 031A248A. The authors thank colleagues at the IFPRI Ethiopia office for their valuable comments on an earlier version of this paper. We are also grateful to Prof. Tilman Brück and his team for their work in developing the concept and methodology underlying the Fragility Exposure Index. Finally, the authors thank the anonymous reviewer(s) for their constructive comments and suggestions, which helped improve the paper.

1. Introduction

Households in low- and middle-income countries are increasingly exposed to complex and overlapping shocks arising from climatic variability, economic volatility, and health shocks. These shocks rarely occur in isolation. Instead, they tend to co-occur and interact, producing compound effects that can exceed the impact of any single shock (Homer-Dixon et al., 2022; Lawrence et al., 2024; Ide et al., 2020). This emerging reality—often described as a polycrisis—poses significant challenges for both measurement and policy design, particularly in fragile and shock-affected settings (Burke et al., 2024; Hsiang et al., 2013; Martin-Shields and Stojetz, 2019).

Despite growing recognition of these dynamics, empirical approaches to analyzing polycrisis remain fragmented. One strand of the literature focuses on shock exposure, documenting how households experience and respond to discrete adverse events such as droughts, price shocks, or illness. Recent advances, including the development of multi-shock indexes (MSI), emphasize the cumulative nature of such exposures and their association with deteriorating welfare outcomes (Ulimwengu, 2026; Zingwe, 2023; Amparore et al., 2023; Ibok et al., 2019). A second strand focuses on fragility, capturing broader structural and experiential dimensions of vulnerability, such as human insecurity, economic exclusion, and weakened social cohesion.

A closely related and more methodologically developed strand of literature operationalizes the concept of resilience, defined as the capacity of households to remain or return to a desired welfare state in the face of shocks. Cissé and Barrett (2018) propose a conditional moments-based approach that estimates resilience as the probability of achieving a normative welfare threshold. The FAO's Resilience Index Measurement and Analysis framework operationalizes resilience capacity through structural indicators of household assets, adaptive strategies, and access to basic services (FAO, 2016; Alinovi et al., 2010). Subsequent applications and methodological refinements (Knippenberg et al., 2019; Upton et al., 2022; Scognamillo et al., 2023) have established a substantial empirical literature on the measurement of resilience. The fragility exposure index (FEI) used in this paper is conceptually adjacent to these resilience measures but differs in two important respects: it is grounded in lived experiences across the domains of human security, economics, and social cohesion rather than in welfare-state probabilities, and it is constructed without conditioning on observed welfare outcomes. This conceptual independence from welfare outcomes is precisely what makes the FEI useful in a dual-index framework alongside an outcome-anchored MSI.

While both approaches provide valuable insights, they are typically applied in isolation, limiting our understanding of how shocks and fragility interact to shape household vulnerability. An emerging body of literature attempts to examine the joint impact of conflict and shocks on household-level welfare outcomes in fragile settings (Stojetz et al., 2026; Burke et al., 2024;

Hsiang et al., 2013; Brück and d'Errico, 2019a). However, these studies mostly focus on analyzing the effect of a single shock on welfare outcomes in fragile settings.

In this study, we use the concept of polycrisis as a broader framing to understand household vulnerability in settings where multiple adverse events coexist with underlying conditions of fragility. A polycrisis is commonly understood as a set of interconnected or mutually reinforcing crises, rather than simply the simultaneous occurrence of multiple shocks. Our data do not directly observe the causal propagation or cascading of crises across systems. We therefore do not seek to empirically identify a polycrisis as such. Instead, we operationalize two household-level dimensions relevant to such environments—realized multi-shock exposure and lived fragility exposure—and examine whether they are empirically connected and how each is associated with household food security outcomes.

Accordingly, this paper addresses a unique gap in the literature by jointly analyzing the relationship between households' exposures to multiple shocks and to fragility as distinct but connected dimensions of polycrisis. Conceptually, we distinguish between realized shocks, which are the events that directly affect households within a given period, and lived fragility, which is the broader condition of human insecurity, economic exclusion, and social cohesion that shapes how households experience and respond to these events. While shocks may trigger immediate welfare losses, repeated or cumulative exposure may also contribute to the emergence or intensification of fragility. At the same time, households already embedded in fragile environments may be more susceptible to the adverse effects of shocks. Understanding this relationship is critical for developing more comprehensive and policy-relevant measures of vulnerability.

We address three questions in this paper. First, do exposures to multiple shocks and to fragility capture overlapping or distinct dimensions of household vulnerability? Second, are earlier and three-wave average shock exposures associated with fragility? Third, how do exposures to multiple shocks and to fragility independently and jointly relate to household food security outcomes?

Empirically, the paper combines two complementary nonparametric indexes. First, we construct an MSI using panel data from the Horticultural Innovations and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) survey in Kenya (2014–2016), which captures household exposure to economic, climatic, and health-related shocks following the approach of Ulimwengu (2026). Second, we use an FEI from 2016, which aggregates indicators of human security, economic inclusion, and social cohesion following Baliki and colleagues (2022). While both indexes are nonparametric, they differ in their construction: the MSI is data-driven and anchored in observed relationships with food security outcomes, whereas the FEI is based on normalized indicators and equal weighting across domains. This distinction allows us to examine how different approaches to measuring vulnerability are related.

The analysis proceeds in four steps. First, we document the extent to which MSI and FEI capture overlapping or distinct dimensions of vulnerability. Second, we examine whether contemporaneous, earlier, and three-wave average shock exposures are associated with fragility observed in 2016. Third, we explore how these associations vary across different dimensions of fragility. The panel structure of the shock data provides temporal ordering for exposures measured in 2014 and 2015, but because FEI was observed only in 2016, the design does not identify causal effects or changes in fragility over time. Fourth, to further assess the relevance of the dual-index framework, we examine how shock and fragility exposure independently and jointly relate to key welfare outcomes, namely household dietary diversity scores (HDDS) and months of adequate household food provisioning (MAHFP).

The paper makes four contributions. First, it bridges two previously disconnected strands of the literature by jointly analyzing shock and fragility exposure at the household level. Second, it introduces a dual-index framework that captures both realized shocks and underlying fragility conditions without imposing arbitrary aggregation across dimensions. Third, it provides evidence of limited aggregate empirical overlap between contemporaneous, earlier, and three-wave average shock exposure and lived fragility in this sample. Fourth, it shows that FEI is more consistently associated with the food security outcomes examined than with contemporaneous MSI, while domain-specific regressions reveal a positive association between MSI and the social cohesion dimension of fragility. Together, these contributions support a dual-index approach to vulnerability analysis in settings characterized by overlapping risks.

