A GENDER-SENSITIVE EARTHQUAKE RECOVERY ASSESSMENT USING ADMINISTRATIVE AND SATELLITE DATA

THE CASE OF INDONESIA'S 2016 ACEH EARTHQUAKE

Sonia Akter, Talitha Fauzia Chairunissa, Madhavi Pundit, and Marcel Schroder

NO. 674

December 2022

ADB ECONOMICS WORKING PAPER SERIES

ASIAN DEVELOPMENT BANK

ADB

ADB Economics Working Paper Series

A Gender-Sensitive Earthquake Recovery Assessment Using Administrative and Satellite Data: The Case of Indonesia's 2016 Aceh Earthquake

Sonia Akter, Talitha Fauzia Chairunissa, Madhavi Pundit, and Marcel Schroder

No. 674 | December 2022

Sonia Akter (sonia.akter@nus.edu.sg) is an associate professor at Lee Kuan Yew School of Public Policy, National University of Singapore. Talitha Fauzia Chairunissa (tchairunissa@u.nus.edu) is a PhD student at Lee Kuan Yew School of Public Policy, National University of Singapore. Madhavi Pundit (mpundit@adb.org) is a senior economist and Marcel Schroder (mschroder@adb.org) is an economist at the Economic Research and Regional Cooperation Department, Asian Development Bank.

ASIAN DEVELOPMENT BANK

6 ADB Avenue, Mandaluyong City, 1550 Metro Manila, Philippines
Tel +63 2 8632 4444; Fax +63 2 8636 2444
www.adb.org

ISSN 2313-6537 (print), 2313-6545 (electronic)
Publication Stock No. WPS220590-2
DOI: http://dx.doi.org/10.22617/WPS220590-2

Notes:
In this publication, "Rp" refers to Indonesian rupiah and "$" refers to United States dollars.
ADB recognizes "China" as the People's Republic of China and "United States of America" as the United States.

ABSTRACT

This study presents a gender-specific assessment of medium-term disaster recovery following a series of earthquakes in Indonesia's Aceh Province on 7 December 2016. For this assessment, we combine the village-level nighttime radiance data obtained from the Visible Infrared Imaging Radiometer Suite instrument, distance from the earthquake epicenters collected from the United Nations Satellite Centre and the Village Potential Statistics (PODES) 2014 and 2018—administrative data collected by Indonesia's Central Statistics Bureau. We develop a novel index to represent women's welfare in the context of a disaster—the Women's Welfare after Disasters Index (W2DI). The nighttime radiance scores are used as indicators of overall economic welfare, while the W2DI specifically represents women's welfare. Using the difference-in-differences method, we compare the average monthly nighttime radiance and W2DI scores in earthquake-affected and unaffected villages of the Aceh Province before and after the 2016 earthquake series. Similar to studies using the nighttime radiance to monitor disaster recovery and relief, our findings reveal that, on average, the monthly nighttime radiance scores of the earthquake-affected villages 2 months after the earthquakes were brighter relative to the changes of the unaffected villages, implying an improvement in overall economic well-being of the earthquake-affected population. However, findings from the W2DI give us richer insights related to women's welfare. While an important domain of women's welfare—particularly, availability and access to the health infrastructure—improved significantly after the earthquake series, there was substantial deterioration in access to basic needs (e.g., water, fuel, sanitation). Such access plays an essential role in women's well-being as they are directly linked to women's role in the society. This study demonstrates that women in disaster-affected areas may experience a setback in some domains of their welfare in the medium term even when the economic welfare in the disaster-affected areas, in general, improved because of the gradual increase of human activities after reconstruction work occurred. The study also shows how a gender-specific disaster assessment tool can be developed and applied to monitor and assess disaster recovery for a subgroup of population and identify areas that require intervention.

Keywords: Disaster relief, recovery, climate injustice, socioeconomic vulnerability, gender

JEL codes: I3, J16, Q54

The authors would like to thank Priscille Villanueva for research assistance; Akanksha Arun Narode, and Homer Pagkalinawan for GIS support; Zonibel Woods for valuable inputs on gender aspects; and participants in the Economic Research and Regional Cooperation Department and Singapore Economic Review Conference seminars for comments and feedback.

I. INTRODUCTION

Globally, the frequency and intensity of disasters have increased almost threefold, significantly enlarging economic damage and the number of affected population (Thomas and López 2015; Kellet and Sparks 2012). Low-income and lower-middle-income countries of Asia and the Pacific, in particular, are highly vulnerable to disasters because of the high rate of poverty, weak infrastructure, low level of technological development, high risk exposure, and weak disaster governance (Hallegatte et al. 2020; UNISDR 2019; Fankhauser and McDermott 2014; Winsemius, Aerts, and Van Beek 2016). Natural hazards cause damage to life, property, and livelihoods, and exacerbate poverty and inequality (Hannan 2002; Akter and Mallick 2013; Schwab, Eschelbach, and Browser 2007; Akter 2021). The economic losses from disasters, as a percentage of the gross domestic product, in the developing world far exceed those of industrial countries (De Goyet, Marti, and Osorio 2006).

Disaster risk and its impacts are highly gendered (Rahiem, Rahim, and Ersing 2021; Felten-Biermann 2006; Neumayer and Plümper 2007; Juran and Trivedi 2015). According to data from 141 countries affected by disasters from the 1980s until early 2000s, disasters lower women's life expectancy more than men, indicating that women face a higher mortality risk than men in the event of a disaster (Neumayer and Plümper 2007; UNDP 2010). Most disasters place a disproportionate burden on women and girls with unpaid work responsibilities such as providing care, food, and water for households (Fatouros and Capetola 2021). Women and girls are also more likely to become victims of domestic and sexual violence following a disaster, prompting many to avoid using shelters when they need them the most (Thurston, Stöckl, and Ranganathan 2021). Unequal access to decision-making processes and limited mobility in rural areas lower women's welfare even more as they are disproportionately affected by disasters (Fatouros and Capetola 2021; Erman et al. 2021). Hence, the well-being and needs of the most affected populations are unlikely to be met if gender perspectives are left out in planning for disaster response and risk reduction measures (Erman et al. 2021).

Men and women face different exposure to disaster risks due to preexisting gender inequalities in the society created by their distinct needs, roles, and responsibilities. Consequently, they also use different coping and adaptation strategies (Jin, Wang, and Gao 2015; Chandra et al. 2017). The existing disaster risk reduction and management frameworks rarely account for preexisting gender differences in disaster risk exposure and gender-specific needs and barriers in the response, recovery, and resilience building phases. The instruments commonly used for damage, needs, and recovery assessments are gender blind (Erman et al. 2021; Zaidi and Fordham 2021; Morchain et al. 2015). Even the Sendai Framework for Disaster Risk Reduction,[1] which is considered as the blueprint for disaster risk management globally, paid little emphasis on the gendered aspect of disaster risk and the need to account for gender-specific needs and barriers in the process of building disaster resilience (UNISDR 2015). Because of inadequate gender consideration in disaster risk reduction and management programs, women and girls bear a disproportionately heavy burden of disaster impacts. Consequently, the preexisting gender gaps in the different aspects of life (e.g., labor market, health care, nutrition, unpaid work, violence against women) widen further in the aftermath of a disaster, creating a

[1] The Sendai Framework acknowledges the importance of disaggregated data—e.g., by sex, age, and disability; however, they are optional across all Sendai indicators.

vicious circle between women's disadvantaged position in society and disaster events (Fatouros and Capetola 2021; Neumayer and Plümper 2007; Cannon 2002).

However, collection techniques can render data to become obsolete relatively quickly. It is also challenging to gather data after disasters hit. Both challenges can prevent governments from doing immediate and detailed disaster damage assessments and prompt them to rely on various sources of high-frequency datasets to undertake rapid damage assessments, such as monitoring the high-frequency data.[2]

The objectives of this study are to assess the medium-term recovery of women at the village level 2 years after the Aceh 2016 earthquake series and to understand how women's recovery differs from the overall economic recovery of the earthquake-affected villages. To this end, we develop a Women's Welfare after Disaster Index (W2DI) using available information from the Village Potential Statistics (PODES)[3] 2014 and 2018 administrative data collected by Indonesia's Central Statistics Bureau (Statistics Indonesia 2014, 2018). We design the W2DI to be both comprehensive and gender-specific by capturing the various aspects of women's disadvantages following disasters. The W2DI can be disaggregated into health, education, basic needs, and security subindexes for a more detailed analysis. To capture the overall economic recovery, we use monthly nightlights data from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument for the period of January 2014 and December 2020.

After conducting an assessment of economic recovery using the nighttime radiance scores of earthquake-affected and unaffected villages of the Aceh Province, we conduct a similar difference-in-differences (DID) analysis of our W2DI scores. The analysis is done as a medium-term assessment to understand how the Aceh earthquake series impacted different aspects of women's welfare relative to economic welfare in general. Our findings reveal the average monthly radiance score in the earthquake-affected villages significantly increased after the earthquake compared to the changes in average monthly radiance score in the nearby unaffected villages. This implies that the overall economic welfare of the earthquake-affected villages improved in the medium term compared to the neighboring villages that were not directly impacted by the earthquakes. This could happen after series of reconstruction work took place and, as a result, the intensity of human activities gradually increases (Li et al. 2019; Gao et al. 2020). A DID regression involving the W2DI reveals a significant improvement of access to health services that primarily benefited women. However, our findings reveal that the earthquakes caused substantial deterioration in the access to basic services, such as access to clean water, sanitary and disposal facilities, and energy and electricity. These services play important role to women's welfare as they are directly linked to women's reproductive role in the society,[4] but they are often overlooked by policy makers during the disaster recovery process as argued by Anwar et al. (2011). The findings of this research suggest that some aspects of women's welfare can significantly deteriorate after a disaster in the medium term even when the disaster-affected villages made significant economic improvement in general. The application of a gender-specific disaster

[2] High-frequency data refers to fine-scaled time-series data collected using computational power for a long period of time. Due to its size and precision, such data are often used to conduct intraday observations about a phenomenon (Ruey 2000; Andersen 2000).

[3] PODES is a village-level survey conducted three times every decade to all 75,000 villages across Indonesia. The survey records information on village characteristics, population and manpower, economic activities, basic infrastructure and access, disaster management, as well as sociocultural characteristics, and educational and health outcomes.

[4] Men's and women's involvement in various types of work often differ because of the culturally defined gender roles. Women's reproductive roles include women's obligation to take care of the family and the household, as well as bearing and rearing children in the society (WHO 2022).

recovery assessment instrument can provide important insights of medium-term disaster recovery process of a subgroup of population and help the design of gender-inclusive recovery programs.

