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ARTICLE

Measuring Natural Hazard-Related Disasters through Self-Reports

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Abstract Exposure to multiple natural hazard-related disasters will become more common due to climate change. This article reports on the development and validation of a cumulative measure of exposure to natural hazard-related disasters (2013–2017) at the area level, and an individual-level measure of disaster impact using data from the Longitudinal Cohort Study on the Filipino Child and linked data from the International Disaster Database (EM-DAT). Caregiver reports of cumulative exposure to disasters had statistically significant associations with disasters reported by neighborhood officials and with disasters in EM-DAT. Using ecometric techniques we generated a reliable community average measure of exposure to natural hazard-related disasters. Based on neighbor but not individual self-reports this exogenous measure of disaster exposure in the local area was more strongly related to EM-DAT and official neighborhood reports than individual reports. To capture household variation we developed an individual-level measure of disaster impacts. Disaster impact was associated with measures of exposure (individual and community average), community ratings by officials, and EM-DAT but only moderately associated with the community average exposure. Both the community average and disaster impacts measures were associated with household income and the adequacy of income in households.

Keywords Disaster exposure · Measuring disasters · Philippines · Socioeconomic impacts · Social surveys · Subjective indicators

1 Introduction

Climate change is leading to an increased number of natural hazards and disasters in many countries (Oppenheimer and Anttila-Hughes 2016). While all members of a community can be negatively affected by natural hazards and disasters, children are often disproportionately affected (Masten and Narayan 2012; Codreanu et al. 2014; Kousky 2016; Dyregrov et al. 2018). To date, research on the impacts of natural hazard-related disasters on children has largely focused on physical and mental health, and schooling (Kousky 2016).

Although a number of studies have found the impact of natural hazard-related disasters on children's well-being to be small, some studies have found significant long-lasting impacts. For example, a study of the long-term impacts of the Australian Black Saturday bushfires in 2009, which resulted in the loss of 180 lives, found that children in primary school who had been in bushfire-exposed areas performed substantially worse on numeracy and literacy tests, and this effect continued four years after the fires (Gibbs et al. 2019). Similarly studies of the impacts of major Australian bushfires in 1983 found higher levels of psychological symptoms among children two years after the fires (McFarlane 1987) and some lingering effects after 20 years (McFarlane and Van Hooff 2009). There is also some evidence of impacts in utero. For example, a month after Super Typhoon Haiyan hit the Philippines in 2013, a qualitative study revealed that pregnant and lactating women were among the most vulnerable healthwise in the

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aftermath (USC-OPS 2014), indicating an impact that is likely to extend to offspring in their formative stages. Most studies of the impact of natural hazards and disasters on children have focused on particular areas and on a particular disaster. Kousky (2016) noted that there is a need for research to examine the cumulative effects of experiencing multiple natural hazard-related disasters on children living in high-risk disaster areas.

Although there are well-established scientific methods for quantifying the occurrence and impact of a number of types of natural hazard-related disasters, methods for quantifying other disasters, such as drought, are not well established. Moreover, we are not aware of a standard technique for quantifying exposure to multiple natural hazard-related disasters. There are also challenges related to quantifying the impact of natural hazard-related disasters on human populations. Developing measures of disaster impact is important because the measures can potentially be used to inform the development and implementation of disaster risk reduction strategies that could reduce the impact of exposure to natural hazards and disasters (World Bank and United Nations 2010).

The Philippines is an ideal country in which to study the impact of natural hazard-related disasters on human development because it has a large number of such disasters. In 2018, 6.5 million people were affected by natural hazard-related disasters, the second highest number after India (data from the International Disaster Database – EM-DAT, CRED 2017). Moreover, recent research in the Philippines reported that rainfall shocks are associated with chronic total poverty and food poverty (Bayudan-Dacuycuy and Baje 2019). In this article, we report on the development and validation of a measure of natural hazard-related disasters based on self-reports of exposure to disasters collected as part of a national cohort survey of children in the Philippines, the Longitudinal Cohort Study on the Filipino Child (LCSFC) (USC-OPS 2018). The self-reports of exposure to natural hazard-related disasters were obtained from the primary caregivers of the study children.

There are a large number of studies that have used self-report measures of exposure to disasters (Verger et al. 2003; Garfin et al. 2014; Harville et al. 2015; Sherwood et al. 2017), but they have not combined individual-level responses to produce an area-level measure. The LCSFC also collected unusually rich data on disaster exposure and impacts reported by caregivers and barangay (smallest administrative unit in the country) officials. In addition to these measures, information compiled in EM-DAT (CRED 2017) is linked at the barangay level to validate the survey measures of disasters that were constructed from individual-level self-reports.

In this study we used self-reports of natural hazard-related disasters and then aggregated them to the geographic area level (Hunter et al. 2012; Edwards et al. 2015, 2019). Aggregation of area ratings by self-report to neighborhoods is not new. It has been routinely used since the late 1990s in studies examining the physical and social environments of neighborhoods (Sampson et al. 1997; Mair et al. 2010). The approach is widely used and accepted. An article published in *Science* describing the technique has been cited by other papers more than 12,000 times, suggesting that the method has been acknowledged by the research community as legitimate for the construction of area measures (Sampson et al. 1997).

The main advantage of a measure of exposure to disaster based on individual self-reports is that the impacts of disasters are often geographically localized. Flooding is a good example of this type of disaster—there could be extensive damage to houses in low-lying areas but not to houses that were built on higher ground in the same village. Thus individual self-report is likely to more accurately measure a household's exposure to disasters than measures derived from national or international monitoring systems such as the EM-DAT, or reported at the community level by officials. It is therefore likely to be a better measure if the aim of a study is to estimate the impact of experiencing a natural hazard-related disaster on household-level outcomes.