The findings have important implications for policy and practice. In contexts characterized by polycrisis, targeting systems that rely solely on single shocks or static measures of vulnerability risk overlooking households that are structurally fragile or repeatedly exposed to shocks. By combining measures of shock and fragility exposure, policymakers and practitioners can better identify households facing compounded risks and design more effective, integrated, and adaptive interventions.

2. Conceptual Framework

Households in fragile and low-income settings are affected by multiple overlapping sources of risk. Understanding vulnerability in such contexts requires distinguishing between different yet related dimensions of crisis. This paper adopts a dual-dimensional framework that conceptualizes vulnerability as arising from the interaction between shock and fragility exposure.

2.1 Two dimensions of polycrisis: Shocks and fragility

We define shock exposure as the realization of adverse events that directly affect households over a given period. These include economic shocks (such as price increases, income loss), climatic shocks (such as droughts, floods), and health shocks (such as illness), among others. Such events are typically discrete, time-bound, observable, and commonly measured through self-reported experiences within a specified recall period.

In contrast, fragility exposure refers to broader structural and experiential conditions that shape household vulnerability. These include dimensions such as human insecurity, economic exclusion, and weak social cohesion. As such, fragility is often more persistent and less directly observable than shocks and is typically captured through composite indicators reflecting multiple domains of lived experience.

This distinction is central to the concept of polycrisis, a concept increasingly used to describe intersecting and mutually reinforcing crises (Homer-Dixon et al., 2022; Lawrence et al., 2024). While shock exposure captures the events that households face, fragility exposure captures the conditions that determine how households experience and manage human insecurity, economic exclusion, and weak social cohesion in fragile settings (Baliki et al., 2022). The two dimensions are analytically distinct but potentially interdependent.

2.2 Linking shocks to fragility: Pathways and cumulative effects

The relationship between shock exposure and fragility exposure can be understood through several mechanisms. First, direct effects arise when shocks immediately worsen conditions associated with fragility. For example, economic shocks such as income loss may exacerbate exclusion from markets, while health shocks such as illness or the death of a household member may weaken social cohesion. Second, cumulative effects occur when repeated or multiple shocks erode household resources and coping capacity over time, consistent with theories of vulnerability accumulation and poverty traps (Barrett and Constas, 2014; Barrett et al., 2018; Knippenberg et al., 2019). As households deplete assets, exhaust savings, or rely on negative coping strategies including asset depletion and reduced consumption smoothing (Ansah et al., 2019; Fafchamps and Gubert, 2007), their ability to withstand future shocks diminishes, potentially leading to heightened fragility. In this sense, fragility may emerge because of sustained exposure to shocks rather than a preexisting condition alone. Third, systemic pathways reflect the broader environment in which households are embedded. Systemic shocks—such as widespread droughts, frequent floods and storms, and price spikes—weaken institutions, disrupt markets, and strain social networks, thereby disrupting social protection and informal risk-sharing systems (Devereux and Getu, 2013; Brück et al., 2019b).

This systemic framing aligns with the emerging literature on compound and cascading climate risks, which formalizes how multiple drivers and hazards interact across sectors, scales, and timeframes to produce risks that exceed the sum of their parts (Simpson et al., 2021; Raymond et al., 2020; de Ruiter et al., 2020). Compound risk frameworks emphasize that shocks rarely propagate through a single channel: a drought may simultaneously raise food prices, strain household budgets, and erode local social networks, producing welfare effects through both direct and indirect pathways. While compound-risk research has so far focused predominantly on hazard interactions and aggregate societal impacts, the dual-index framework adopted here applies the same logic at the household level by distinguishing the events households face (MSI) from the conditions through which those events are experienced (FEI). These processes may simultaneously increase both shock exposure and fragility, reinforcing their interaction. Households already exposed to higher levels of fragility may be more vulnerable to shocks, either because they face greater exposure (such as living in insecure areas) or because they have fewer resources to cope. This suggests a feedback relationship, where exposure and vulnerability coevolve over time.

These pathways motivate empirical expectations, but whether they emerge clearly in household-level data remains an open question. These pathways represent conceptual mechanisms through which shocks and fragility may become connected. The empirical analysis does not directly identify these causal mechanisms, because fragility was observed only in 2016. Rather, the analysis examines whether contemporaneous, earlier, and average multi-shock exposures are systematically associated with fragility observed in 2016.

2.3 Measurement framework: Multi-shock index and fragility exposure index

To operationalize these concepts, the paper employs two complementary indexes. The MSI, based on Ulimwengu (2026), captures realized shock exposure at the household level. It aggregates multiple types of shocks using a nonparametric, data-driven screening and weighting procedure. By summarizing weighted exposure to multiple adverse events within each survey wave, the MSI captures the breadth and composition of realized shock exposure.

We use a simplified version of the approach developed by Ulimwengu (2026). Household-reported shocks are screened separately within each survey wave using the average food consumption score (FCS_av). A shock is retained in a given year when FCS_av is lower among households reporting the shock than among households not reporting it; no threshold of statistical significance is imposed (Table 1). Retained shock indicators are then combined using inverse-prevalence weights. Specifically, each retained shock k receives weight 1/p_k, where p_k is the pooled prevalence of the retained-shock indicator in the MSI construction sample, so relatively rare retained shocks receive greater weight. The weighted retained shocks are added at the household-wave level, and the resulting raw MSI is min–max normalized over the pooled 2014–2016 observations to range from 0 to 1. All the main analyses in the paper use this normalized inverse-prevalence-weighted MSI.

Table 1. Construction and interpretation of the multi-shock index

Component	Construction in this study	Interpretation
Shocks	Household-reported adverse events covering climatic, production, economic, health, and household-specific shocks	Potential sources of realized shock exposure
Shock screening	Shocks are screened separately for each survey year using FCS_av. A shock is retained when mean FCS_av is lower among households reporting the shock than among households not reporting it; no significance threshold is imposed	Retains shocks associated with poorer food consumption conditions in the respective year
Shock weighting	Each retained shock k receives an inverse-prevalence weight 1/p_k, where p_k is its pooled prevalence	Relatively rare, retained shocks receive greater weight
Aggregation	Inverse-prevalence-weighted retained shocks are summed at household-wave level	Higher raw scores indicate greater inverse-prevalence-weighted multi-shock exposure
Normalization	The weighted MSI is min–max normalized over the pooled 2014–2016 observations to a common 0–1 scale	Higher values = greater multi-shock exposure
Three-wave measure	The three-wave average MSI is the arithmetic mean of the normalized MSI for 2014, 2015, and 2016	Higher values indicate greater average multi-shock exposure across the three waves

The FEI based on Baliki and colleagues (2022) captures fragility experiences across three domains: human security, economic inclusion, and social cohesion (Table 2). It is constructed by aggregating multiple indicators within each domain using equal weights. Unlike the MSI, which is anchored in observed outcomes, the FEI reflects a broader conceptualization of vulnerability rooted in structural and experiential conditions.