This paper proceeds as follows. Section II describes the features of and losses from the Aceh earthquake series. Section III presents a brief review of literatures on how a disaster—an earthquake in particular—differently affect women. Section IV describes the data and the identification strategy we use in our empirical analysis. The section also summarizes the construction of the W2DI. Section 5 describes the empirical model. Section 6 presents our regression results, Section 7 discusses the results and lessons learned, and Section 8 concludes.

II. THE 2016 ACEH EARTHQUAKES

Nanggroe Aceh Darussalam is located at the tip of Sumatra, the northernmost and westernmost island of Indonesia. With approximately 5.2 million people, Aceh ranked 20th in population density across Indonesia (Statistics Indonesia). The population density is low as the Acehnese are spread across 18 districts (*kabupaten*) and 5 municipalities (*kota*).

On 7 December 2016, Aceh was hit by a devastating series of earthquakes. The earthquakes hit three times on the same day, starting with the lowest magnitude of 4.5 moment magnitudes (M_W), followed by 5.2 M_W, and ended with 6.5 M_W. The last one was the strongest and the shallowest earthquake. The epicenter of the last earthquake was located near Reuleuet village in rural Pidie Jaya district (Figure 1), which is southeast of the province's capital city, Banda Aceh (USGS 2016). With over 100 people dead, 1,000 injured, 11,000 buildings destroyed, and 45,000 people displaced (WHO 2016), the series of earthquakes was the deadliest in Aceh since the 2004 earthquake, a 9.1 M_W megathrust followed by a tsunami that killed more than 167,000 people (USGS 2004).

Figure 1:Map of the 2016 Aceh Earthquake

km = kilometer.
Source: United States Geological Survey. M 6.5 - 14 km WNW of Reuleuet, Indonesia. https://earthquake.usgs.gov/earthquakes/eventpage/us10007ghm/executive (accessed 13 May 2022).

The provincial government declared a state of emergency for 2 weeks after the earthquakes. President Joko Widodo, who visited earthquake-hit areas 3 days after the impacts, mentioned that accelerating recovery in Aceh would be the national government's priority. The directions stated that all recovery processes must be completed by 2018, which included rebuilding housing, physical infrastructure, and public infrastructure (e.g., health, education, and livelihood sectors) to revive the local economy (Government of Indonesia 2017). Shortly after the President's visit, several ministries and agencies worked together with international organizations in their response.[5] Coordination centers were set up and search and rescue teams were assembled and deployed to the hardest-hit areas (Kholid 2016). As local hospitals were overwhelmed, severely injured victims were evacuated to Banda Aceh (Ibrahim 2016), which is located more than 170 kilometers (km) away. The Ministry of Social Affairs provided temporary shelters, clothing, food, support for mental health and trauma, as well as financial compensation for the victim's families. Help from other local governments came in the form of medicine, food, and search and rescue personnel, along with international aid from neighboring countries, international organizations, as well as aid from the private sector. On 12 December 2016, the National Search and Rescue Agency confirmed that their operation officially ended (Masriadi 2016) and the emergency response period ended on 20 December 2016 (WHO 2016).

By June 2017, 18%, or a total of Rp626.3 billion (equivalent to $43.1 million) out of the committed Rp3.4 trillion (equivalent to $234 million) was disbursed to the Ministry of Public Works by the National Disaster Management Agency for rehabilitation and reconstruction in the three affected districts (Government of Indonesia 2017). The funds were allocated from national budget and grants, local budget, as well as international aids, and corporate social responsibilities. A portion of the total budget was added to the provincial and district government budgets to accelerate the rehabilitation and reconstruction of public facilities and houses.[6]

III. LITERATURE REVIEW

Women make up the majority of the world's poor and, hence, are more dependent on natural resources and basic infrastructures (UN WomenWatch 2009). They bear most household responsibilities, e.g., cooking, looking for clean water, cleaning, caring for the children and the elderly (UNDP 2010). These burdens, coupled with unequal access to decision-making and limited mobility especially in the rural communities, lower women's welfare even more. Thus, women can be disproportionately affected by disasters (UN WomenWatch 2009; Llorente-Marrón et al. 2021). This section lays out the different aspects of women's welfare that might be affected after a rapid onset of disaster, like earthquake, which are documented in literatures—health, education, basic needs, and security.

[5] The teams included the Aceh provincial government, the National Disaster Management Agency, sector ministries, the National Police, World Health Organization, and the United Nations (WHO 2016).

[6] As stated in WHO (2016), the series of earthquakes mostly hit three districts of Aceh: Pidie Jaya, Pidie, and Bireuen. The portion of the total budget distributed to the Aceh Province is Rp23.8 billion (equivalent to $1.6 million) mostly to rebuild infrastructure. Pidie Jaya allocated Rp343.5 billion (equivalent to $24 million); Pidie, Rp66.73 trillion (equivalent to $4.7 million); and Bireuen, Rp30.8 billion (equivalent to $2.15 million), to rebuild houses and infrastructure (Government of Indonesia 2017).

Women can be impacted by disasters in many ways as gender intersects with various other factors related to discrimination, marginalization, and social exclusion. Multiple studies have documented adverse reproductive health outcomes among women following an earthquake, such as unplanned pregnancies and reduced birth spacing because of disrupted access to contraceptives (Nobles, Frankenberg, and Thomas 2015; Nandi, Mazumdar, and Behrman 2018), as well as increased psychological distress and mental disorders (Cao, McFarlane, and Klimidis 2003; Hibino et al. 2009; Llorente-Marrón et al. 2021). These factors could lead to adverse birth outcome like miscarriages (Norris and Elrod 2006). Women are also prone to suffer from malnutrition, which could lower their capacity to cope with disasters (Cannon 2002). When pregnant, breastfeeding, or doing heavy work, women need extra nutrition; yet, some cultural norms require they consume fewer calories so that men receive more food (FAO 2017).

Disaster impacts are highly gendered due to preexisting gender gaps and distinct roles and responsibilities played by men and women. Traditional gender norms could directly shape basic survival capabilities through differences in the ways men and women were educated and brought up. According to Oxfam International (2005), the 2004 tsunami in Indonesia, India, and Sri Lanka killed four times more women than men. The survey reveals that men were more resilient because they were taught to swim and climb trees, while women were not. Generally, gender norms could manifest in women's decisions and hinder them from doing other things outside their homes, including participating in the labor force (ILO 2017). In a pre- and post-disaster context, a simple life-saving decision to evacuate from a disaster area can become difficult for women (Hallegatte et al. 2016; Vidili 2018).

Childcare is generally considered a woman's responsibility, particularly in rural societies. In 2018, more than 600 million productive-age women worldwide self-reported being unavailable for employment or not seeking a job due to care work, compared to 41 million productive-age men (ILO 2017). In a post-disaster context, this gender inequality can have further negative implications. Grantham et al. (2021), for instance, laid out the global childcare crisis following the coronavirus disease (COVID-19) pandemic and argued that it could be the "tipping point" that undoes decades of women's economic progress. Following childcare closures, women report spending more than 30 hours a week looking after children, including taking care of their online learning activities. In this condition, it is becoming more challenging for women to balance paid work and unpaid care, particularly for those in the informal sector, since there is typically no paid leave, social protection, or remote work. Disrupted access to education would prevent children from attending school, interfere with their development and well-being, and keep mothers away from employment and income opportunities (Gromada, Richardson, and Rees 2020). In most Organisation for Economic Co-operation and Development (OECD) countries, access to affordable childcare and early childhood education and development centers supports maternal employment and reduces gender inequalities (OECD 2018).

Studies have found that disasters could deteriorate human capital outcomes among individuals from lower socioeconomic backgrounds. Similarly, disasters can affect their resilience. Paudel and Ryu (2018) found that girls exposed to a severe earthquake in Nepal performed significantly worse than boys in school. However, related to disaster relief, Belmonte et al. (2020) suggested that increased spending on school infrastructure after the 2012 earthquake in Northern Italy improved educational outcomes, particularly among lower-achieving students.

The educational impact for girls, on the other hand, is reaped in the long term. Increased spending to improve public schools can help improve women's future human capital. This finding is supported by Liu and Xu (2021), whose study showed improvements in girls' educational outcomes 7 years after a devastating earthquake in Sichuan Province, People's Republic of China. The academic gain may be attributable to school reconstruction and school fee reduction

after the disaster, leading to more long-term outcomes, such as delaying marriage, postponing childbearing, and increasing female participation in the labor force. Moreover, education can also strengthen women's resilience as studies suggest that individuals with higher educational attainment tend to have better coping mechanisms and report a better quality of life months after an earthquake compared to their less educated peers (Valenti et al. 2013; Liang, Chu, and Wang 2014).

Furthermore, disrupted access to basic services could adversely impact women's well-being. Related to health, women are disproportionately disadvantaged in terms of deteriorated hygiene. Budhathoki et al. (2018) reported a significant number of women and girls menstruating within the first week of an earthquake. This makes them in need of clean water, basic sanitary, and disposal facilities. However, during and after disasters, there is usually limited access to these basic infrastructures, reproductive health services, and safe menstrual hygiene materials (Anwar et al. 2011).

Related to household duties, globally, in normal circumstances, women spend at least 2.5 times more hours doing unpaid household and care work than men (ILO 2017; Rubiano-Matulevich and Viollaz 2019). The number increases tenfold in rural societies (Charmes 2019). The disruption to basic needs due to disasters can be very taxing to both women's time use and health (IUCN 2018). The United Nations (UN) estimates that a roundtrip to collect water in rural areas in Asia is around 21 minutes and in urban areas around 19 minutes. The numbers increase to 33 minutes in rural areas and 25 minutes in urban areas in sub-Saharan Africa; whereas, for those in countries like Yemen, Tunisia, Somalia, and Mauritania, a single trip could take longer than an hour, prompting the UN to argue that collecting water is a colossal waste of women's and girls' time every day (UNICEF 2016). In Ethiopia, girls could spend up to 8 hours looking for water (Farley 2018).

Similarly, in the rural setting, women and girls are mostly responsible for cooking (Akter 2021). Due to adverse health effects, in some developing countries, liquefied petroleum gas (LPG) has been adopted to substitute traditional cooking fuels like firewood, crop residues, or cow dung. On top of the health and environmental benefit of adopting LPG as a clean cooking fuel, women and girls benefit from less frequent firewood collection, time saved for cooking, and a more convenient and simpler meal preparation arrangement (Akter and Pratap 2022). Finally, women of all ages are also at greater risk of sexual and gender-based violence, including rape, sexual exploitation, and significantly increased domestic violence by intimate partners, family members, and outsiders (Khan 2016), during and after disasters. Yoshihama et al. (2019) pointed out that sudden disasters like earthquakes often lead to loss of assets and sources of income for women, making them more reliant on their intimate partners, and exposing them to control and exploitation. Heightened vulnerability is often exacerbated by shortages of basic necessities like shelter, food, and clothing, providing non-intimate perpetrators with opportunities for coercion and quid pro quo exploitation (Yoshihama et al. 2019). Because of these reasons, women avoid using shelters, even when they need them the most (Thurston, Stöckl, and Ranganathan 2021).