One limitation of self-reported measures of disasters is that they can be influenced by individual circumstances, such as exposure to poverty or mental health issues. We overcame this limitation by creating an individual-specific average rating of disaster exposure in the local area that uses neighbor reports and excludes caregivers' own reports in constructing the measure for caregiver households. In this way the measure of neighborhood disaster exposure is exogenous to individual circumstances but retains the capacity to capture geographic variation in disaster exposure.

The study also developed a measure of the impact of natural hazard-related disasters in which impact is conceptualized in terms of economic or health effects. This disaster impacts measure is only for the household level, since many household-specific factors can mitigate severe impacts of natural hazards and disasters—for example, precise location of housing, quality of housing, and economic reserves held by a household. The measure of disaster impacts is nevertheless based on reports on objective characteristics such as damage to houses or property, loss of livelihood, or injuries to household members.

The general aim of this study was to develop measures of disaster exposure and impact from individual self-reports. We also aimed to establish their convergent validity with objective disaster measures—official reports and the International Disaster Database—and their predictive validity with household income and income adequacy.

Although there was limited research literature to generate specific hypotheses, we had some more specific aims: (1) to test whether individual self-reports of disaster exposure were significantly associated with objective disaster measures (convergent validity); (2) to examine whether there was sufficient community variation in self-report measures of disaster exposure at the community level and ecometric reliability to support average ratings of other residents at the community level (average community report); (3) to test whether average community reports and individual reports of disasters were correlated with objective disaster measures to test convergent validity; (4) to construct an individual measure of impacts of natural hazard-related disasters using factor analysis—we tested whether this measure of disaster impacts was correlated to other disaster measures (evidence of convergent validity) but not too highly (evidence of discriminant validity). Finally, given that it is well documented that there are household economic impacts of natural hazard-related disasters (Anttila-Hughes and Hsiang 2013; Botzen et al. 2019), we examined whether our disaster measures were associated with income and income adequacy (evidence of predictive validity).

2 Methods

This section provides an overview of the data sources and statistical methods used in this study.

2.1 Longitudinal Cohort Study on the Filipino Child (LCSFC)

The LCSFC is the Philippines' first nationally representative longitudinal study of child development. It is planned as a 15-year study that started in 2016, and was designed to examine how the lives of young Filipinos change as the Sustainable Development Goals (SDGs) are implemented. The study recruited 4952 10-years old children at Baseline (October 2016−January 2017), and this cohort will be observed through to age 25. The study sample was selected to be nationally representative of 10-year old Filipinos, from the country's three main island groups of Luzon, Visayas, and Mindanao. The sampling design included children from Indigenous peoples and households with children with disabilities through implicit stratification (Lynn 2018). Households were sampled from 345 barangays in total. On average, 43% of the study barangays were urban, on average there were 3071 households and 13,335 people per barangay. Agriculture was the main source of livelihood in 63% of the barangays. Thirteen percent of the barangays had slums or informal settlements and 8.4% had experienced armed conflict in the last three years. The goal is to retain about 2000 of the original cohort by the final survey (2030−2031). Each wave (repeat survey) of the study collects community-level data from the barangays where the study children live.

2.2 Measures of Natural Hazard-Related Disasters in the Longitudinal Cohort Study on the Filipino Child (LCSFC)

In the LCSFC, information about exposure to natural hazard-related disasters is collected from two sources: a barangay official (generally the barangay captain or secretary) and the primary caregiver (about 83% mothers) of the study child (household self-report). Table 1 summarizes the nature of the information on the experience of natural hazards and disasters collected from the barangay official and the primary caregiver. Barangay officials were asked to provide detailed information about the number and types of disasters experienced in the barangay in the previous three years. For each disaster, we obtained information on the number of deaths and the number of households affected. The primary caregiver of the study child was asked to report on disasters experienced by their household since 2013. Depending on the timing of the interview, this was during either the previous three years or the previous four years. The primary caregiver was also asked about the types of damage inflicted by each disaster (for example, deaths, injuries, damage to the house, loss of property, loss of livelihood or crops). However, the primary caregiver was not asked to quantify the extent of the damage experienced by their household.

The primary caregiver survey responses were used to construct a measure of the number of types of natural hazard-related disasters the household had experienced since 2013. The community-level measure of experience of natural hazard-related disasters is the number of disasters that the barangay official reported the community to have experienced during the previous three years.

2.3 The International Disaster Database (EM-DAT)

A third source of data on the experience of natural hazard-related disaster used in this study is the EM-DAT that provides worldwide data on the occurrence and effects of more than 23,000 natural hazard-related and technological disasters from 1900 to the present. It is compiled from information provided by United Nations agencies, the United States Office of Foreign Disaster Assistance, national governments, the International Federation of Red Cross and Red Crescent Societies, other nongovernment organizations, insurance companies, research institutes, and the media.