Table 2. Domains and dimensions of the fragility exposure index

FEI domain	Main dimensions represented	Direction
Human security	Security perceptions, crime and violence, safety, discrimination, rights, and institutional protection	Higher value means greater human insecurity
Economic inclusion	Financial situation, living standards, corruption, access to economic opportunities, and institutional/economic inclusion	Higher value means greater economic exclusion/fragility
Social cohesion	Community integration, social equality, trust, institutional participation, political participation, and group membership	Higher value means weaker social cohesion/greater fragility

Note: Indicators are equally weighted within domains and the three domains receive equal weights in constructing the aggregate FEI. Individual indicators are normalized and higher values consistently indicate greater fragility. For the complete list of indicators and response categories, see Table A2 and Baliki et al. (2022).

Importantly, the two indexes differ not only in what they measure but also in how they are constructed. The MSI is empirically grounded and outcome-oriented, while the FEI is normative and domain-based. This distinction allows for a richer analysis of vulnerability by preserving the conceptual integrity of each dimension rather than combining them into a single composite measure. The food security outcomes used in the subsequent welfare analysis—HDDS and MAHFP—are not included in the construction of either index. The average food consumption score (FCS_av) is used only in the shock screening stage of MSI construction.

The differing construction of MSI and FEI is intentional. MSI captures realized adverse events selected for their empirical relevance to food security outcomes, whereas FEI captures broader structural and experiential conditions of vulnerability. Comparing them therefore helps distinguish event-based dimensions of household risk from condition-based dimensions. This reinforces the case for treating fragility exposure as a distinct dimension of vulnerability rather than a derivative of shock history.

2.4 Analytical implications

This dual-index framework yields several testable implications. First, if shock exposure and fragility exposure capture different dimensions of vulnerability, they should exhibit limited empirical overlap. Second, if repeated or sustained shock exposure is associated with fragility, earlier shock measures and the three-wave average MSI should be positively associated with fragility observed in 2016. Third, the strength and direction of these associations may vary across domains of fragility, reflecting different underlying mechanisms. The paper examines two household-level vulnerability dimensions that are relevant to polycrisis: exposure to multiple realized shocks and exposure to underlying conditions of fragility. By explicitly distinguishing and jointly analyzing these two dimensions, the framework provides a more comprehensive approach to understanding vulnerability in polycrisis contexts.

3. Data and Empirical Strategy

3.1. Data

The empirical analysis draws on the HORTINLEA household survey, which followed a panel of rural and peri-urban households in Kenya across three waves of data collection in 2014, 2015, and 2016. The rural sites were Kisii and Kakamega counties in western Kenya, while the peri-urban sites were Kiambu and Nakuru counties. The survey targeted agricultural households, with a particular focus on producers of African indigenous vegetables (AIV). The survey was designed to capture detailed information on household livelihoods, agricultural production, market participation, and welfare outcomes (Kebede and Bokelmann, 2017). Surveyed households were selected using a multistage sampling design. First, counties were purposively chosen based on the prevalence of AIV production. Subcounties and divisions were subsequently identified in consultation with district agricultural offices. Within each division, locations or wards were randomly selected, followed by random sampling of households. Data collection was carried out through face-to-face interviews. Although the HORTINLEA survey is not nationally representative, it offers a comprehensive view of agricultural producers in rural and peri-urban Kenya. Given the randomized sampling and substantial sample size within each county, the results can be considered representative of agricultural producers in comparable contexts.

A key strength of the dataset for this study is the presence of a consistent and detailed shock module across all three waves, which recorded household exposure to a wide range of economic, climatic, and health-related shocks over a 12-month recall period. This panel structure allows for the construction of comparable measures of shock exposure over time and enables the analysis of repeated and average shock exposure across survey waves. Due to panel attrition and missing values, the estimation sample differs across years and specifications. The main regression sample is restricted to households with complete information on fragility, shock exposure, and control variables. Specifically, the descriptive statistics (Table 3) draw from 685 households with valid FEI measurements in 2016. The regression sample is further restricted to 590 households with complete information on the full set of MSI, FEI, and control variables across all three waves. The slightly larger sample of 599 in the food security regressions (Table 7) reflects the fact that those specifications do not require complete information on lagged MSI measures, allowing a small number of additional households with valid contemporaneous data to be retained.

The measurement of fragility is available only in the final wave of the survey. A dedicated fragility module was introduced in the 2016 round, capturing household-level experiences of human insecurity, economic exclusion, and social cohesion. This module provides the basis for constructing the FEI, which reflects experiences of fragility at the time of observation. While the absence of fragility measures in earlier waves prevents analysis of changes in fragility over time, the combination of panel data on shocks and cross-sectional data on fragility allows us to examine whether contemporaneous, earlier, and three-wave average shock exposures are associated with fragility observed in 2016. The results should therefore be interpreted as associational rather than as evidence of causal effects or fragility dynamics.

3.2. Empirical strategy

The empirical strategy proceeds in four steps. First, we assess the extent to which shock exposure and fragility exposure capture overlapping or distinct dimensions of vulnerability. Second, we estimate the association between contemporaneous shock exposure and fragility. Third, we examine whether earlier shock exposure and the three-wave average MSI are associated with fragility observed in 2016. Fourth, to further assess the relevance of the dual-index framework, we analyze how shock and fragility exposures independently and jointly relate to key food security outcomes.

Given that the FEI was observed only in 2016, the analysis adopts a cross-sectional framework with lagged explanatory variables, using panel information on shock exposure from 2014 to 2016. The objective is not to establish causal effects, but rather to identify robust empirical associations consistent with the conceptual framework outlined above.

Let FEI_i denote the FEI for household i in 2016 and let MSI_{it} denote the MSI for household i in year t, where $t \in \{2014, 2015, 2016\}$. Let X_i be a vector of household controls, δ_c county fixed effects, and ε_i an error term.

The baseline specification is that contemporaneous shock exposure and fragility is as follows:

$$FEI_i = \alpha + \beta\, MSI_{i,2016} + \gamma' X_i + \delta_c + \varepsilon_i$$

Here, β captures the association between current shock exposure and fragility exposure.

Lagged shock exposure and fragility is as follows:

$$FEI_i = \alpha + \beta_1 MSI_{i,2014} + \beta_2 MSI_{i,2015} + \beta_3 MSI_{i,2016} + \gamma' X_i + \delta_c + \varepsilon_i$$

This specification distinguishes the association of fragility with earlier, intermediate, and contemporaneous shock exposure.