IV. DATA

Both government and academia are interested in developing measures of welfare or well-being that go beyond economic methods to provide a more complete understanding of living conditions. Moreover, disentangling the impacts of gender in understanding male and female welfare differences has gained more attention for advancing research and closing knowledge

gaps in public policy. However, doing this using secondary data where direct measures are not available can be challenging.

To do a gender-specific assessment of medium-term disaster recovery, this study combines various data sources. First, we use the PODES, 2014 and 2018 (Statistics Indonesia 2014, 2018). Second, we use the village-level nighttime radiance data obtained from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument; and third, we use the distance from the earthquake epicenters collected by the UN Satellite Centre (UNOSAT).

A. The Women's Welfare after Disaster Index

Using PODES, we develop the Women's Welfare after Disasters Index (W2DI), building on work by Smith and Koehoorn (2016) and Benjamin et al. (2017) on developing a gender measure using survey data. The W2DI consists of four subindexes—health, education, basic needs, and security—to capture the availability of services and access to resources that benefit women. The index is constructed based on indicators suggested by the literature, as described in Section III, and is derived from survey data (details in the Appendix).

The W2DI indicators are constructed using relevant information from the PODES dataset, which is collected by the Government of Indonesia at regular intervals, i.e., once every 3 years. The survey captures a wide range of characteristics of over 80,000 Indonesian villages (*desa*), including village identification number and different measures of the availability and access to services and infrastructure (Statistics Indonesia 2018). In Nanggroe Aceh Darussalam, the PODES dataset contains all 9,000 villages for the two periods of time under consideration around the 2016 Aceh earthquake series, i.e., before (2014) and after (2018).

The first subindex, *Health*, captures the most important impact of disaster to women's well-being covered in the literature, which is health-care access. The *Health* subindex consists of four village-level health services that are affordable and mostly utilized by women for maternal and antenatal care: (i) the public health center (known as *Puskesmas*) without inpatient service, (ii) the midwife practice, (iii) the village maternity post (known as *Polindes*), and (iv) the integrated service post (known as *Posyandu*).

The *Education* subindex consists of five publicly funded educational facilities, from early childhood education and development center, elementary school, junior high school, to senior high school and vocational school. The components of the *Education* subindex benefit women in two ways: (i) by indirectly empowering mothers to participate in the labor force and earn income while children are in the educational facilities, e.g., childcare or early childhood education and development, kindergarten, primary until senior high school; and (ii) in the longer term, by giving girls access to affordable or free education to improve their future employment prospects and quality of life.

The *Basic Needs* subindex consists of access to five basic needs closely related to women's health and household responsibilities: water, sanitation, disposal facility, electricity, and clean cooking fuel. The components of the *Basic Needs* subindex increase women's well-being in two ways: (i) by improving their health related to physical and menstrual hygiene management; and (ii) by cutting down time and effort spent on household tasks, such as collecting cooking fuel, meal preparation, and cooking.

Lastly, the *Security* subindex consists of four indicators that support women's safety in the villages. This subindex includes (i) the availability of lighting on the village's main road; (ii) no

recorded cases of crimes that mostly target women during and after disaster (e.g., domestic violence, rape, and human trafficking); (iii) availability of basic services (e.g., civil security service); and (iv) advanced security services (e.g., police post).

A weighted sum of the subindexes results in the W2DI, as described in equation 1. The W2DI ranges from 0 (lowest) to 4 (highest), with a higher value indicating higher welfare.

$$\sum_{i=0}^{n} \frac{Health\ score}{\#\ of\ healt\quad indicators} + \frac{Education\ score}{\#\ of\ education\ indicators} + \frac{Basic\ needs\ score}{\#\ of\ basic\ needs\ indicators} + \frac{Security\ score}{\#\ of\ security\ indicators} \quad (1)$$

B. Other Data

We use the nighttime lights data—an open access spatial imaging data made available by the United States National Oceanographic and Atmospheric Administration (US NOAA). The satellite imaging data was initially collected to capture information related to global weather, such as to monitor cloud cover, which is easier to monitor during the daytime. During the nighttime, the satellite instrumentation is able to detect light coming from the Earth surface, which primarily results from electricity-powered illumination (Elvidge et al. 1997; US NOAA 2022). As such, due to its source, the nighttime lights data has been used in various research as a proxy for socioeconomic variables and economic outputs like economic growth, population density, and urbanization. Mellander et al. (2015) suggested that, due to the strong correlation, the nighttime lights data could be a good proxy of economic activity. Further, Bruederle and Hodler (2017) argued that, in the context of African countries, the nighttime lights data can be a good proxy for human development at the local level as it is positively associated with various outcome variables like household wealth, education, and health. Chen and Nordhaus (2011) suggested that the nighttime lights data or luminosity provides informational value, particularly for countries with low-quality statistical systems or no recent economic surveys. Post-disaster periods would qualify as such conditions since conducting real-time data collection would be challenging. Gao et al. (2020) suggested that after the 2015 Nepal earthquake, the nighttime lights data can provide an effective means to analyze and evaluate post-earthquake recovery and reconstruction as it reveals consistent patterns and trends of human activities, which improve during reconstruction and development phases. Similarly, Li et al. (2019) found that intensity of human activities increased significantly in the 3 years after the 2008 Wenchuan earthquake. In this study, the nighttime lights data is disaggregated monthly from January 2014 to December 2021 to capture periods before and after the earthquake series in both affected and unaffected areas. Hence, the data can be used as outcome variable in the analysis or utilized for parallel trend analysis tests. The variable will be used both as an indicator of welfare as well as to conduct robustness checks.

Furthermore, we use the data from UNOSAT to measure earthquake exposure.[7] UNOSAT uses geospatial information technologies (GITs) and applies big data approach to conduct real-time earth observation in member countries of the Association of Southeast Asian Nations (ASEAN) (UNITAR 2019).[8] In cases of earthquakes, UNOSAT uses high-resolution satellite imaging to map the locations of the earthquake epicenters. It then conducts population exposure

[7] UNOSAT is the operational satellite applications program at the UN Institute for Training and Research (UNITAR). It was created in 2001 and has become a UN knowledge center that promotes the use of evidence-based decision-making using geospatial information technology.

[8] ASEAN member countries comprise Brunei Darussalam, Cambodia, Indonesia, the Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

analyses and damage mapping based on the earthquake intensities, population size, as well as presence of infrastructures in the area.

V. EMPIRICAL FRAMEWORK

The three key constructs of this study are earthquake exposure (i.e., treatment variable), nighttime radiance (an indicator of general economic welfare), and W2DI (i.e., an indicator of women's welfare). In this study, the treatment variable is operationalized by measuring the distance between the village and the earthquake epicenters. Our null and alternative hypotheses are:

H0: Earthquake exposure has no impact on nighttime radiance and W2DI.

HA: Earthquake exposure has an impact on nighttime radiance and W2DI.

We use the difference-in-differences (DID) method to estimate the impact of earthquake exposure on nighttime radiance and W2DI. The DID is one of the most frequently utilized methods in impact evaluation studies (Fredriksson and de Oliveira 2019). It is an evaluation method used in a quasi-experimental setting (Angrist and Pischke 2009; Wooldridge 2012). The DID is based on a combination of insights from cross-sectional before–after and treatment–control comparisons to robustly estimate the causal effects of a shock or an intervention (Fredriksson and de Oliveira 2019). Further, the DID relies on a parallel trend assumption, which suggests that the treatment group, in the absence of a shock or intervention, would have showed the same time trend as the control group, particularly for the outcome variable of interest (Fredriksson and de Oliveira 2019). This assumption is testable using a parallel trend assumption test to observe the time trend of the outcome variable in the absence of the earthquake. Next, combining the before–after and treatment–control group comparisons, we estimate the impact of earthquake exposure using the following specification:

$$Y_{it} = \beta_0 + \beta_1 Earthquake_i + \beta_2 POST_t + \beta_3 (Earthquake_i \times POST_t) + \varepsilon_{it} \qquad (2)$$

In equation 2,

Y_{it} is the welfare outcome (nighttime radiance or W2DI);

$Earthquake_i$ is a dummy for earthquake-affected villages at village *i*;

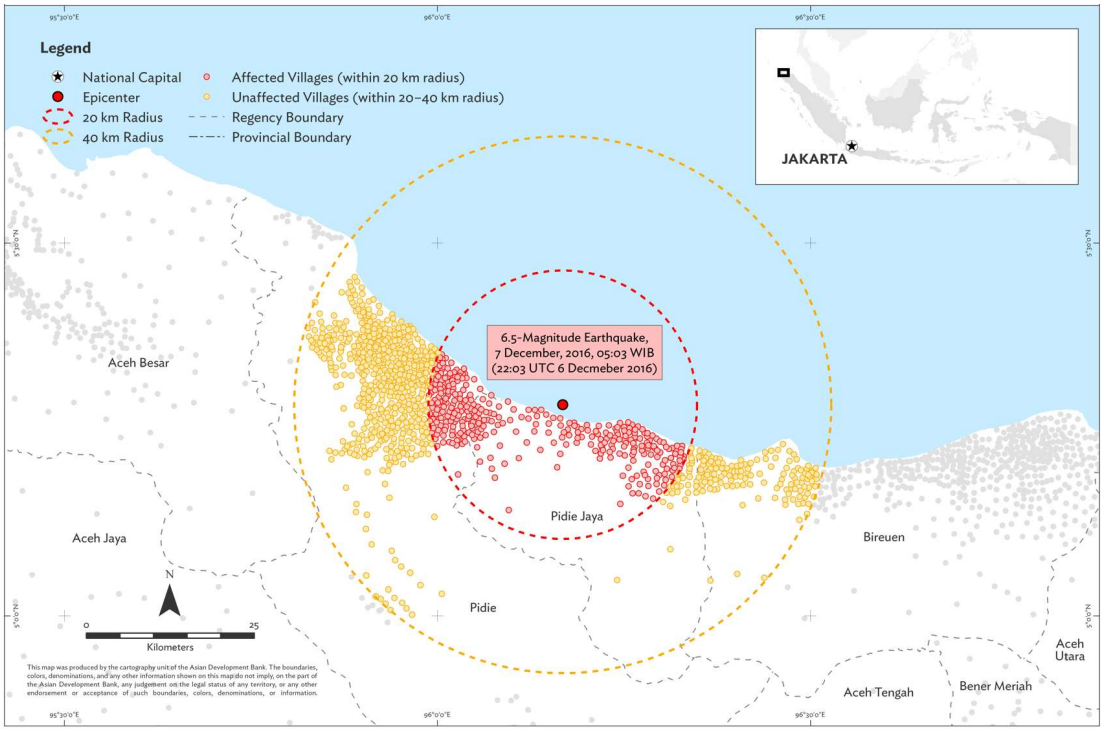
$POST_t$ is a dummy for the time period after the Aceh earthquake, which is the year of 2018, that was specified in the President's directive as the year when all recovery processes were to be completed (Government of Indonesia 2017); and

ε_{it} is an error term clustered at the village-level.