Table 1 Disaster variables collected in the longitudinal Cohort Study of the Filipino Child (LCSFC), Wave 1

Respondent	Variable	Response format
Barangay official	Type of disaster	Tropical cyclone (tropical depression, storm, typhoon, super typhoon), extreme rainfall, drought, volcanic eruption/lava flow, storm surge, sea level rise, flooding/flash flood, tsunami, earthquake-induced landslide, rainfall-induced landslide, fire, armed conflict/strife/wars, wildfire, epidemic, marine pollution (oil spill, fish kill, red tide, and so on)
	Experienced in the last 3 years	Yes, No
	Year(s) happened	Year(s)
	Number of households affected by disaster last occurrence	Number
	Number of deaths in the last occurrence	Number
Primary caregiver	Type of disaster experienced since 2013 by the household	Tropical cyclone (tropical depression, storm, typhoon, super typhoon), extreme rainfall, drought, volcanic eruption/lava flow, storm surge, sea level rise, flooding/flash flood, tsunami, earthquake-induced landslide, rainfall-induced landslide, fire, armed conflict/strife/wars, wildfire, epidemic, marine pollution (oil spill, fish kill, red tide, and so on)
	Loss of lives	Yes, No
	Injury	Yes, No
	House damage	Yes, No
	Loss of property	Yes, No
	Loss of livelihood/crops	Yes, No
	Others, specify	Open text

Source LSCFC Wave 1 Barangay official and primary caregiver questionnaires

A useful definition of disasters, provided by the Centre for Research on the Epidemiology of Disasters (CRED),[1] is "a situation or event that overwhelms local capacity, necessitating a request at the national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (CRED 2017).

For a disaster to be entered into the EM-DAT, one or more of the following criteria must be met:

- 10 or more people reported killed;
- 100 or more people reported affected;
- A declaration of a state of emergency;
- A call for international assistance.

For this study, we linked disasters collected in EM-DAT to the barangay level. The types of disaster in EM-DAT that we used are described in Table 2. Disasters are classified according to a standardized classification system adapted from the Integrated Research on Disaster Risk peril classification and hazard glossary (IRDR 2014).

The EM-DAT database includes information on other aspects of disasters.[2] Although this information could potentially be used for generating economic and social costs of disasters, there is no accepted protocol for summarizing these other varied measures of disaster impact at the small area level. There is also variation between variables and countries in what is captured and the reliability of the measures. Given these uncertainties and the exploratory nature of the study, we only included a cumulative measure of disaster exposure from 2006 to 2017.

On initial examination, it appears as though the reports from the LCSFC capture more detailed information than EM-DAT. However, this is a result of the way disasters are covered in EM-DAT.[3] Many of the disasters captured in the LCSFC questionnaire would be categorized in EM-DAT as disaster subtypes or associated disasters. For example, tropical cyclone is a subtype of storm in EM-DAT. Another example is a storm surge, which would also be categorized as a disaster subtype. In this study, we

[1] CRED is the organization responsible for the creation of EM-DAT.

[2] EM-DAT includes the event name; geographical information (standard geography, latitude and longitude); disaster magnitude scale and value (for example, Richter scale for earthquake, area for flood and drought); date of the disaster; group, subgroup, type, and subtype of the disaster; secondary or associated effects or consequences of a primary event (for example, landslide for a flood, explosion after an earthquake); and the human impact (for example, number of deaths, people affected, total estimated damages, insured losses). See https://www.emdat.be/guidelines.

[3] See www.emdat.be/classification.

Table 2 Types of disasters and definitions in the international disaster database EM-DAT

Variable	Description
Drought	An extended period of unusually low precipitation that produces a shortage of water for people, animals and plants. Drought is different from most other hazards in that it develops slowly, sometimes even over years, and its onset is generally difficult to detect. Drought is not solely a physical phenomenon because its impacts can be exacerbated by human activities and water supply demands. Drought is therefore often defined both conceptually and operationally. Operational definitions of drought, meaning the degree of precipitation reduction that constitutes a drought, vary by locality, climate and environmental sector
Earthquake	Sudden movement of a block of the Earth's crust along a geological fault and associated ground shaking
Epidemic	Either an unusual increase in the number of cases of an infectious disease, which already exists in the region or population concerned; or the appearance of an infection previously absent from a region.
Flood	A general term for the overflow of water from a stream channel onto normally dry land in the floodplain (riverine flooding), higher-than- normal levels along the coast and in lakes or reservoirs (coastal flooding) as well as ponding of water at or near the point where the rain fell (flash floods)
Landslide (rainfall induced)	Any kind of moderate to rapid soil movement incl. lahar, mudslide, debris flow. A landslide is the movement of soil or rock controlled by gravity and the speed of the movement usually ranges between slow and rapid, but not very slow. It can be superficial or deep, but the materials have to make up a mass that is a portion of the slope or the slope itself. The movement has to be downward and outward with a free face
Tropical storm	A tropical storm originates over tropical or subtropical waters. It is characterised by a warm-core, non-frontal synoptic-scale cyclone with a low pressure centre, spiral rain bands and strong winds. Depending on their location, tropical cyclones are referred to as hurricanes (Atlantic, Northeast Pacific), typhoons (Northwest Pacific), or cyclones (South Pacific and Indian Ocean)
Volcanic activity	A type of volcanic event near an opening/vent in the Earth's surface including volcanic eruptions of lava, ash, hot vapour, gas, and pyroclastic material

Source EM-DAT Glossary, https://www.emdat.be/Glossary#letter_s

counted disaster subtypes and associated disasters in the same manner as disasters to align with how data are collected in the LCSFC.

2.4 Statistical Analyses

Random effects linear regression was used to examine the association between self-reported household experience of disasters and two other independent measures of the occurrence of disasters: the barangay official report and a measure derived from EM-DAT (Hox et al. 2017). Other covariates included in these models are Indigenous status of the caregiver, household structure, number of people in the household, number of rooms used for sleeping, mean household income, island grouping (Luzon, Visayas, Mindanao), year of interview, and whether the household had Internet access. Clustering was at the neighborhood or barangay level.

Ecometric reliability We used ecometric methods to generate the neighborhood reliability of aggregated individual household self-reported disasters. Using methods developed by Raudenbush and Sampson (1999) we applied the random effects linear regression to estimate the variance in self-reported disasters at the household and at the neighborhood levels. The ecometric reliability of self-reported disasters was generated by the following formula:

$$Reliability = \frac{neighborhood\ variance}{neighborhood\ variance + \left(\frac{individual\ variance}{average\ number\ of\ people\ per\ area}\right)}$$

While there is no agreed cut-off for reliability at the neighborhood level, scores above 0.60 are generally considered to be good (Hox et al. 2017).