Three-wave average shock exposure

Average shock exposure over the three survey waves can be defined as:

$$AvgMSI_i = \frac{1}{3}\left(MSI_{i,2014} + MSI_{i,2015} + MSI_{i,2016}\right)$$

Then, to capture the average intensity of shock exposure over 2014 to 2016, estimate:

$$FEI_i = \alpha + \beta\, AvgMSI_i + \gamma' X_i + \delta_c + \varepsilon_i$$

Domain-specific fragility regressions

Let $FEI_i^{(d)}$ denote fragility exposure for household $i$in domain d, where:

- $d = 1$: Human security
- $d = 2$: Economic inclusion
- $d = 3$: Social cohesion

To allow the association between shock exposure and fragility to differ across fragility domains, then estimate the following:

$$FEI_i^{(d)} = \alpha_d + \beta_d\, MSI_{i,2016} + \gamma_d' X_i + \delta_{c,d} + \varepsilon_{i,d}$$

Food security outcomes: Independent and joint associations

Let Y_i denote a food security outcome for household i, such as HDDS or MAHFP. For shock exposure only, then estimate:

$$Y_i = \alpha + \beta\, MSI_{i,2016} + \gamma' X_i + \delta_c + \varepsilon_i$$

For fragility exposure only, estimate:

$$Y_i = \alpha + \theta\, FEI_i + \gamma' X_i + \delta_c + \varepsilon_i$$

For joint specification, estimate:

$$Y_i = \alpha + \beta\, MSI_{i,2016} + \theta\, FEI_i + \gamma' X_i + \delta_c + \varepsilon_i$$

Interaction specification

$$Y_i = \alpha + \beta\, MSI_{i,2016} + \theta\, FEI_i + \lambda\left(MSI_{i,2016} \times FEI_i\right) + \gamma' X_i + \delta_c + \varepsilon_i$$

The interaction term tests whether the association between shocks and food security varies with the level of fragility.

Control variables

All specifications include a set of household-level controls X_i, including demographic and socioeconomic characteristics such as gender of household head, age of household head, education, household size, and location fixed effects. These variables account for observable differences in household characteristics that may be correlated with both shock exposure and fragility.

We also include earlier shock exposures as explanatory variables to provide temporal ordering in the analysis. However, this does not address potential endogeneity arising from unobserved heterogeneity or reverse causality. Households with higher underlying fragility may be more likely to experience or report shocks. The empirical strategy is therefore designed to characterize conditional associations rather than causal effects. By combining contemporaneous, earlier, and three-wave average MSI measures, the analysis describes how these dimensions of vulnerability are related to each other and to the food security outcomes HDDS and MAHFP.

A natural further step would be to estimate household-level fixed effects regressions to control for time-invariant unobserved heterogeneity correlated with both shock exposure and fragility. This is not feasible in the present design because the FEI was observed only in the 2016 wave of HORTINLEA: there is no within-household variation in the dependent variable to exploit, so household fixed effects would absorb the entire outcome of interest. While shocks and household characteristics are observed across all three waves, the lack of repeated FEI measurements prevents within-household identification of the shock–fragility relationship. The empirical strategy addresses this constraint in three descriptive ways. First, MSI measures from 2014 and 2015 introduce temporal separation between shock exposure and fragility observed in 2016, although this does not resolve endogeneity or establish causality. Second, the three-wave average MSI specification (Table 6) summarizes mean shock exposure across the 2014–2016 period rather than cumulative exposure. Third, the robustness check of shock persistence, reported in Table A3 in Annex, tests whether categorical measures of repeated high exposure produce different conclusions from the linear MSI. None of these strategies substitutes for household fixed effects, and unobserved time-invariant household characteristics correlated with both fragility and shock exposure cannot be ruled out. All estimates should therefore be interpreted as conditional associations rather than causal effects.

The MSI does not include fragility-related experiences. Shock exposure covers adverse events such as drought, flood, crop failure, illness, and other household-level events, whereas fragility is captured through experiences relating to human security, economic inclusion, and social cohesion. The complete shock list and MSI screening information are reported in Annex 1, while the detailed FEI indicators and their interpretation are reported in Annex 2.

4. Results and Discussion

4.1. Results

Because the MSI and FEI are normalized using different procedures and serve different measurement purposes, their magnitude are not directly comparable. The analysis therefore focuses on correlations and regression associations rather than absolute scale comparisons. Table 3 presents descriptive statistics for the main variables used in the analysis. Control variables are measured at baseline (2014), shock exposure is observed over the 2014–2016 period, and fragility is measured in 2016. The mean FEI in 2016 is 0.516 (SD = 0.141), with observed values ranging from 0 to 0.931, indicating substantial cross-household variation. Across domains, economic inclusion and human security exhibit higher average values than social cohesion. The normalized MSI has low mean values but considerable dispersion, with a small number of households experiencing relatively high weighted shock exposure. Household food security measures and demographic characteristics also vary substantially across the sample.

Table 3. Descriptive statistics

Variables	Mean	Std. Dev.	Min	Max	N
FEI_2016	.516	.141	.000	.931	685
Human security_2016	.526	.170	.000	.939	685
Economic inclusion_2016	.559	.154	.000	.946	685
Social cohesion_2016	.340	.126	.010	.816	685
MSI_2014	.006	.019	.000	.342	1,232
MSI_2015	.009	.032	.000	.507	707
MSI_2016	.007	.039	.000	1.00	685
Three-wave average MSI	.007	.018	.000	.340	684
HDDS_2014	8.17	1.71	1.00	11.0	1,213
MAHFP_2014	9.47	3.76	.000	12.0	1,213
Hhsize_2014	5.64	2.27	1.00	15.0	1,232
Hhhead_male_2014	.807	.395	.000	1.00	1,231
Hhhead_average_age_2014	49.8	12.7	17.0	95.0	1,214
Hhhead_average_educ years_2014	8.00	4.72	.000	22.0	1,115
No. Children_2014	1.93	1.66	.000	8.00	1,232
No. Elderly_2014	.316	.618	.000	5.00	1,232
Dependency ratio_2014	.917	.896	.000	7.00	1,200
Land ha tot_2014	.793	.868	.020	7.28	1,232

Note: MSI=multi-shock index.

Table 4 presents pairwise correlations between fragility and shock exposure measures. The results show that the correlation between the FEI and MSI is positive but very small and statistically insignificant across all years. This suggests that shock exposure and fragility exposure capture largely distinct dimensions of vulnerability. This is consistent with their conceptual distinction: the MSI captures realized exposure to adverse events during specified reference periods, whereas the FEI captures broader lived conditions of human security, economic inclusion, and social cohesion observed in 2016. In addition, differences in measurement structure, reference periods, and reporting may also contribute to the limited observed association.

As expected from the construction of the aggregate FEI, it is positively and strongly correlated with each of its constituent domains. These correlations are partly mechanical and should not be interpreted as an independent validation test. Correlations across annual MSI measures are generally low, indicating that measured shock exposure varies substantially across survey waves.