Similar to Sakai, Wakamatsu, and Miyata (2018), in assigning the treatment group, we use information of affected districts from official government reports.

As reported in the World Health Organization (WHO 2016), Pidie Jaya district was the hardest hit area. We first calculate the mean distance of each village in that district from the earthquake epicenters and find that the mean distance from the villages to the first earthquake was 16.345 km, the second earthquake was 10.563 km, and the third earthquake was 12.937 km. Additionally, the minimum distance was 0.300 km while the maximum distance was 23.365 km. As such, based on the mean, minimum, and maximum distances, we assign as the treatment group earthquake-affected villages those located within 20 km of the earthquake epicenters. Consequently, all villages beyond 20 km are treated as control group (Figure 2). To generate a valid comparison, we double the distance and assign those villages located within the proximity of 20–40 km from the earthquake epicenters as the control group. The cutoff is made to ensure similar characteristics between villages.

Figure 2: Proximity of Affected and Unaffected Villages to the Earthquake Epicenters



km = kilometer.
Source: United States Geological Survey. M 6.5 - 14 km WNW of Reuleuet, Indonesia. https://earthquake.usgs.gov/earthquakes/eventpage/us10007ghm/executive (accessed 13 May 2022).

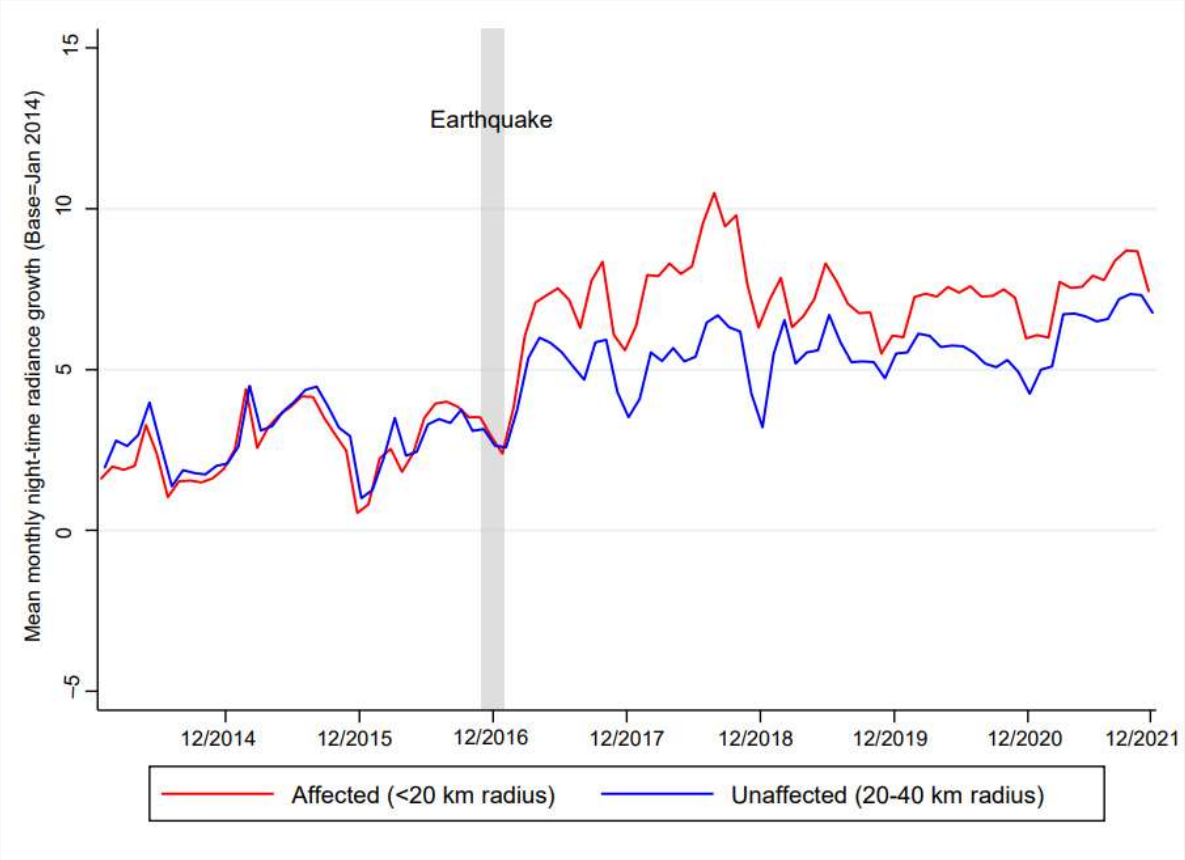
VI. RESULTS

A. Trends of Nighttime Radiance

Using monthly nighttime radiance data from the period prior to and some years after the earthquake series (January 2014–December 2021), we apply the parallel trend assumption test to both treatment and control villages. Figure 3 shows that both earthquake-affected and

unaffected villages had a similar pattern of monthly nighttime radiance scores prior to the earthquakes in December 2016, hence passing the parallel trend assumption test. To quantitatively verify the validity of the parallel trend assumption, we undertook an F-test. The hypothesis of the F-test is that pre-earthquake trends of the earthquake-affected and unaffected villages are parallel. This hypothesis cannot be rejected at the 10% confidence level ($F(1, 774) = 1.34$, $p > F = 0.2469$). After the earthquake, the trends of nightlights of the affected and unaffected villages start diverging. When the 2016 Aceh earthquakes hit, the impacted villages' nighttime brightness dropped, and declined further a month after. However, the villages' brightness increased significantly starting 2 months after the earthquakes hit and became brighter compared to its unimpacted peers. This continued until the end of 2021, when both groups start converging toward the end of the comparison period.

Figure 3: Parallel Trend Assumption Test



km = kilometer.
Note: Calculated using data from the United Nations Satellite Centre (UNOSAT) and the Visible Infrared Imaging Radiometer Suite (VIIRS).
Source: Authors' calculations.

B. Regression Results

The starting point of our regression analysis is the DID estimate of the effect that the 2016 Aceh earthquakes had on the total W2DI in Aceh villages within the proximity of 20 km and 20–40 km from the earthquake epicenters. The coefficients presented in the *Constant* row of Table 1 provide us information of the W2DI of unaffected or control villages in the base year before the earthquake. These coefficients show us the baseline condition of control villages in 2014. Next, the coefficients presented in the *Post (2018)* row tell us the W2DI of control villages after 2018. The coefficients presented in the *Earthquake* row inform us the baseline W2DI of all affected villages. Using the coefficients, we could disentangle the baseline difference in W2DI between the affected and unaffected villages.

The coefficients presented in the *Earthquake x Post (2018)* row provide us information of the W2DI of affected villages after the earthquake, which are the coefficients of interests. Controlling for time and village fixed effects, we estimate a treatment effect of 0.012 points (column 1, Table 1), which is equivalent to a slight improvement of 0.58% compared to the control group. However, the treatment effect on total W2DI is statistically insignificant, suggesting that the subindexes might be impacted differently by the earthquakes.

Table 1: Impact of Earthquake on Women's Welfare, Difference-in-Differences Regression Results

Condition	(1) W2DI All	(2) W2DI Health	(3) W2DI Education	(4) W2DI Basic Needs	(5) W2DI Security
Earthquake x Post (2018)	0.012	0.232[a]	0.009	–0.151[a]	–0.069
	0.021	0.042	0.050	0.056	0.042
Earthquake	0.090[a]	0.123[a]	0.086	0.098[b]	0.091[a]
	0.025	0.037	0.055	0.055	0.033
Post (2018)	0.174[a]	–0.273[a]	0.124[a]	0.538[a]	0.441[a]
	0.013	0.026	0.026	0.041	0.029
Constant	2.089[a]	2.206[a]	3.181[a]	2.413[a]	1.675[a]
	0.018	0.018	0.041	0.036	0.022
Observations	2,098	2,098	2,098	2,098	2,098
R-squared	0.062	0.063	0.008	0.074	0.109

W2DI = Women's Welfare after Disaster Index.

Notes: Villages located <20 kilometers (km) of the earthquake epicenters are coded as the treatment group, while those within the 20–40 km radius of the earthquake epicenters are coded as the control group. Robust standard errors in blue are clustered at the village-level.

[a] p<0.01

[b] p<0.10

Source: Authors' calculations.