Convergent validity and discriminant validity Pearson correlations above 0.30 to 0.50 are classified by Cohen (1988) as "medium" and support convergent validity. Very strong correlations of 0.80 or above would suggest a lack of uniqueness of disaster measures and therefore a lack of discriminant validity (Cohen 1988).

Predictive validity To examine whether the disaster measures were associated with mean monthly household income, we estimated random effects linear regression and estimated marginal means for disaster quintiles. We used the log of income to address skewness. Income adequacy was measured by the following question:

> When you think about the income of all the members of your household and all the expenses for maintaining (or running) the whole household, would you say:

(1) There is enough (income), with money left over.
(2) Just enough to pay expenses, with no difficulty.
(3) Some difficulty in meeting expenses.
(4) Considerable difficulty in meeting expenses.

Given the ordered nature of responses, we estimated an ordered logistic regression and then calculated the predicted probabilities of being in the four categories by quintile of disaster measure to examine the association between disasters and income adequacy. Consistent associations between disaster measures and household income and income adequacy would be considered evidence of the predictive validity of the relevant disaster measure. We did not include any additional covariates for both sets of regression models.

3 Results

The first section validates the self-reported experience of disasters. The second section reports on the reliability of community reports of disasters and the third section on the convergent validity of self and community reports of disasters. The fourth section reports on the development of a variable measuring disaster impacts and the fifth section focusses on the validity of the measure of disaster impacts. The final section examines the relationship between disaster measures and household economic outcomes.

3.1 Validating Household Self-Reported Experience of Disasters

This section outlines the results of validating the self-reported caregiver household experience of the number of disasters that their household experienced during the period 2013–2017. The individual household self-report is validated by estimating its relationship to two other independent measures of the occurrence of disasters: the barangay official report and a measure derived from EM-DAT. When the barangay official report and the EM-DAT measure are associated with the household self-report, there is evidence of convergent validity—that is the self-report is a valid measure of the experience of disaster. We would not expect either the barangay official report or the EM-DAT measure to be perfectly correlated with the individual household report because the experience of disaster, for at least some types of disaster, can be localized and because of geographic mobility of households.

The estimates of the relationship between the household self-report of the number of disasters experienced by the household and the barangay official report, and the household self-report and the EM-DAT measure of the number of disasters experienced by the barangay are shown in Table 3. None of the included demographic variables were significantly associated with disaster ratings at the household level.

There was significant regional variation—households in Visayas had the highest ratings of disasters, followed by Luzon and Mindanao. The barangay official report and the EM-DAT measures of the number of natural hazard-related disasters experienced by the barangay were statistically significantly related ($P < 0.001$) to the household self-report of the number of disasters experienced by the household.

3.2 Ecometric Reliability of Average Community Reports of Disasters

The intra class correlation coefficients estimated from random effects model also showed that 25% of variation in ratings occurred at the barangay (neighborhood) level,[4] and the ecometric reliability for a community aggregate of self-reported disasters was 0.89 and suggests that average ratings at the barangay level are reliable (see Table 3).

3.3 Convergent Validity of Self-Report Disaster Measures

This section describes the measure of the average number of disasters experienced by households in a barangay. Figure 1 shows the distribution of the number of disasters reported by individual households. Figure 2 shows the average number of disasters reported by households in each barangay. If the barangay-level measure of the number of disasters experienced is used to estimate the impact of disasters on individual or household outcomes, households' own responses should be excluded from this measure to ensure that the measure of disasters is exogenous to other outcomes of interest in the survey (for example, caregiver ratings of exposure to violence, stress and depression). This approach follows Hunter et al. (2012). In addition to being an individual-specific mean of neighbor reports of disaster exposure, the ratings at the barangay level have fewer extreme values at either end of the distribution.

Figure 3 shows the relationship between the individual household report of the number of disasters experienced and the average community report of the number of disasters experienced in the last three years. The relationship between the disaster measures is illustrated using a non-linear lowess curve. There is a linear relationship between the two variables. The correlation of 0.55 (Table 4) also shows that, although a strong relationship exists, the variables are not identical.

A relationship also exists between the average community report and EM-DAT (Fig. 4). Interestingly, Table 4 shows a stronger correlation between the average community report and EM-DAT ($r = 0.42$) than between the

[4] The variance in ratings at the barangay level was 0.65 and 1.12 at the individual level, and there are an average of 14.3 raters per barangay.

Table 3 Correlates of individual household self-reported experience of disaster *r* (number of disasters 2013−2017), random effects linear regression models, in the Philippines