Table 4. Correlation matrix: Fragility and shock exposure

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) FEI, 2016	1.000							
(2) Human security, 2016	0.777***	1.000						
(3) Economic inclusion, 2016	0.846***	0.475***	1.000					
(4) Social cohesion, 2016	0.681***	0.220***	0.477***	1.000				
(5) MSI, 2014	0.019	0.001	0.056	-0.016	1.000			
(6) MSI, 2015	0.021	0.061	0.022	-0.051	0.009	1.000		
(7) MSI, 2016	0.007	0.015	-0.043	0.053	-0.008	0.017	1.000	
(8) Three-wave average MSI	0.024	0.048	-0.001	0.002	0.292***	0.628***	0.732***	1.000

Note: MSI=multi-shock index. * p<0.1, ** p<0.05, *** p<0.01

Table 5 presents the association between contemporaneous shock exposure and fragility exposure. Across all three specifications, including those controlling for location fixed effects, the coefficient on the 2016 MSI is positive but small and statistically insignificant. The inclusion of household characteristics (Column 2) and additional controls for baseline food security (Column 3) does not materially change the estimate. The results therefore provide no evidence of a systematic contemporaneous association between MSI and aggregate FEI in this sample. This finding is consistent with limited empirical overlap between the two measures, although differences in timing, measurement structure, and reporting may also contribute to the weak observed relationship. The next step examines whether earlier and three-wave average shock exposure are associated with fragility observed in 2016.

Table 5. Baseline regression: Contemporaneous multi-shock index and fragility exposure

Variables	(1) FEI_2016	(2) FEI_2016	(3) FEI_2016
MSI_2016	0.011	0.017	0.010
	(0.032)	(0.033)	(0.034)
Household size		0.002	0.002
		(0.004)	(0.004)
Male household head		-0.019	-0.020
		(0.015)	(0.015)
Age		0.000	0.000
		(0.001)	(0.001)
Education (years)		-0.001	-0.001
		(0.001)	(0.001)
Children		-0.005	-0.006
		(0.009)	(0.009)
Elderly		-0.008	-0.008
		(0.017)	(0.017)
Dependency ratio		-0.004	-0.004
		(0.013)	(0.013)
Land (ha)		-0.006	-0.007
		(0.007)	(0.007)
County_Kakamega	0.024	0.028***	
	(0.016)	(0.016)	
County_Nakuru	0.017	0.019	
	(0.017)	(0.018)	
County_Kiambu	-0.013	-0.015	
	(0.016)	(0.017)	
Diet diversity			0.004
			(0.003)
Food provisioning (months)			-0.000
			(0.002)
Constant	0.510***	0.539***	0.511***
	(0.011)	(0.040)	(0.050)
Observations	590	590	590
R-squared	0.010	0.019	0.021
Location FE	Yes	Yes	Yes

Note: FEI=fragility exposure index. Robust standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

Table 6 examines the relationship between fragility exposure and both earlier and three-wave average shock exposure. Across Models 1–3, which include year-specific MSI measures, the coefficients on shock exposure in 2014, 2015, and 2016 are positive but statistically insignificant. The estimates therefore do not provide evidence that shock exposure in any single survey wave is systematically associated with aggregate fragility observed in 2016.

A similar pattern emerges in Models 4 and 5, which replace individual yearly shocks with the three-wave average measure of shock exposure. Although the coefficient on three-wave average MSI is consistently positive and somewhat larger than the contemporaneous MSI estimates in Table 5, it remains statistically insignificant across all specifications. The inclusion of household characteristics and baseline food security controls does not alter these results, and overall model fit remains low. The absence of strong associations between earlier or three-wave average MSI and FEI is substantively important. It indicates that the FEI captures conditions that are not readily summarized by observed shock experiences alone. Taken together, these findings reinforce the earlier evidence that fragility exposure is not significantly associated with observed shock exposure, whether measured contemporaneously, earlier, or as a three-wave average. This suggests that average shock exposure across the three waves, as measured here, is insufficient to account for variation in fragility exposure (Barrett and Constas, 2014; Montalbano and Romano, 2023), highlighting the importance of treating fragility and shock exposure as distinct dimensions of vulnerability. The low R-squared values across Tables 5 and 6 are consistent with this interpretation: if shocks and fragility measured the same underlying construct, observed shock histories would have strong explanatory power for fragility. The consistently small aggregate associations across contemporaneous, earlier, and three-wave average MSI specifications indicate limited empirical overlap between the two indexes in this sample. Nevertheless, the magnitude of this overlap may also be influenced by differences in how and when the two constructs are measured.[1]

[1] To make this argument quantitative, the standard error on the contemporaneous MSI coefficient in Table 6 (0.034) implies a minimum detectable effect of approximately 0.095 at 80 percent power for a two-sided test at the 5 percent level. With N = 590, the analysis therefore has sufficient power to detect moderate associations between shock and fragility exposure; the precisely estimated null is consistent with the two indexes capturing genuinely distinct dimensions of vulnerability, rather than reflecting a lack of statistical precision.

Table 6. Lagged and average shock exposure and fragility

Variables	(1) **FEI_2016**	(2) **FEI_2016**	(3) **FEI_2016**	(4) **FEI_2016**	(5) **FEI_2016**
MSI (2014)	0.124	0.083	0.096		
	(0.358)	(0.353)	(0.369)		
MSI (2015)	0.056	0.063	0.079		
	(0.147)	(0.152)	(0.158)		
MSI (2016)	0.011	0.017	0.009		
	(0.033)	(0.033)	(0.034)		
Three-wave average MSI (2014–2016)				0.110	0.127
				(0.190)	(0.197)
		(0.004)	(0.004)		(0.004)
Male household head		-0.020	-0.021		-0.021
		(0.015)	(0.015)		(0.015)
Age		-0.000	0.000		0.000
		(0.001)	(0.001)		(0.001)
Education (years)		-0.001	-0.001		-0.001
		(0.001)	(0.001)		(0.001)
Children		-0.005	-0.006		-0.006
		(0.009)	(0.009)		(0.009)
Elderly		-0.008	-0.009		-0.009
		(0.017)	(0.018)		(0.017)
Dependency ratio		-0.003	-0.003		-0.003
		(0.013)	(0.014)		(0.013)
Land (ha)		-0.006	-0.007		-0.007
		(0.007)	(0.007)		(0.007)
Diet diversity			0.004		0.004
			(0.004)		(0.003)
Food provisioning (months)			-0.000		-0.000
			(0.002)		(0.002)
Constant	0.508***	0.537***	0.508***	0.509***	0.509***
	(0.011)	(0.040)	(0.051)	(0.011)	(0.051)
Observations	590	590	590	590	590
R-squared	0.010	0.020	0.022	0.010	0.021
Location FE	Yes	Yes	Yes	Yes	Yes

Note: FEI=fragility exposure index; MSI=multi-shock index. Robust standard errors in parentheses * p<0.1, ** p<0.05, *** p<0.01

Three alternative explanations for the weak MSI–FEI association merit consideration. First, classical measurement error in self-reported shocks could attenuate the MSI coefficient toward zero. Second, FEI is observed only in 2016, so associations with shocks experienced in earlier waves may be weakened by timing differences between exposure and measurement. The three-wave average MSI specifications in Table 6 partially address timing by summarizing exposure across all three waves, but the coefficients remain statistically insignificant. Third, because shocks enter the MSI after screening on FCS_av, selected shocks may relate to welfare through channels not captured by aggregate fragility. Taken together, these considerations mean that the aggregate null should not be interpreted as proof that shocks and fragility are conceptually independent.