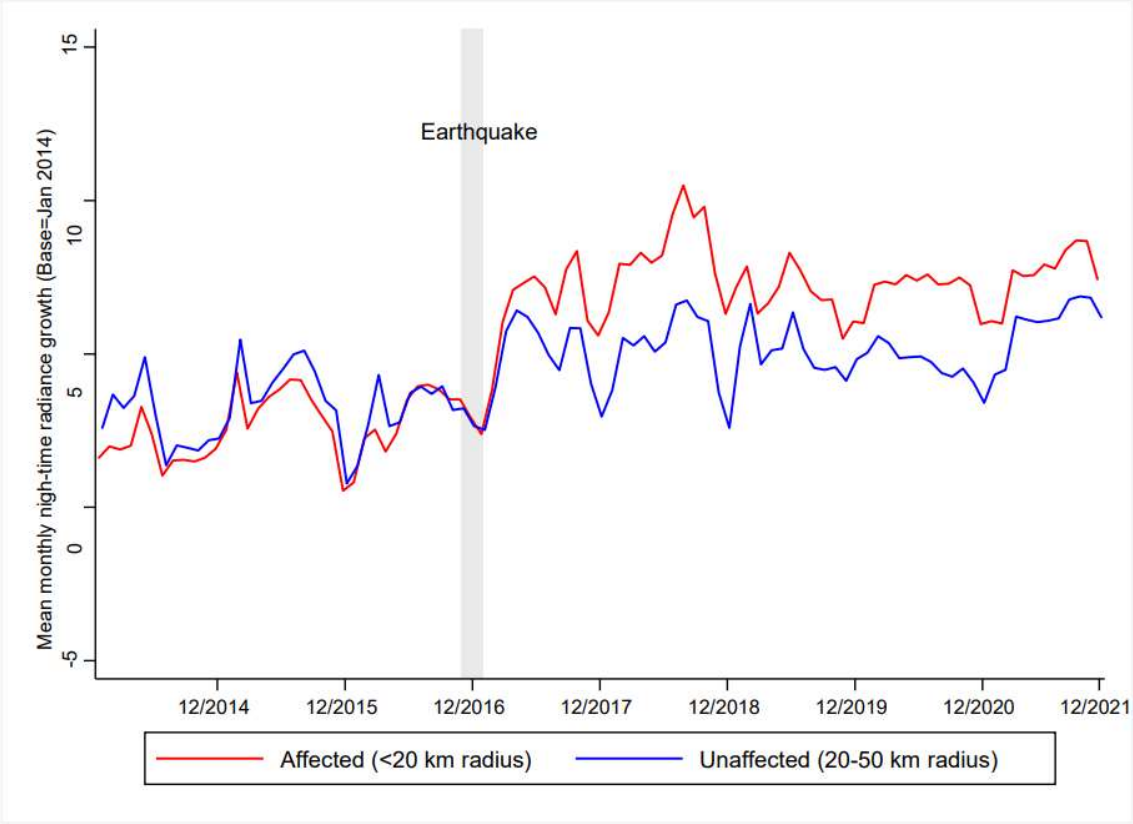
We conduct the same regression on all W2DI subindexes to understand the earthquake impact more granularly. The regression results suggest that the improvement in total W2DI after the 2016 Aceh earthquakes was dominated by increased availability and access to health infrastructure, with a treatment effect of 0.232 points (column 2, Table 1), statistically significant at 5% level. The treatment effect on the *Health* subindex was equivalent to a 10.52% improvement compared to the control group, which is consistent with the positive nighttime lights growth trajectory in earthquake-affected villages in Figure 3.

However, we identify a considerable deterioration in the *Basic Needs* subindex, with a treatment effect of –0.151 points (column 4, Table 1), statistically significant at 5% level. The results suggest that the *Basic Needs* subindex was equivalent to a 6.27% deterioration compared to the control group within 40 km of proximity. Furthermore, the *Education* subindex changed by 0.009 (column 3, Table 1), or equivalent to 0.27% change compared to the unimpacted villages; whereas, the *Security* subindex changed by –0.069 points (column 5, Table 1), or equivalent to 4.12% deterioration. However, both coefficients are not statistically significant at the 10% level.

C. Robustness Checks

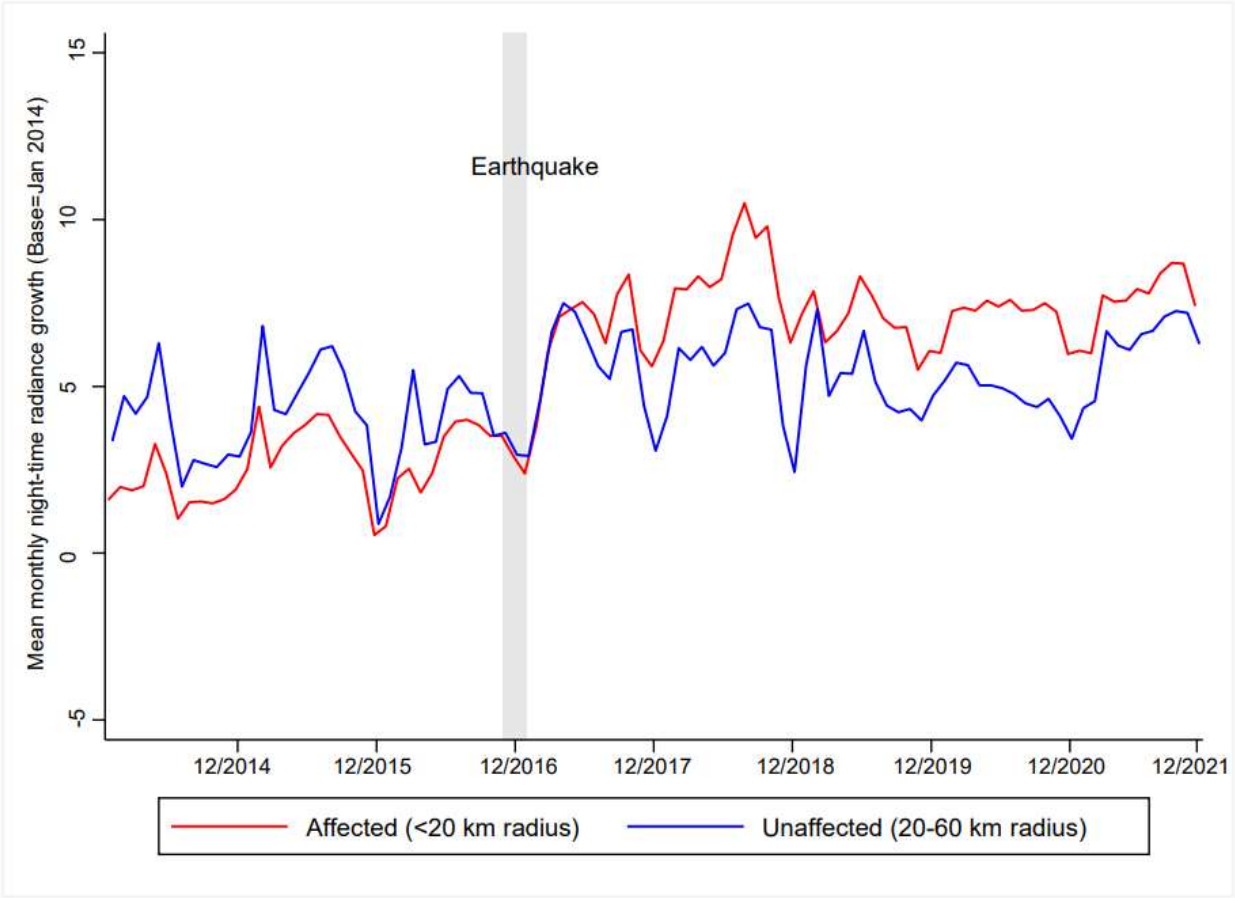
To test the robustness of our estimates, we estimate the DID regression analysis by keeping the treatment villages the same but expanding the radius of the control villages. We do this exercise in two steps. First, we redo the parallel trend assumption tests by expanding the distance of the control villages and find that the parallel trend assumption only holds when we compare the treatment villages (<20 km) to control villages located within 20–60 km of the earthquake epicenters. Figure 4 and Figure 5 present the results of these parallel trend assumption tests. When we set the distance for control villages to above 20–60 km, the parallel trend assumption is no longer satisfied ($F(1, 1214) = 10.05$, $p > F = 0.0016$). Controlling for time and village fixed effects, we find consistent results with our main regression, which are positive and significant improvement to the *Health* subindex and significant deterioration of the *Basic Needs* subindex.

Figure 4: Parallel Trend Assumption Test for a Control Sample Located Between >20-Kilometer and ≤50-Kilometer Radius



km = kilometer.
Note: Calculated using data from the United Nations Satellite Centre (UNOSAT) and the Visible Infrared Imaging Radiometer Suite (VIIRS).
Source: Authors' calculations.

Figure 5: Parallel Trend Assumption Test for a Control Sample Located Between >20 Kilometer and ≤60 Kilometer Radius



km = kilometer.
Note: Calculated using data from the United Nations Satellite Centre (UNOSAT) and the Visible Infrared Imaging Radiometer Suite (VIIRS).
Source: Authors' calculations.

When the control villages are set to be at least 50 km from the earthquake epicenters, consistently, the DID regression results suggest that the improvement in the *Health* subindex was 0.297 points (column 2, Table 2) and the deterioration in the *Basic Needs* subindex was −0.164 points (column 4, Table 2), with both effects being statistically significant at the 5% level. The results suggest that the *Health* subindex in earthquake-affected villages improved by 13.32% compared to unimpacted villages within 50 km of proximity. On the other hand, the *Basic Needs* subindex deteriorated by 6.79% compared to unimpacted villages. The *Education* subindex changed by −0.012 points (column 3, Table 2) and the *Security* subindex by −0.044 points (column 5, Table 2). However, similar to the results in the main regression, both effects are not statistically significant.

Table 2: Impact of Earthquake on Women's Welfare, Difference-in-Differences Regression Results for Treatment Sample Located Between >20-Kilometer and ≤50-Kilometer Radius

Condition	(1) W2DI All	(2) W2DI Health	(3) W2DI Education	(4) W2DI Basic Needs	(5) W2DI Security
Earthquake x Post (2018)	0.028	0.297[a]	–0.012	–0.164[a]	–0.044
	0.019	0.041	0.051	0.053	0.038
Earthquake	0.091[a]	0.102[a]	0.130[b]	0.104[b]	0.077[b]
	0.023	0.035	0.055	0.052	0.032
Post (2018)	0.158[a]	–0.337[a]	0.144[a]	0.550[a]	0.415[a]
	0.011	0.025	0.028	0.036	0.025
Constant	2.088[a]	2.226[a]	3.137[a]	2.407[a]	1.689[a]
	0.016	0.016	0.040	0.037	0.020
Observations	2,298	2,298	2,298	2,298	2,298
R-squared	0.058	0.079	0.012	0.078	0.099

W2DI = Women's Welfare after Disaster Index.

Note: Villages located <20 kilometers (km) of the earthquake epicenters are coded as the treatment group, while those within the 20–50 km radius of the earthquake epicenters are coded as the control group. Robust standard errors in blue are clustered at the village-level.

[a] p<0.01

[b] p<0.05

Source: Authors' calculations.

Furthermore, when the control villages are set to be at least 60 km from the earthquake epicenters, the DID regression still shows consistent results of improvement in the *Health* subindex by 0.341 points (column 2, Table 3) and deterioration in the *Basic Needs* subindex by −0.147 points (column 4, Table 3), with both effects being statistically significant at the 5% level. The results suggest that the *Health* subindex in earthquake-affected villages improved by 15.03% compared to unimpacted villages within 60 km of proximity. On the other hand, the *Basic Needs* subindex deteriorated by 5.97% compared to unimpacted villages. The *Education* subindex changed by −0.015 points (column 3, Table 3) and the *Security* subindex by −0.034 points (column 5, Table 3), and both effects are not statistically significant.