	Model (1)	Model (2)	Model (3)
Indigenous status	−0.10	−0.10	−0.07
	(0.07)	(0.07)	(0.08)
Household type (ref: Nuclear family)			
Horizontally extended nuclear family	0.06	0.05	0.05
	(0.10)	(0.10)	(0.10)
Vertically extended nuclear family	0.04	0.04	0.04
	(0.05)	(0.05)	(0.05)
Horizontally and vertically extended nuclear family	0.16	0.15	0.16
	(0.16)	(0.16)	(0.16)
Multi−nuclear family	0.07	0.07	0.07
	(0.06)	(0.06)	(0.06)
Number of people in household	0.01	0.01	0.01
	(0.01)	(0.01)	(0.01)
Number of rooms used for sleeping	−0.01	−0.01	−0.01
	(0.01)	(0.01)	(0.01)
Mean household income (1000 pesos)	−0.003	−0.003	−0.003
	(0.002)	(0.002)	(0.002)
Domain (ref: Luzon)			
Visayas	0.53***	0.50***	0.52
	(0.0988)	(0.10)	(0.09)
Mindanao	−0.59	−0.71	−0.40
	(0.10)	(0.10)	(0.12)
Year of interview (*ref:* 2016)			
2017	0.09	0.11	0.10
	(0.14)	(0.13)	(0.14)
Internet access (ref: No)			
Yes	−0.07	−0.08	−0.07
	(0.0423)	(0.04)	(0.04)
Barangay official's report		0.09***	
		(0.02)	
EM−DAT disaster database			0.03**
			(0.01)
Intercept	2.83***	2.60***	2.12***
	(0.09)	(0.10)	(0.27)
Number of households	4932	4932	4932
Number of Barangays	345	345	345
Intra Class Correlation	0.25	0.23	0.25
R2−Within	0.003	0.003	0.003
R2−Between	0.304	0.358	0.319
Overall R2	0.122	0.142	0.128

Standard errors in parentheses. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Source Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

individual ratings and EM-DAT ($r = 0.26$). Moreover, barangay official reports of disaster had a small correlation with individual household self-reports ($r = 0.07$) and average community reports ($r = 0.12$), and there was a negative correlation with the disaster variable from EM-

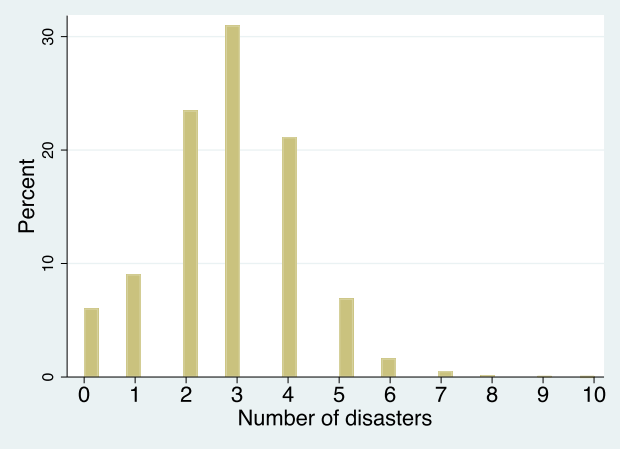


Fig. 1 Number of disasters experienced by household, individual household self-report, 2013–2017. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

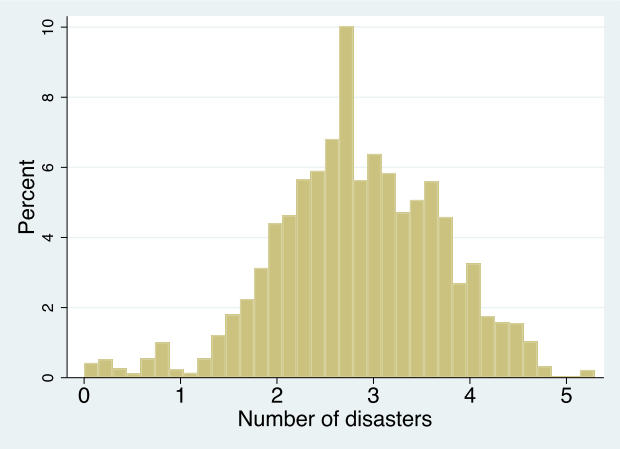


Fig. 2 Number of disasters experienced by household, average community report, 2013–2017. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

DAT ($r = -0.10$), suggesting that the official reports in LCSFC are not a particularly good measure of disasters.

3.4 Development of a Disaster Impacts Variable

Exposure to a natural hazard-related disaster does not necessarily mean that there will be substantial impacts on the physical and psychological well-being of individuals, nor does it necessarily affect the livelihood of those exposed. Given the frequency of disasters in the Philippines, another important question is the impact of natural hazard-related disasters on children and their families. Therefore, we developed a measure of disaster impact based on self-report of participants exposed to natural hazard-related disasters in the Philippines. This measure was operationalized at the individual level because we were concerned with the direct impacts of disasters on individual households rather than community impacts.

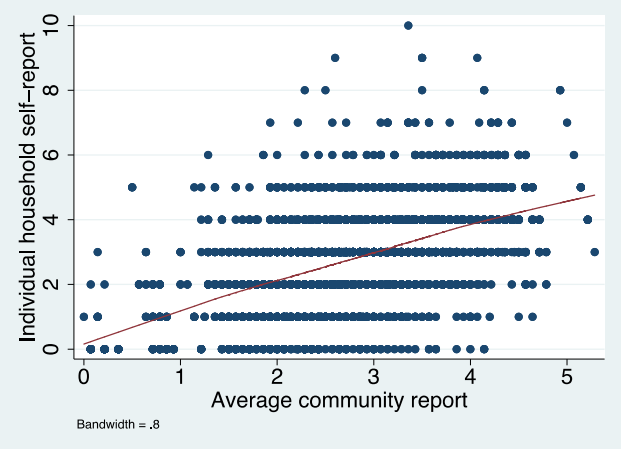


Fig. 3 Relationship between individual household self-report and the average community report, Lowess curve. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

For each natural hazard-related disaster experienced in the last three years, survey participants were asked whether any member of the household was injured, and whether there was any damage to the house, loss of property, or loss of livelihood or crops. Participants were asked to respond "Yes" or "No" for each disaster experienced (see Table 1). For each respondent, responses to these four types of impacts were summed to generate an indicator of injuries, damage to the house, loss of property, and loss of livelihood or crops. The descriptive statistics are provided in Table 5.