Rather, the results indicate limited aggregate empirical overlap between the MSI and FEI in this sample. Domain-level regressions in Table 8 nevertheless reveal statistically significant associations of opposite signs for economic inclusion and social cohesion, highlighting the value of examining the FEI domains separately.

As a robustness check, we also examine whether repeated exposure to high shock levels is associated with fragility using categorical measures of persistence. This addresses the possibility that a linear MSI obscures threshold or persistence patterns. The results reported in Table A3 in the Annex show no statistically significant differences across the persistence categories. Thus, the robustness check provides no evidence that repeated high shock exposure is systematically associated with aggregate FEI in this sample.

Given the limited aggregate empirical overlap between shock exposure and fragility exposure, we next examine how each measure is associated with household welfare. Table 7 reports relationships with HDDS and MAHFP. Fragility exposure is strongly and negatively associated with both food security outcomes across the reported specifications, including models with household characteristics and location fixed effects.

In contrast, the association between contemporaneous MSI and food security is less stable. For HDDS, MSI is positively associated with dietary diversity in simpler specifications, while for MAHFP, the MSI coefficient is generally negative and statistically insignificant. FEI remains negatively associated with both outcomes in the joint specifications. The interaction between MSI and FEI is not statistically significant for either food security outcome, and the estimates are imprecise. The data therefore do not provide clear evidence that the association between shocks and food security varies systematically with the level of fragility. Because MSI and FEI are differently scaled, differences in their raw coefficient magnitudes should not be interpreted as evidence that one index is intrinsically more important than the other.

The positive MSI–HDDS coefficient in some simpler specifications is not stable across the models reported in Table 7 and should therefore be interpreted cautiously. We do not attach a substantive mechanism to this specification-sensitive pattern. In contrast, FEI remains negatively associated with both HDDS and MAHFP across the reported joint specifications, indicating a more consistent relationship between measured fragility and food security outcomes in this sample.

Table 7. Food security outcomes, shock exposure, and fragility exposure

Variables	(1) HDDS 1	(2) HDDS 2	(3) HDDS 3	(4) HDDS 4	(5) MAHFP 1	(6) MAHFP 2	(7) MAHFP 3	(8) MAHFP 4
MSI (2016)	2.12***		2.13***	16.3	-1.05		-1.01	85.83
	(0.36)		(0.35)	(23.20)	(0.66)		(0.66)	(53.14)
FEI		-1.38***	-1.39***	-1.13***		-2.74***	-2.73***	-1.82***
		(0.33)	(0.33)	(0.42)		(0.86)	(0.86)	(1.09)
MSI *FEI				-25.74				-154.42
				(41.19)				(94.47)
Household size				-0.02 (0.042)				-0.068 (0.100)
Male household head				0.353*** (0.147)				0.011 (0.335)
Age				-0.01***				-0.02
				(0.016)				(0.015)
Education (years)				0.01 (0.011)				0.05*** (0.026)
Children				0.01				-0.17
				(0.080)				(0.225)
Elderly				-0.03				-0.18
				(0.129)				(0.369)
Dependency ratio				0.01 (0.106)				0.06 (0.341)
Land (ha)				0.20***				0.41***
				(0.060)				(0.166)
Constant	9.06***	9.77***	9.76***	9.95***	9.61***	11.00***	11.00***	11.40***
	(0.099)	(0.191)	(0.191)	(0.423)	(0.280)	(0.480)	(0.480)	(1.109)
Observations	599	599	599	599	599	599	599	599
R-squared	0.016	0.035	0.039	0.082	0.072	0.085	0.085	0.113
Location FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: FEI=fragility exposure index; HDDS=household dietary diversity scores; MAHFP=months of adequate household food provisioning; MSI=multi-shock index. Robust standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Table 8 presents domain-specific regressions examining the relationship between shock exposure and different dimensions of fragility. For human security, the MSI coefficient is positive but not statistically significant, providing no evidence of a systematic association in this domain. In contrast, MSI is significantly associated with both economic inclusion and social cohesion, but in opposite directions. The negative association with economic inclusion fragility is counterintuitive and should be interpreted cautiously. The positive association with the social cohesion domain indicates that households with greater multi-shock exposure also report greater fragility in social cohesion. Because fragility is observed only in 2016, these domain-specific results identify associations rather than causal mechanisms.

Overall, the weak aggregate MSI–FEI relationship masks domain-specific heterogeneity. MSI is negatively associated with economic inclusion fragility and positively associated with social cohesion fragility, while its association with human security is not statistically significant. Because Table 8 reports three separate domain regressions, we also assess the significant coefficients under a Bonferroni correction for three tests. The economic inclusion ($p < 0.001$) and social cohesion ($p \approx 0.006$) associations remain statistically significant at the 1 percent level, while the human security association remains insignificant.

The negative association between MSI and economic fragility is counterintuitive and should be interpreted with caution. One possible explanation is a market-integration mechanism: households more integrated into markets and economic networks may face greater exposure to price and production shocks while simultaneously exhibiting lower measured economic exclusion. Two related factors may also contribute. First, the economic inclusion domain captures structural access conditions that need not move with short-term shocks. Second, differences in shock reporting may be associated with economic activity and market participation. These explanations are hypotheses rather than mechanisms identified by the present analysis.