Table 3: Impact of Earthquake on Women's Welfare, Difference-in-Differences Regression Results for Treatment Sample Located Between >20-Kilometer and ≤60-Kilometer Radius

Condition	(1) W2DI All	(2) W2DI Health	(3) W2DI Education	(4) W2DI Basic Needs	(5) W2DI Security
Earthquake x Post (2018)	0.044[a]	0.341[b]	–0.015	–0.147[b]	–0.034
	0.019	0.041	0.052	0.053	0.038
Earthquake	0.065[b]	0.063[c]	0.126[a]	0.048	0.060[c]
	0.023	0.036	0.054	0.052	0.032
Post (2018)	0.142[b]	–0.381[b]	0.147[b]	0.534[b]	0.405[b]
	0.011	0.023	0.026	0.033	0.025
Constant	2.114[b]	2.265[b]	3.141[b]	2.464[b]	1.706[b]
	0.016	0.017	0.039	0.033	0.021
Observations	2,528	2,528	2,528	2,528	2,528
R-squared	0.046	0.084	0.011	0.075	0.096

W2DI = Women's Welfare after Disaster Index.

Notes: Villages located <20 kilometers (km) of the earthquake epicenters are coded as the treatment group, while those within the 20–60 km radius of the earthquake epicenters are coded as the control group. Robust standard errors in blue are clustered at the village-level.

[a] p<0.05

[b] p<0.01

[c] p<0.10

Source: Authors' calculations.

Though we find consistent results with our main regression, the impacts on most subindexes are bigger than that of our main comparison. This might suggest lower spillover effect of earthquakes, or higher variability, or different characteristics between our treatment and control villages as we go further away from the earthquake epicenters. Finding consistent results even after expanding the radius of the control villages suggests that the results in our main regression are robust.

VII. DISCUSSION

The objectives of this study were to do a medium-term recovery assessment at the village level following the 2016 Aceh earthquakes and to understand how the recovery of women's welfare differs from the overall economic recovery of the earthquake-affected villages. Findings from this study suggest that the overall economic welfare of the earthquake-affected villages improved in the medium term compared to the neighboring villages that were not directly impacted by the earthquakes. This could happen because of a series of reconstruction work carried out in the earthquake-affected villages (Government of Indonesia 2017), as summarized in Section II, which lead to an increase in human activities, as argued by Li et al. (2019) and Gao et al. (2020).

To ensure that recovery benefits different subgroups of population equitably, this study monitors several domains of women's welfare using the W2DI.

Literature suggests that immediately after a disaster, women are mostly hurt by the lack of access to health facilities, particularly maternal care. Our main regression using the W2DI reveals that in the medium term, recovery from a disaster is primarily supported by significant improvements in access to maternal care, such as access to pre- and post-natal services and midwife practices. In the Aceh context, a reason could have been the clear directive issued by the President that emphasized rebuilding health and educational facilities in addition to housing and physical infrastructure (Government of Indonesia 2017). Another possible explanation would be that, since the assessment is done in the medium term (i.e., 2 years after the 2016 Aceh earthquake series), a lot of damaged infrastructure might already be rebuilt. In the immediate aftermath, this might not be the case, and women could still suffer from deteriorated access to health facilities. It is also important to highlight that because of its location in the "Ring of Fire," Indonesia is among the most earthquake-prone countries. Between 1900 and 2016 alone, there have been more than a hundred earthquakes of significant magnitude, with many occurrences in Sumatera (Oishimaya 2019). Therefore, it is possible that there have been major government actions to increase capacity and resilience because of the repeated exposure to earthquakes.

However, findings from this study suggest that not all domains of women's welfare improved and recovered alongside the increased economic activities, as proxied by the increased nighttime lights radiance. Our findings are consistent with Anwar et al. (2011) that women and girls are more dependent on clean water, basic sanitary, and disposal facilities after disasters, when there is usually a limited access to these basic infrastructures. Similarly, we document a considerable deterioration in access to basic needs, which include water and sanitation, electricity, and energy. Reliable access to these basic services is also essential for women's well-being. Access to these resources is often disrupted following disasters and may not be top priority as they need longer time to recover. In the case of Aceh earthquakes, rehabilitating and recovering access to basic services were not the main focus. In one of his directives, the President mandated accelerated recovery for housing and public infrastructures, such as health and educational facilities, to support local economic growth (Government of Indonesia 2017).

Consistent with Qiang, Huang, and Xu (2020) and Xu and Yi (2021), this paper opens the possibility of combining government administrative data and high-frequency datasets for immediate and midterm recovery assessment after a disaster. In this study, the high-frequency data is useful for assessing immediate village-level economic recovery, in general, and the W2DI that is derived from routinely collected government administrative data is useful for evaluating medium-term recovery of a vulnerable group.

Since the findings suggest that disasters could impact various aspect of women's welfare differently, it becomes important to monitor progress and identify areas that require further intervention after a disaster. Hence, the study opens the possibility of constructing an index with specific targets using the different measures in administrative data, as constructed in Benjamin et al. (2017) and Smith and Koehoorn (2016). Our W2DI is constructed following the call for a comprehensive index to provide a more holistic approach of development in Aziz et al. (2015).

VIII. CONCLUSION

The findings of our study reveal that the recovery is not equal in all aspects as well as for all subgroups of population. Our main regression involving the W2DI suggests that the fast recovery and higher economic activities in impacted villages are supported by significant improvement of access to health services that primarily benefit women. This is evident as the W2DI *Health* in earthquake-affected villages improved by 10.52% compared to unaffected villages. The study also finds a substantial deterioration in access to basic needs, as the W2DI *Basic Needs* in earthquake-affected villages decreased by 6.27% compared to unaffected villages, suggesting that the earthquakes might disrupt access to basic services. The *Basic Needs* subindex includes measures of access to clean water, sanitary and disposal facilities, and energy and electricity. All of these also play an important role in women's well-being but may not be top priorities as they need more time to recover.

An important feature and contribution of this study is the combination of various datasets of high and low frequency to increase the accuracy of the medium-term recovery assessment at the village level. This approach is highly replicable, particularly for governments in disaster-prone countries and researchers who are interested in monitoring post-disaster recovery process.

Remote sensing data—in this case, high-frequency nighttime radiance as well as distance from earthquake epicenters after the earthquake—have been used often because of timely availability. Further, these datasets are publicly available and can be accessed from data providers like the NOAA and UNOSAT. However, these data could only be used to proxy general economic welfare as they are not disaggregated by subgroup of population of interest.

On the other hand, to capture and monitor a specific subgroup of population, another dataset is needed. In this study, PODES, which is government administrative data, is used. Administrative data are routinely collected by governments to monitor progress and changes in access to different kind of services and infrastructures. Despite their richness, the data are typically gender blind. However, some indicators in the data can be used to glean gender-specific information about welfare. The data collected by statistics and data collection agencies in most economies are usually publicly available, although researchers may need to file a request and pay a small fee to access the full version. Another advantage is that, since the data are collected in batches, it is possible to use different batches as baseline and endline data. In this study, 2014 and 2018 PODES batches were used in a before–after comparison.

Given that the PODES survey instrument was not designed specifically to facilitate gender-specific welfare analysis, we had limited choice for relevant domains and indicators (the Appendix shows how the W2DI was constructed). Additionally, the indicators could not be disaggregated for age groups. For example, the education domain was proxied using the number of schools. More appropriate indicator for this domain would have been sex-disaggregated school enrolment statistics for different age groups. Additionally, domestic violence is an important domain of women's welfare. Since the PODES data do not collect information on domestic violence, we could not incorporate this domain in the W2DI.

Admittedly, the best alternative for a more accurate assessment of recovery for men and women would be to collect primary data. Considering the time and resource-intensive nature of a primary survey, the usefulness of routinely collected administrative data, such as PODES, can be improved if the data collection instrument is designed to consider gender-specific domains at the survey design stage. In addition to better disaster risk management, such gender-specific data would generate more return to public investment in this endeavor. Other important domains of women's welfare that are adversely affected after a disaster are food and nutritional security,

violence or abuse against women, access to paid work, and asset ownership. Future studies should account for these domains to obtain a comprehensive picture of women's welfare after a disaster. Data collection agencies should consider incorporating gender-specific questions in the survey instruments. A tailored survey instrument should be developed that is brief, focused, easy, and cheap to implement. Such an instrument would support rapid data collection after a disaster.

APPENDIX: INDICATORS AND MEASUREMENT OF WOMEN'S WELFARE AFTER DISASTER INDEX

Subindex	Variables	Measurement	Aggregation
Health	• Public health center without inpatient service available in a village, or within 5 km = 1, otherwise = 0 • Midwife practice available in a village, or within 5 km = 1, otherwise = 0 • Village maternity post available in a village, or within 5 km = 1, otherwise = 0 • Integrated service post available in a village, or within 5 km = 1, otherwise = 0	Availability is marked as 1 if facilities are available in village, or within 5 km in distance if unavailable (Yes = 1; No = 0) Ranges from 0 (lowest) to 4 (highest), weighted by dividing village score with the maximum score	Aggregated weighted score, W2DI ranges from 0 (lowest) to 4 (highest)
Education	• Early childhood education and development available in a village, or within 5 km = 1, otherwise = 0 • Public elementary school available in a village, or within 5 km = 1, otherwise = 0 • Public junior high school available in a village, or within 5 km = 1, otherwise = 0 • Public senior high school available in a village, or within 5 km = 1, otherwise = 0 • Public vocational school available in a village, or within 5 km = 1, otherwise = 0	Availability is marked as 1 if facilities are available in village, or within 5 km in distance if unavailable (Yes = 1; No = 0) Ranges from 0 (lowest) to 5 (highest), weighted by dividing village score with the maximum score	
Basic Needs	• Clean water available in a village = 1, otherwise = 0 • Sanitary facility available in a village = 1, otherwise = 0 • Disposal facility available in a village = 1, otherwise = 0 • Electricity available in a village = 1, otherwise = 0 • Clean cooking fuel available in a village = 1, otherwise = 0	Availability is marked as 1 if resources can be found in village (Yes = 1; No = 0) Ranges from 0 (lowest) to 5 (highest), weighted by dividing village score with the maximum score	
Security	• Safety from crime against women; no occurrence of abuse, rape, and human trafficking in the past year = 1, otherwise = 0 • Lighting in main village roads available in village = 1, otherwise = 0 • Basic community-level security available in village = 1, otherwise = 0 • Advanced national-level security available in village = 1, otherwise = 0	Marked as 1 for safety if there is no crime against women in the past year, mark as 1 if lighting in main village roads is available, and mark as 1 if security facilities are available in village, or within 5 km in distance if unavailable (Yes = 1; No = 0). Ranges from 0 (lowest) to 4 (highest), weighted by dividing village score with the maximum score	

km = kilometer, W2DI = Women's Welfare after Disaster Index.