A summary score for impact was generated based on exploratory factor analysis. The death of a family member occurred infrequently and is a highly significant event. Our initial exploratory factor analysis using maximum likelihood estimation and a quartimax rotation indicated that deaths due to natural hazard-related disasters did not correlate highly with the other indicators. Therefore, we removed this indicator. The second exploratory factor analysis using maximum likelihood estimation and a quartimax rotation suggested that there was only one factor, with an eigenvalue of 1.53. The factor loadings are shown in Table 6.[5] The factor loadings suggest that property loss and damage to the house were the highest loading items. We created a factor score on the basis of these factor loadings.

Figure 5 shows the highly skewed distribution of the disaster impacts factor score. There are two main points to note from this figure. First, 50% of respondents did not report any impact from any natural hazard-related disasters.

[5] Cronbach's alpha for the unweighted impacts of disaster variable was 0.61.

Table 4 Pearson correlations between disaster variables

	Individual household self-report	Average community report	Barangay official report
Average community report	0.55***		
Barangay official report	0.07***	0.12***	
EM-DAT	0.26***	0.42***	-0.10***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$;

Sources EM-DAT – the International Disaster Database; Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

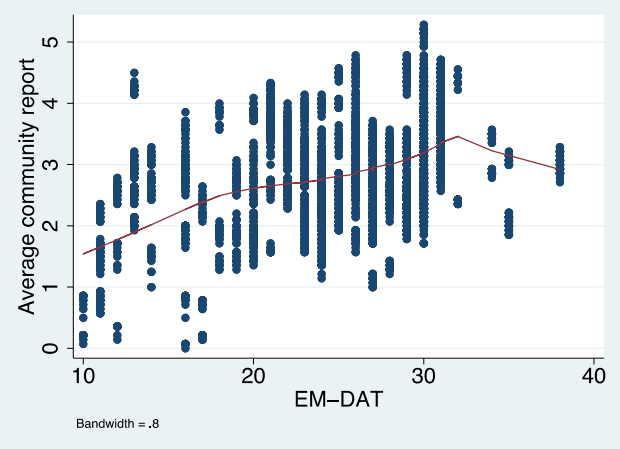


Fig. 4 Relationship between the average community report and the number of disasters experienced by barangay as measured in EM-DAT, Lowess curve. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

Table 5 Descriptive statistics for impact of disasters indicators, individual household self-report

	Mean	SD	Minimum	Maximum
Injuries	0.05	0.29	0	5
Property loss	0.21	0.59	0	5
Damage to house	0.51	0.77	0	5
Loss of livelihood or crops	0.54	1.04	0	6
Deaths	0.03	0.19	0	4

$N = 4952$

Source Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

Second, 25% scored between 0.4 and 1.1, and a further 15% scored between 1.2 and 1.99. The remaining 10% scored between 2.0 and 11.86, with around 2.5% of cases scoring 4.01–11.86.

Table 6 Factor loadings and uniqueness for impact of disasters indicators

Variable	Factor Loadings	Uniqueness
Injuries	0.45	0.80
Property loss	0.80	0.36
Damage to house	0.73	0.47
Loss of livelihood or crops	0.39	0.85

Source Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

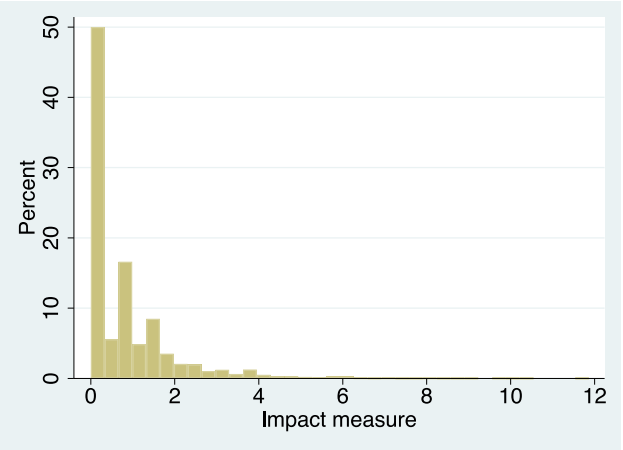


Fig. 5 Index of the impact of disasters experienced by the household, individual household self-report. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

3.5 Validity of the Disaster Impacts Variable

Table 7 shows that correlations between the disaster impacts and disaster deaths variables and the four other disaster variables were statistically significant, with medium sized correlations with other self-reported measures of disaster and small correlations with objective measures of disaster. This suggests that the disaster impacts variable was measuring substantively different constructs. As expected, the number of disasters reported at the household

Table 7 Pearson correlations between disaster impacts and incidence of disaster measures

	Disaster Impact	Disaster Deaths
Disaster deaths	0.25***	–
Average community report	0.28***	0.13***
Individual household self-report	0.37***	0.13***
Barangay official report	0.08***	0.04**
EM-DAT	0.13***	0.05***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

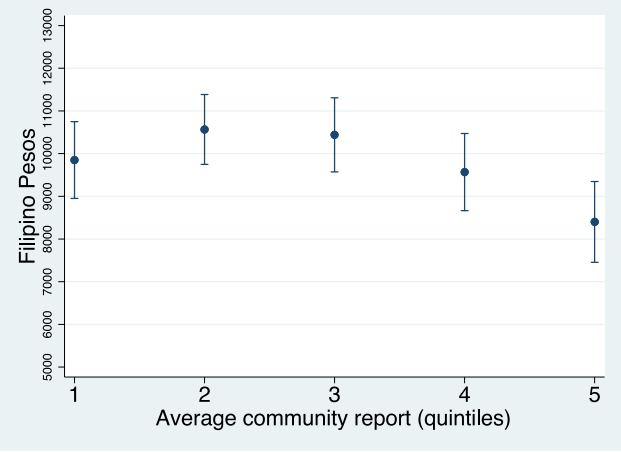
Source Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017; EM-DAT – the International Disaster Database.