Table 8. Domain-specific regressions: Shock exposure and dimensions of fragility

	(1)	(2)	(3)
Variables	**Human security**	**Economic inclusion**	**Social cohesion**
MSI (2016)	0.072	-0.203***	0.155***
	(0.089)	(0.032)	(0.050)
Household size	-0.002	0.005	0.002
	(0.005)	(0.004)	(0.004)
Male household head	-0.031***	0.002	-0.021
	(0.018)	(0.016)	(0.014)
Age	0.000	0.001	-0.001
	(0.001)	(0.001)	(0.001)
Education (years)	0.001	-0.001	-0.001
	(0.002)	(0.002)	(0.001)
Children	0.000	-0.007	-0.008
	(0.011)	(0.009)	(0.008)
Elderly	-0.007	-0.011	-0.002
	(0.020)	(0.018)	(0.015)
Dependency ratio	-0.013	-0.004	0.008
	(0.017)	(0.014)	(0.011)
Land (ha)	0.000	-0.016***	-0.002
	(0.009)	(0.007)	(0.007)
Diet diversity	0.003	0.006	0.001
	(0.004)	(0.004)	(0.003)
Food provisioning (months)	0.000	0.000	-0.001
	(0.002)	(0.002)	(0.001)
Constant	0.547***	0.469***	0.397***
	(0.061)	(0.057)	(0.050)
Observations	590	590	590
R-squared	0.032	0.030	0.018
Location FE	Yes	Yes	Yes

Note: MSI=multi-shock index. Robust standard errors in parentheses. * $p<0.1$, ** $p<0.05$, *** $p<0.01$

The positive association between MSI and the social cohesion domain is consistent with theories in which adverse events can strain reciprocal relations, trust, and informal risk-sharing systems (Fafchamps and Gubert, 2007; Devereux and Getu, 2013). It also resonates with the polycrisis perspective, which emphasizes disruption of social ties and institutions under interacting pressures (Lawrence et al., 2024). Empirically, however, the result should be stated more narrowly: MSI is positively associated with social cohesion fragility, while the aggregate MSI–FEI association is weak. This pattern motivates attention to social ties and informal support systems in future research and intervention design, but it does not establish a causal channel.

4.2. Discussion of implications

The findings provide evidence of limited aggregate empirical overlap between shock exposure and fragility in this sample, even when shock exposure is measured in earlier waves and through the three-wave average MSI. This pattern is consistent with the interpretation that FEI captures structural and experiential dimensions of vulnerability not fully represented by realized shocks. At the same time, differences in timing, measurement structure, and reporting may contribute to the weak observed relationship and prevent the aggregate null from being interpreted as proof of conceptual independence.

Fragility exposure is strongly and consistently associated with both dietary diversity and months of adequate food provisioning in the reported models. In contrast, the association between contemporaneous MSI and these outcomes is less stable across specifications. This comparison concerns the consistency of estimated associations, not the relative size of raw coefficients, because MSI and FEI are constructed and scaled differently.

These findings have implications for policy and intervention design. Many social protection systems combine chronic poverty targeting with mechanisms that respond to observable shocks such as droughts or food price disruptions. Kenya's Hunger Safety Net Programme, for example, provides regular cash transfers and can be scaled up during droughts (Maione, 2020), while Ethiopia's Productive Safety Net Programme combines transfers and public works in chronically food-insecure areas (Hoddinott et al., 2012). The present results do not test whether adding FEI to program targeting improves performance. Rather, they motivate testing whether selected fragility indicators could complement shock-based information and identify vulnerable households not captured by acute shock criteria alone. Any operational use would require validation of indicator reliability, administrative feasibility, predictive performance, exclusion and inclusion errors, and safeguards for sensitive information.

More broadly, the weak aggregate relationship between shocks and fragility suggests that shock-responsive indicators alone may not capture all dimensions of household vulnerability. In polycrisis contexts, this motivates consideration of integrated frameworks that combine information on realized shocks with longer-term conditions such as insecurity, exclusion, and weak social cohesion, while recognizing that the present analysis does not evaluate the effectiveness of specific policy packages.

Finally, the interaction between MSI and FEI in the food security models are imprecisely estimated and not statistically significant. The data therefore do not provide clear evidence that fragility amplifies or buffers the association between shock exposure and food security. What the reported models do show is a substantial negative association between FEI and both food security outcomes after accounting for contemporaneous MSI. This independent association, rather than an estimated amplification mechanism, supports retaining shock exposure and fragility as separate dimensions in vulnerability analysis.

5. Conclusion

This paper examines the relationship between multi-shock exposure and fragility exposure as two key dimensions of vulnerability in contexts characterized by polycrisis. Using household-level data from the HORTINLEA survey in Kenya, we combined an MSI, capturing realized exposure to shocks over time, with an FEI, reflecting lived conditions of insecurity, economic exclusion, and social cohesion.

The empirical results indicate limited aggregate empirical overlap between shock exposure and fragility exposure. Across descriptive and regression analyses, MSI is weakly associated with FEI, including when earlier and three-wave average shock exposure are considered. These findings are consistent with the interpretation that FEI captures dimensions of vulnerability not fully reflected in realized multi-shock exposure, although differences in timing, measurement, and reporting may also contribute to the weak observed association. Fragility exposure nevertheless shows a strong and consistent negative association with the two food security outcomes examined. A 10-percentage-point higher FEI is associated with 0.11–0.14 fewer food groups in HDDS and 0.18–0.27 fewer MAHFP. In contrast, associations between contemporaneous MSI and food security are less consistent across specifications. Because the indexes are differently constructed and scaled, these findings should be interpreted in terms of consistency of association rather than direct comparison of raw coefficient magnitudes.

These findings highlight the importance of distinguishing between shock exposure and fragility exposure when analyzing vulnerability in polycrisis contexts. Relying solely on measures of shocks risks overlooking households that are structurally fragile but not currently experiencing acute events. The dual-index framework proposed in this paper offers a practical approach to capturing both dimensions simultaneously.

The limitations of this study need to be acknowledged. Fragility exposure is observed only in the 2016 survey wave, which prevents analysis of how fragility evolves over time and limits the ability to make causal claims about the relationship between shocks and fragility. The empirical results should therefore be interpreted as associational rather than causal. In addition, both the MSI and FEI rely on self-reported survey data, which may be affected by recall error or reporting bias. The shock measures are also limited to the types of events captured in the survey and may not fully reflect the intensity, duration, or broader systemic nature of crises. Finally, the analysis is based on rural and peri-urban households in the HORTINLEA sample in Kenya, so the findings may not be directly generalizable to other settings with different institutional, economic, or conflict conditions.

From a policy perspective, the findings motivate testing whether fragility indicators can complement shock-responsive targeting and monitoring systems, rather than assuming that such integration will necessarily improve program performance. Operational adoption would require validation of indicator reliability, administrative feasibility, predictive value, targeting errors, and safeguards for sensitive information. Future research should extend this approach by incorporating panel measures of fragility and evaluating the dual-index framework across different contexts and program settings.

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Annexes

Annex 1: Multi-shock index construction[2]

Baseline multi-shock index

Let $S_{itk} \in \{0,1\}$ indicate whether household i experienced shock $k$in year t, for $k = 1, \ldots, K$,

The baseline nonparametric multi-shock index (MSI) is:

$$MSI_{it}^{B} = \sum_{k \in K^*} w_k \, S_{itk}$$

where K^* is the subset of shocks retained after empirical screening and w_k is the weight assigned to each retained shock. The MSI uses a data-driven screening step applied separately within each survey wave (Table A1). A shock is retained when FCS_av is lower among households reporting the shock than among households not reporting it; no statistical significance threshold is imposed (Ulimwengu, 2026).