Source: Authors.

REFERENCES

Akter, S. 2021. Do Catastrophic Floods Change the Gender Division of Labor? Panel Data Evidence from Pakistan. *International Journal of Disaster Risk Reduction.* 60. pp. 1–9.

Akter, S. and B. Mallick. 2013. The Poverty-Vulnerability-Resilience Nexus: Evidence from Bangladesh*. Ecological Economics*. 96. pp.114–124.

Akter, S. and C. Pratap. 2022. Impact of clean cooking fuel adoption on women's welfare in India: the mediating role of women's autonomy. *Sustainable Science*. 17. pp. 243–257.

Angrist, J. D. and J. S. Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion.* Princeton, NJ: Princeton University Press.

Anwar, J., E. Mpofu, L. R. Matthews, A. F. Shadoul, and K. E. Brock. 2011. Reproductive Health and Access to Healthcare Facilities: Risk Factors for Depression and Anxiety in Women with an Earthquake Experience. *BMC Public Health*. 11 (1). 523.

Andersen, T. G. 2000. Some Reflections on Analysis of High-frequency Data. *Journal of Business & Economic Statistics.* 18 (2). pp.146–153.

Aziz, S., R. Mohd Amin, S. Yusof, M. A. Haneef, M. Mohamed, and G. Oziev. 2015. A Critical Analysis of Development Indices. *Australian Journal of Sustainable Business and Society*. 1 (1). pp. 37–53.

Belmonte, A., V. Bove, G. D'Inverno, and M. Modica. 2020. School Infrastructure Spending and Educational Outcomes: Evidence from the 2012 Earthquake in Northern Italy. *Economics of Education Review*. 75. 101951.

Benjamin, D. J., K. B. Cooper, O. Heffetz, and M. Kimball. 2017. Challenges in Constructing a Survey-Based Well-Being Index. *The American Economic Review*. 107 (5). pp. 81–85.

Bruederle, A. and R. Hodler. 2017. Nighttime Lights as a Proxy for Human Development at the Local Level. *CESifo Working Paper*. No. 6555. Category 6. Fiscal Policy, Macroeconomics and Growth. Munich Society for the Promotion of Economic Research - CESifo GmbH.

Budhathoki, S. S., M. Bhattachan, E. Castro-Sánchez, R. A. Sagtani, R. B. Rayamajhi, P. Rai, and G. Sharma. 2018. Menstrual Hygiene Management Among Women and Adolescent Girls in the Aftermath of the Earthquake in Nepal. *BMC Women's Health*. 18 (1). 33.

Cannon, T. 2002. Gender and climate hazards in Bangladesh. *Gender & Development*. 10 (2). pp 45–50.

Cao, H., A. C. McFarlane, and S. Klimidis. 2003. Prevalence of Psychiatric Disorder Following the 1988 Yun Nan (China) Earthquake: The First 5-Month Period. *Social Psychiatry and Psychiatric Epidemiology*. 38 (4). pp. 204–212.

Chandra, A., K. E. McNamara, P. Dargusch, A. M. Caspe, and D. Dalabajan. 2017. Gendered Vulnerabilities of Smallholder Farmers to Climate Change in Conflict-prone Areas: A Case Study from Mindanao, Philippines. *Journal of Rural Studies.* 50. pp. 45–59.

Charmes, J. 2019. *The Unpaid Care Work and the Labour Market: An Analysis of Time Use Data Based on the Latest World Compilation of Time-Use Surveys*. Geneva: International Labour Organization.

Chen, X. and W.D. Nordhaus. 2011. Using Luminosity Data as a Proxy for Economic Satistics. *Proceedings of the National Academy of Sciences of the United States of America*. 108. pp. 8589–8594.

De Goyet, C., R. Z. Marti, and C. Osorio. 2006. Natural Disaster Mitigation and Relief. In D. T. Jamison et al., eds. *Disease Control Priorities in Developing Countries*. 2nd edition. Chapter 61. Washington, DC: World Bank.

Elvidge, C. D., K. E. Baugh, V. R. Hobson, E. A. Kihn, H. W. Kroehl, E. R. Davis, and D. Coceros. 1997. Satellite Inventory of Human Settlements using Nocturnal Radiation Emissions: A Contribution for the Global Tool Chest. *Global Change Biology*. 3. pp. 387–395.

Engel, S. M., G. S. Berkowitz, M. S. Wolff, and R. Yehuda. 2005. Psychological Trauma Associated with the World Trade Center Attacks and Its Effect on Pregnancy Outcome. *Paediatric and Perinatal Epidemiology*. 19 (5). pp. 334–341.

Erman, A., S. A. De Vries Robbe, S. F. Thies, K. Kabir, and M. Maruo. 2021. *Gender Dimensions of Disaster Risk and Resilience: Existing Evidence*. Washington, DC: World Bank.

Fankhauser, S. and T.K. McDermott. 2014. Understanding the Adaptation Deficit: Why are Poor Countries More Vulnerable to Climate Events than rich Countries? *Global Environmental Change.* 27. pp. 9–18.

Farley, M. 2018. How Long Does it Take to Get Water for Aysha, Eight Hours a Day. *Water & Sanitation*. Retrieved Jun 27, 2022 from: UNICEF USA.

Fatouros, S. and T. Capetola. 2021. Examining Gendered Expectations on Women's Vulnerability to Natural Hazards in Low to Middle Income Countries: A Critical Literature Review. *International Journal of Disaster Risk Reduction*. 64. 102495.

Felten-Biermann, C. 2006. Gender and Natural Disaster: Sexualized Violence and the Tsunami. *Development.* 49 (3). pp. 82–86.

Food and Agriculture Organization of the United Nations (FAO). 2017. FAO Gender, Food Security and Nutrition: Women and Girls as Agents of Resilience. Retrieved June 27, 2022 from: F*AO Gender, food security and nutrition: Women and girls as agents of resilience 2016. Food Security Cluster (fscluster.org)*

Fredriksson, A. and G. M. de Oliveira. 2019. Impact Evaluation Using Difference-In-Differences. *RAUSP Management Journal*. 54 (4). pp. 519–532.

Gao, S., Y. Long, L. Long, and A. Gong. 2020. Post-earthquake Night-time Light Piecewise (PNLP) Pattern Based on NPP/VIIRS Night-Time Light Data: A Case Study of the 2015 Nepal Earthquake. *Remote Sensing.* 12. 2009.

Government of Indonesia. 2017. Rehabilitation and Reconstruction Fund for Post Disaster of Aceh Earthquake 626 Billion Rupiah Disbursed. News and press release. *Reliefweb*. 15 August.

Grantham, K. L., Rouhani, N. Gupta, M. Melesse. D. Dhar, S. K. Mehta, and K. J. Kingra. 2021. Evidence Review of the Global Childcare Crisis and the Road for Post-Covid-19 Recovery and Resilience. International Development Research Centre. Retrieved June 27, 2022 from: *Evidence Review of the Global Childcare Crisis and the Road for Post-Covid-19 Recovery and Resilience | childcarecanada.org.*

Gromada, A., D. Richardson, and G. Rees. 2020. Childcare in a Global Crisis: The Impact of COVID-19 on Work and Family Life. *Innocenti Research Briefs*. No. 2020-18. Innocenti, Florence: UNICEF Office of Research.

Hallegatte, S., B. Mook, L. Bonzanigo, M. Fay, T. Kane, J. Rozenberg, D. Treguer, and A. Vogt-Schilb. 2016. *Shock Waves: Managing the Impact of Climate Change on Poverty*. Washington, DC: World Bank.

Hallegatte, S., A. Vogt-Schilb, J. Rozenberg, M. Bangalore, and C. Beaudet. 2020. From Poverty to Disaster and Back: A Review of the Literature. *Economics of Disasters and Climate Change.* 4 (1). pp. 223–247.

Hannan, C. 2002. *Disproportionate Impact of Natural Disasters on Women*. Presentation prepared for the United Nations Division for the Advancement of Women and the NGO Committee on the Status of Women Roundtable Panel and Discussion. Geneva. 17 January.

Hibino, Y., J. Takaki, Y. Kambayashi, Y. Hitomi, A. Sakai, N. Sekizuka, K. Ogino, and H. Nakamura. 2009. Health Impact of Disaster-Related Stress on Pregnant Women Living in the Affected Area of the Noto Peninsula Earthquake in Japan. *Psychiatry and Clinical Neurosciences*. 63 (1). pp. 107–115.

Ibrahim, G. M. 2016. Pidie Jaya Earthquake Injury Victim Reaches 500 People, Treated at Chik Ditiro Hospital. *Detik News.* 7 December.

International Labour Organization (ILO). 2017. The Gender Gap in Employment: What's Holding Women Back? Infostories. https://www.ilo.org/infostories/en-GB/Stories/Employment/barriers-women#global-gap (accessed 20 May 2022).

International Union for Conservation of Nature (IUCN). 2018. Disaster and Gender Statistics. IUCN Fact Sheet. Retrieved June 27, 2022 from: Microsoft Word - Disaster and Gender Statistics.doc (unisdr.org).

Jin, J., X. Wang, and Y. Gao. 2015. Gender Differences in Farmers' Responses to Climate Change Adaptation in Yongqiao District, China. *Science of the Total Environment.* 538. pp. 942–948.

Juran, L., and J. Trivedi. 2015. Women, Gender Norms, and Natural Disasters in Bangladesh. *Geographical Review.* 105 4). pp. 601–611.

Kellet, J. and D. Sparks. 2012. *Disaster Risk Reduction: Spending Where It Should Count.* Briefing Paper. London: Global Humanitarian Assistance.

Khan, H. 2016. Sexual and Gender-Based Violence in Natural Disasters: Emerging Norms. *Commonwealth Law Bulletin*. 42 (3). pp. 460–468.

Kholid, I. 2016. 6.5 SR Earthquake in Aceh, National Police Sends DVI Team. *Detik News*. 7 December.

Li, X., R. Ma, Q. Zhang, D. Li, S. Liu, T. He, and L. Zhao. 2019. Anisotropic Characteristic of Artificial Light at Night— Systematic Investigation with VIIRS DNB Multi-temporal Observations. *Remote Sens. Environ.* 233.

Liang, Y., P. Chu, and X. Wang. 2014. Health-Related Quality of Life of Chinese Earthquake Survivors: A Case Study of Five Hard-Hit Disaster Counties in Sichuan. *Social Indicators Research*. 119 (2). pp. 943–966.