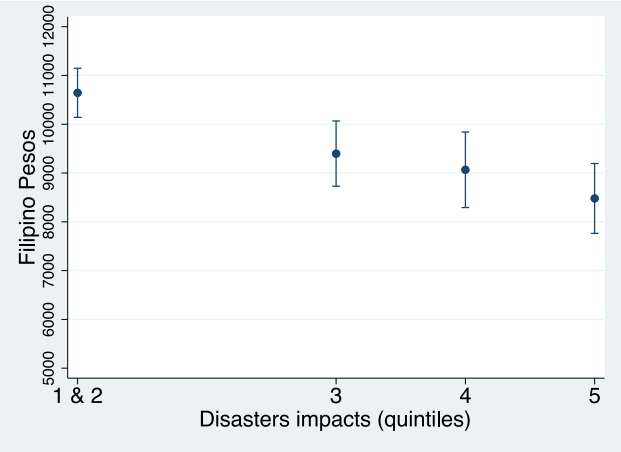
level was most closely related to disaster impacts, followed by disasters at the barangay level and deaths. EM-DAT was also significantly associated with disaster impacts, as was the barangay official community-level report, but the correlations were small. For disaster-related deaths, correlations were consistently smaller but had a similar pattern to disaster impacts. All associations with disaster-related deaths were small, reflecting the low prevalence of deaths in the sample—2.1% experienced one or more death(s).

3.6 Relationship between the Disaster Measures and Household Economic Outcomes

Other research has shown the economic impacts of disasters (Anttila-Hughes and Hsiang 2013; Botzen et al. 2019) and that self-report of disasters translates into financial impacts at the household level, providing further evidence of the validity of the measure (Edwards et al. 2019). We estimated the association between our disaster variables and measures of monthly household income and income adequacy. The average community report and EM-DAT disasters measures were categorized into quintiles to include in a regression model predicting monthly household income. We also attempted to create a quintile for disaster impacts; however, because of the distribution of the variable, the bottom 40% of the distribution could not be disaggregated (as a result of a lack of any impact). Therefore our "quintile 1" in this instance is the bottom 40% (including those who scored zero); quintiles 3, 4, and 5 followed the conventional categorization. For consistency of comparison across disaster measures, we decided to keep this categorization rather than creating quartiles.

Figure 6 shows the predicted mean monthly household income by disasters variable. The predicted incomes are derived from the model. As would be expected, the community average exposure to the disasters variables shows that only households in areas exposed to the most disasters (quintile 5) had significantly lower levels of household





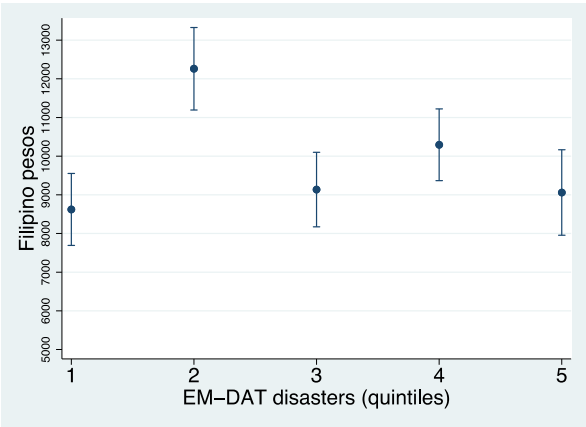


Fig. 6 Predicted average household monthly income by **a** average community report of disaster, **b** household self-reported impact of disaster, and **c** EM-DAT—the International Disaster Database. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

income. In contrast, the impact of disasters was evident from the third quintile. Despite the consistent pattern of results for disaster exposure at the barangay level and for disaster impacts, there was little meaningful pattern in the association between the EM-DAT measure and monthly

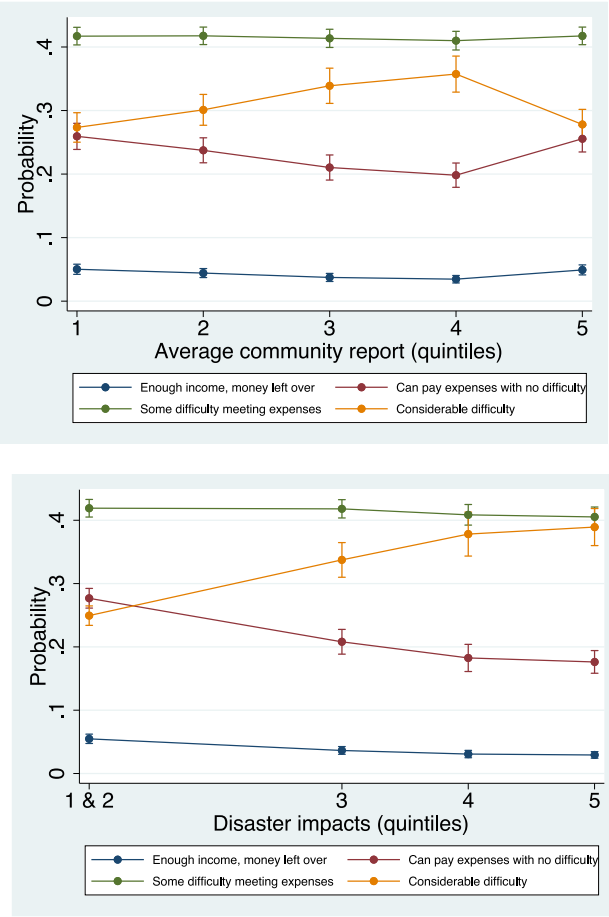


Fig. 7 Predicted probability of level of income adequacy by disaster. **a** Average community report. **b** Disaster impact at the household level. *Source* Longitudinal Cohort Study on the Filipino Child (LCSFC), 2017.

household income (Figure 6c). In this instance, household income was highest for those in the second quintile, and there were no statistically significant differences in household income for the other four EM-DAT disaster quintiles.