Table A1. List of shocks from HORTINLEA survey

Shock	Retained 2014	Retained 2015	Retained 2016	Pooled prevalence p_k (MSI construction sample)
Drought	0	1	1	0.248
Heavy_rain	1	1	1	0.233
Crop_failure	1	0	1	0.218
Illness_member	0	1	1	0.150
Crop_disease	1	0	0	0.106
Food_price_increase	1	1	0	0.097
Livestock_death	0	0	1	0.070
Input_price increase	1	1	1	0.062
storm	1	1	0	0.041
Death_hhs member	0	1	1	0.031
Flood	1	1	0	0.029
Livestock_disease	0	0	1	0.025
Livestock_pest	1	0	0	0.016
Landslide	1	0	1	0.014
Fuel_price increase	1	0	1	0.010
Household member_left	0	1	0	0.002
Forced_contribution	1	0	0	0.001
Divorce	0	1	0	0.001
Job_loss	0	0	1	0.000
Ceremony_cost	0	0	0	0.000
Crop_pest	0	0	0	0.000
New member_joined hhs	0	0	0	0.000
Theft	0	0	0	0.000

[2] This section is largely drawn from Ulimwengu, J. M. (2026).

Water_shortage	0	0	0	0.000

Two natural weighting schemes follow from the original MSI logic. The first is an unweighted count:

$$w_k = 1$$

which yields

$$MSI_{it}^{B,U} = \sum_{k \in K^*} S_{itk}\,.$$

The second, and the measure used in the main analysis, is an inverse-prevalence-weighted version:

$$w_k = \frac{1}{p_k},$$

where $p_k = \Pr(S_{itk} = 1)$ is the pooled prevalence of the retained-shock indicator for shock k. This gives

$$MSI_{it}^{B,P} = \sum_{k \in K^*} \frac{S_{itk}}{p_k}.$$

The retained set K^* is determined empirically rather than selected ad hoc (Ulimwengu, 2026).

Annex 2: Fragility exposure index[3]

The fragility exposure index (FEI) for individual *i* in time *t* is specified as:

$$FEI_{it} = 100 \times Norm(D_{it})$$

$$D_{it} = Norm(\sum_{j=1}^{N} X_{ijt}) + Norm(\sum_{j=1}^{M} Y_{ijt}) + Norm(\sum_{j=1}^{O} Z_{ijt}) \qquad (1)$$

where X_{ijt}, Y_{ijt}, and Z_{ijt} represent the three domains: human security, economic inclusion, and social cohesion, respectively (Table A2).

[3] This section is largely drawn from Baliki et al. (2022).

Each sub-indicator within the following domains is normalized to take a value between 0 and 1 as follows:

$$X_{ijt} = Norm(x_{ijt}) = \frac{x_{ijt} - min(x_{jt})}{max(x_{jt}) - min(x_{jt})}$$

where i, j and t denote the individual, sub-indicator, and time period (such as year), respectively. This is important to ensure that each sub-indicator within each domain takes the same weight in the final index, as not all variables have similar answer ranges. Hence, for each domain, we add up the total number of the normalized sub-indicators to develop an equally weighted domain index. In the final step, as shown in equation (1), each domain is then normalized to provide equal weights between these domains for the generation of the FEI. Given a lack of strong priors, which are the most important, and a lack of bespoke data on those that individuals consider key, we argue that this equally weighted index is the most appropriate method available for this analysis. These equal weights can be augmented to deal with many of the concerns raised in a range of multidimensional indexing literature.

Using Equation (1), we can classify individual experiences of or exposure to fragility into one index which has, initially, a value between 0 and 3, where 0 is the least fragile and 3 is the most fragile. However, the normalization of the index allows us, or other researchers, to transform the values to suit specific analytical needs without jeopardizing the underlying distributions. Here the final FEI takes a value of 0 and 1.

Table A2. FEI domain and list of indicators

FEI domain	Indicators/dimensions included	Interpretation of higher normalized values
Human security	Satisfaction with personal security; security in the neighborhood and district; feeling unsafe walking in the neighborhood; fear of crime at home; presence of organized groups causing insecurity; perceived importance of owning a weapon for protection; willingness to report violent crime; household exposure to sexual incidents, assault/threat, theft, and bribery/corruption; fear of juvenile delinquency, war, religious/ethnic conflict, misconduct by government and local authorities, police violence, arbitrary police control, crime, and land conflicts; perceptions of relevant institutions' service delivery, trustworthiness, and accessibility	**Higher = greater human insecurity / greater fragility exposure**
Economic inclusion	Satisfaction with financial situation and living standard; fear/concern relating to corruption, unemployment, and loan sharking; perceptions of relevant institutions' service delivery and accessibility without paying a bribe	**Higher = greater economic exclusion / greater fragility exposure**
Social cohesion	Satisfaction with community/social integration, social equality, leisure time, and family life; trust in family, neighbors and other social groups; participation in community, religious, civic and political organizations; electoral/political participation; perceptions of and trust in formal and informal institutions	**Higher = weaker social cohesion / greater fragility exposure**

Annex 3: Robustness checks

Persistence and exposure patterns

To explore nonlinearities and persistence in shock exposure, we classify households based on their exposure history. Specifically, we define indicators for the number of years in which households experience high shock exposure (such as above the median or upper quartile of MSI). This allows us to estimate:

$$FEI_{i,2016} = \alpha + \delta_1 OnceHigh_i + \delta_2 TwiceHigh_i + \delta_3 AlwaysHigh_i + X_i'\gamma + \varepsilon_i$$

where the omitted category corresponds to households that are never highly exposed. This specification captures whether repeated exposure to shocks is associated with disproportionately higher levels of fragility. Results are shown in Table A3.

Table A3. Persistence of shock exposure and fragility

Variables	Persistence model
Once High	-0.006
	(0.018)
Twice High	0.005
	(0.019)
Always High	-0.005
	(0.028)
Hhsize_2014	0.003
	(0.004)
hhh_sex_2014	-0.016
	(0.015)
hhh_age_2014	0.000
	(0.001)
hhh_educ_years_2014	-0.001
	(0.001)
Number_children_2014	-0.004
	(0.009)
Number_elderly_2014	-0.008
	(0.017)
Dependency_ratio_2014	-0.005
	(0.013)
land_ha_tot_2014	-0.004
	(0.007)
Constant	0.536***
	(0.038)
Observations	590
R-squared	0.008
Observations	590

Note: Robust standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.01

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