Liu, X. and Y. Xu. 2021. Unexpected Opportunity for Girls: Earthquake, Disaster Relief and Female Education in China's Poor Counties. *China Economic Review*. 70 (C). 101701.

Llorente-Marrón, M., Y. Fontanil-Gómez, M. Díaz-Fernández, P. S. García. 2021. Disasters, Gender, and HIV Infection: The Impact of the 2010 Haiti Earthquake. *International Journal of Environmental Research and Public Health*. 18 (13). 7198.

Masriadi, M. 2016. Search for Aceh Earthquake Victims Stopped. *Kompas*. 13 December.

Mellander, C., J. Lobo, K. Stolarick, and Z. Matheson. 2015. Night-time Light Data: A Good Proxy Measure for Economic Activity? *PLoS ONE*. 10(10): e0139779.

Morchain, D., G. Prati, F. Kelsey, and L. Ravon. 2015. What if Gender Became an Essential, Standard Element of Vulnerability assessments? *Gender & Development.* 23 (3). pp. 481–496.

Nandi, A., S. Mazumdar, and J. R. Behrman. 2018. The Effect of Natural Disaster on Fertility, Birth Spacing, and Child Sex Ratio: Evidence from a Major Earthquake in India. *Journal of Population Economics*. 31 (4). pp. 267–293.

Neumayer, E. and T. Plümper. 2007. The Gendered Nature of Natural Disasters: The Impact of Catastrophic Events on the Gender Gap in Life Expectancy, 1981–2002. *Annals of the Association of American Geographers*. 97 (3). pp. 551–566.

Nobles, J., E. Frankenberg, and D. Thomas. 2015. The Effects of Mortality on Fertility: Population Dynamics after a Natural Disaster. *Demography*. 52 (1). pp. 15–38.

Norris, F. and C. Elrod. 2006. Psychosocial Consequences of Disaster. A Review of Past Research. In F. Norris, S. Galea, M. Friedman, and P. Watson, eds. *Methods for Disaster Mental Health Research*. London: Guildford Press. pp 20–42.

Oishimaya, S. N. 2019. The World's 10 Most Earthquake Prone Countries. Retrieved August 7, 2022 from: WorldAtlas.

Organisation for Economic Co-operation and Development (OECD). 2018. *Engaging Young Children*. Paris.

_____. 2019. *OECD Economic Survey-Japan 2019*. Paris.

Oxfam International. 2005. The Tsunami's Impact on Women. Oxfam Briefing Notes. Retrieved June 27, 2022 from: The tsunami's impact on women (openrepository.com).

Paudel, J. and H. Ryu. 2018. Natural Disasters and Human Capital: The Case of Nepal's Earthquake. *World Development*. 111 (C). pp. 1–12.

Qiang, Y., Q. Huang, and J. Xu. 2020. Observing Community Resilience from Space: Using Nighttime Lights to Model Economic Disturbance and Recovery Pattern in Natural Disaster. *Sustainable Cities and Society*. 57 (5). 102115.

Rahiem, M. D., H. Rahim, and R. Ersing. 2021. Why did so Many Women Die in the 2004 Aceh Tsunami? Child Survivor Accounts of the Disaster. *International Journal of Disaster Risk Reduction.* 55. 102069.

Rubiano-Matulevich, E. and M. Viollaz. 2019. Gender Differences in Time Use: Allocating Time Between the Market and the Household. *Policy Research Working Paper*. No. 8981. Washington, DC: World Bank.

Ruey, S. T. 2000. Editor's Introduction to Panel Discussion on Analysis of High-frequency Data. *Journal of Business & Economic Statistics*. 18 (2). pp. 139.

Sakai, Y., H. Wakamatsu, and T. Miyata. 2018. Impact of the Great East Japan Earthquake on the Oyster Market: A Difference-in-differences Estimation. *Fisheries Science.* 84. pp. 1109–1118.

Schwab, A. K., K. Eschelbach, and D. J. Browser. 2007. Hazard Mitigation and Preparedness. Wiley & Sons. Hoboken.

Smith, P. M. and M. Koehoorn. 2016. Measuring Gender when you don't have a Gender Measure: Constructing a Gender Index Using Survey Data. *International Journal for Equity in Health.* 15. 82.

Statistics Indonesia (Badan Pusat Statistik). Statistics of Aceh Province. https://aceh.bps.go.id/quickMap.html (accessed 13 May 2022).

Statistics Indonesia (Badan Pusat Statistik). 2014. *Village Potential Statistics (PODES) 2014*. Jakarta: Statistics Indonesia. Retrieved July 7, 2022 from: https://sirusa.bps.go.id/sirusa/index.php/dasar/view?kd=29&th=2014.

Statistics Indonesia. 2018. *Village Potential Statistics (PODES) 2018*. Jakarta: Statistics Indonesia. Retrieved May 13, 2022 from: 2017_3472_ped_Pedoman Pencacah Pilot Podes 2018.pdf (bps.go.id).

Thomas, V. and R. López. 2015. Global Increase in Climate-Related Disasters. *ADB Economics Working Paper Series*. No. 466. Manila: Asian Development Bank.

Thurston, A. M., H. Stöckl, and M. Ranganathan. 2021. Natural Hazards, Disasters and Violence Against Women and Girls: A Global Mixed-Methods Systematic Review. *British Medical Journal Global Health*. 6 (4). e004377.

United Nations Children's Fund (UNICEF). 2016. UNICEF: Collecting Water is often a Colossal Waste of Time for Women and Girls. Press Release. Retrieved Jun 27, 2022 from: *UNICEF: Collecting Water is often a Colossal Waste of Time for Women and Girls.*

United Nations Development Programme (UNDP). 2010. *Gender and Disasters*. Fact Sheet. UNDP Bureau for Crisis Prevention and Recovery. New York. https://www.undp.org/sites/g/files/zskgke326/files/migration/arabstates/7Disaster-Risk-Reduction---Gender.pdf.

United Nations Entity for Gender Equality and the Empowerment of Women (UN Women). 2014. *Climate Change, Disasters and Gender-Based Violence in the Pacific*. Suva: UN Women Fiji Multi-Country Office.

UN WomenWatch. 2009. *Women, Gender Equality and Climate Change*. Fact Sheet. New York. https://www.un.org/womenwatch/feature/climate_change/downloads/Women_and_Climate_Change_Factsheet.pdf.

United Nations Institute for Training and Research (UNITAR). 2019. UNOSAT – Big Data Applications for Earth Observation in ASEAN Member States. Retrieved Jun 27, 2022 from: UNOSAT - Big Data Applications for Earth Observation in ASEAN Member States | UNITAR.

United Nations International Strategy for Disaster Reduction (UNISDR). 2015. Sendai Framework of Disaster Risk Reduction (2015-2030). Retrieved July 6, 2022 from: Sendai Framework for Disaster Risk Reduction 2015 - 2030 (unisdr.org).

_____. 2019. United Nations Office for Disaster Risk Reduction 2018 Annual Report. Retrieved June 27, 2022. From: https://www.unisdr.org/files/64454_unisdrannualreport2018eversionlight.pdf

United States Geological Survey (USGS). 2004. M 9.1 - 2004 Sumatra - Andaman Islands Earthquake. Earthquake Hazards Program. 26 December. https://earthquake.usgs.gov/earthquakes/eventpage/official20041226005853450_30/region-info (accessed 13 May 2022).

_____. 2016. M 6.5 – 14 km WNW of Reuleuet, Indonesia. Earthquake Hazards Program. 6 December. https://earthquake.usgs.gov/earthquakes/eventpage/us10007ghm/executive#executive (accessed 13 May 2022).

United States National Oceanographic and Atmospheric Administration (US NOAA). 2022. Earth Observation Group. Retrieved June 22, 2022. From: http://ngdc.noaa.gov/eog/

Valenti, M., F. Masedu, M. Mazza, S. Tiberti, C. Di Giovanni, A. Calvarese, R. Pirro, and V. Sconci. 2013. A Longitudinal Study of Quality of Life of Earthquake Survivors in L'Aquila, Italy. *BMC Public Health*. 13 (1). 1143.

Vidili, M. 2018. Why We Must Engage Women and Children in Disaster Risk Management. World Bank Blogs. Retrieved Jun 27, 2022. From: Why we must engage women and

Winsemius, H., J. Aerts, and L. Van Beek. 2016. Global Drivers of Future River Flood Risk. *Nature Clim. Change.* 6. pp. 381–385.Wooldridge, J. M. 2012. *Introductory Econometrics: A Modern Approach*. 5th edition. Mason, OH: South-Western, Cengage Learning.

World Health Organization (WHO). 2016. Indonesia, Aceh Earthquake – 12 December 2016. *Situation Report 4*. Emergency Operations. WHO South-East Asia Regional Office (SEARO).

_____. 2022. Women's Health. Retrieved July 31, 2022. From: Women's health (who.int).

Xu, J. and Q. Yi. 2021. Spatial Assessment of Community Resilience from 2012 Hurricane Sandy Using Nighttime Light. *Remote Sensing.* 13 (20). 4128.

Yoshihama, M., T. Yunomae, A. Tsuge, K. Ikeda, and R. Masai. 2019. Violence Against Women and Children Following the 2011 Great East Japan Disaster: Making the Invisible Visible Through Research. *Violence Against Women*. 25 (7). pp. 862–881.

Zaidi, R.Z. and M. Fordham. 2021. The Missing Half of the Sendai Framework: Gender and Women in the Implementation of Global Disaster Risk Reduction Policy. *Progress in Disaster Science.* 10. 100170.

A Gender-Sensitive Earthquake Recovery Assessment Using Administrative and Satellite Data

The Case of Indonesia's 2016 Aceh Earthquake

This study assesses the medium-term recovery of women at the village level after the Aceh 2016 earthquake. Using data from Indonesia's Village Potential Statistics, a Women's Welfare after Disaster Index (W2DI) was developed and then disaggregated into four subindexes—health, education, basic needs, and security—for a more detailed analysis. Monthly nightlights data from the Visible Infrared Imaging Radiometer Suite instrument were used as proxy of overall economic recovery. The study concludes that, in the medium term, some aspects of women's welfare can significantly deteriorate after a disaster even when the affected villages generally made economic progress.

About the Asian Development Bank

ADB is committed to achieving a prosperous, inclusive, resilient, and sustainable Asia and the Pacific, while sustaining its efforts to eradicate extreme poverty. Established in 1966, it is owned by 68 members —49 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.

ADB

ASIAN DEVELOPMENT BANK
6 ADB Avenue, Mandaluyong City
1550 Metro Manila, Philippines
www.adb.org