We also tested whether average community reports and impact at the household level were associated with adequacy of income. Figure 7 shows predicted probabilities for each of the four categories of income adequacy. It shows that categories 1 and 2 were relatively stable over the average community reports but that there was a linear increase in category 4 and a decrease in category 3 from quintile 1 to quintile 4. For an unknown reason, quintiles 1 and 5 had very similar patterns. For disaster impact, the results were more clear-cut, with categories 1 and 2 relatively stable but a consistent linear increase in households experiencing considerable difficulty in meeting expenses as disaster impact increased and a decrease in households who reported that they had just enough to pay expenses. These results provide some evidence of the predictive validity of the disaster average at the barangay level and the disaster impacts variable.

4 Discussion

This article reports on the development and validation of cumulative measures of exposure to natural hazard-related disasters, at the individual household and community levels, using Philippines data for the period 2013–2017. It also reports on the development of an individual household-level measure of the impact of natural hazard-related disasters. First, we showed that the individually reported household cumulative exposure had statistically significant associations with disasters reported by officials responsible for the geographic area and with disasters collected in EM-DAT. Also noteworthy was that 25% of variation in individual reports of exposure occurred at the community level, and that average community reports demonstrated good ecometric reliability. We then generated a community-level measure of exposure to natural hazard-related disasters based on neighbors' reports, but not individual self-reports, thereby providing an exogenous measure of disaster exposure in the local area for each household.

Second, we showed that these community-level scores are more strongly related to EM-DAT and reports from barangay officials than individual reports. Third, we developed a summary score of disaster impacts at the individual level that has adequate internal consistency. The rationale for an individual-level report of disaster impacts was that, whereas exposure is likely to be a shared experience, many household factors will reduce the impact of exposure to a disaster (for example, quality housing, sources of livelihood). Importantly, this individual-level measure of disaster impact was associated with measures of exposure (individual and area level), barangay official community-level reports, and EM-DAT (CRED 2017). However, the impact measure was only moderately associated with the community average, indicating that it was an independent measure of disaster impact.

One key outcome of a natural hazard-related disaster is the economic impact on households and communities (World Bank and UN 2010). We showed that our preferred measure of disaster exposure, the average community report, and disaster impact show evidence of predictive validity in that they are consistently related to household income and the adequacy of income in households.

Previous research in this area is limited, but our findings do align with the existing research. For example, Hunter and colleagues (2012) showed that a self-reported measure of drought was related to objective measures of rainfall, that there was substantial agreement within geographic areas on whether there is a drought, that the heterogeneity

of farmers' reports of drought was due to access to other ways of sourcing water through irrigation, and that self-report measures of drought were correlated with financial hardship and worsening financial position. In subsequent work, the same research group showed that self-reported drought, aggregated at the area level in the same way as in our study, was associated with mental health problems, financial stress, decreases in household income, and loss of services (with those engaged in agriculture experiencing greater impacts on mental health, financial stress, and household income) (Edwards et al. 2019).

One of the limitations of the current study was that the measures of disasters varied in the time period that was covered. Whereas household ratings reported on the past 3 years and barangay official community-level reports covered the previous 3 years, the cumulative data captured in EM-DAT was for the previous 11 years. Therefore, it is not surprising that the relationship between the variables was not higher. Coding of the EM-DAT data is under way to establish a temporally consistent variable. Another limitation of self-reported measures of disasters is that they can be endogenous, or influenced by individual circumstances such as exposure to poverty or mental health issues. We overcame this limitation by creating an individual-specific average rating of disaster exposure in the barangay that uses neighbor reports but not caregiver reports. The fact that the two other "objective" measures of disasters—reports by barangay officials and EM-DAT—were more highly correlated with community average reports reinforces the strength of this methodological approach.

We chose to develop an individual measure of disaster impact, but EM-DAT also has estimates of the economic impacts of each natural hazard-related disaster. A limitation of EM-DAT data for the purposes of this study is that these economic impacts are estimated for the whole disaster and not disaggregated to small neighborhood areas. Although we did have another source for impacts—reports from barangay officials—these reports were subject to substantially missing information (40% or more barangays). Therefore, although there are attractions in using another rater of disaster impact or another source of information on disaster impact, the significant data limitations precluded such an approach in this study.

5 Conclusion

This research has several implications. The study further demonstrates that individual self-reports, when aggregated at the area level, can be a valid and reliable measure of disaster exposure (Hunter et al. 2012). This has direct implications for researchers. In the same way that "ecometric" measures of neighborhood social capital and disorder (Sampson et al. 1997; Raudenbush and Sampson 1999) heralded an explosion of research into neighborhood-level measures of social capital and physical disorder, there is potential for our methodology to be adopted by other research groups to generate more nuanced measures of people's disaster exposure than are currently available from objective measures such as EM-DAT. Our technique could also be applied beyond surveys to crowd-sourced information through social media or other online platforms—with further development and refinement, these could be used as "social barometers" of the impact of extreme weather events on populations. They could potentially be used to monitor the implications of climate change, and lead to better and more nuanced support and mitigation strategies. Beyond improvements and refinements of measures of extreme weather events, we confirm prior research on the economic impacts of natural hazard-related disasters on households (Anttila-Hughes and Hsiang 2013; Botzen et al. 2019).

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