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Can we mitigate the effect of natural disasters on child health? Evidence from the Indian Ocean tsunami in Indonesia

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Abstract

The 2004 Indian Ocean tsunami was an international natural disaster unlike any seen before, killing 166,561 people in Aceh province, Indonesia. It prompted an unprecedented humanitarian response and was a catalyst in ending almost 30 years of civil conflict in Aceh. Since the tsunami was followed by a multitude of events, we first conduct a systematic review to identify those events in Indonesia. Then, we use a synthetic control method to estimate the combination of those effects on child mortality indicators in Aceh for the 13 years that followed the disaster using data from 258,918 children born between 1990 and 2017. The results show a significant increase in under-5 mortality only the year after the tsunami and no effect in the medium term. However, younger and older children were affected differently in the medium term. In fact, we show a decrease in child mortality among children aged 1-4 years. In contrast, we observe an increase in mortality among children under-1 in 2009 and 2010. Overall, the resilience of Aceh province points to the importance of coordinated international disaster response.

Key Words: Natural disaster, child mortality, 2004 tsunami, synthetic control.

Classification Codes: I100, I120, I150, C21, C22, H84

Highlights:

1. The tsunami led to a statistically significant increase in under-5 mortality only the year that followed the disaster
2. The tsunami led to a significant reduction in child mortality among children aged 1-4 in the medium term

3. Under-1 mortality increased significantly five years after the tsunami

1 Introduction

Individuals in low-income countries are exposed to different types of exogenous shocks. Among such shocks, the least studied and most likely to affect people lives in the long term are natural disasters. As a matter of fact, each year there are over 300 natural disasters globally with millions of victims that cost economic losses near USD\$100 billion (Yehuda, 2002). With the likely future rise in climate variation, and thus an increase in the intensity of natural disasters, understanding the mechanisms that allows the mitigation of the impact of natural disasters on population health is vital. Because the most vulnerable groups are disproportionately affected by natural disasters globally, such shocks can leave permanent impacts on health, hence reinforcing the intergenerational transmission of poverty. Recent evidence suggests that natural disasters affect well-being more than asset losses (Hallegatte et al., 2016) and that the occurrence of these shocks in utero and in early childhood is considered to be especially harmful because of their long lasting effect (Walker et al., 2005, Hoddinott et al., 2008, Gertler et al., 2014, Maluccio et al., 2009, Neelsen and Stratmann, 2011, Gluckman et al., 2008). Despite this, there is limited evidence of the effect of natural disasters on child health (Caruso and Miller, 2015, Chen et al., 2016, Maccini and Yang, 2009, Datar et al., 2013, Frankenberg et al.).

Several studies have aimed to identify the causes of mortality in natural disasters (Frankenberg et al., 2011, Gutierrez et al., 2005), but only a few have investigated the prolonged effects of natural disasters on mortality. Ho et al. (2017) use longitudinal data from households living in affected Indonesian provinces to estimate adult mortality and its causes the five years that followed the 2004 Tsunami. The results do not show strong evidence of an increase in adult mortality among residents in tsunami-affected communities. In Armenia, Armenian et al. (1998) showed that the earthquake led to an increase in adult mortality the first 6 months and to an increase in heart disease, while Nakagawa et al. (2009) find that there was an increase in acute myocardial infarction the three years that followed the Niigata-Chuetsu earthquake in Japan. Aida et al. (2017) provide evidence that mortality increases up to 38 months after the 2011 Japanese tsunami, especially among survivors with no social connections.

Our paper makes an important contribution to the literature on the effect of natural disaster

on mortality by providing the first evidence of the prolonged effects of a severe natural disaster on mortality of children under-5. To do so, we focus on events caused by the largest earthquake recorded in over 40 years, which occurred on the 26th of December 2004 in the Indian Ocean off the Northwest coast of Indonesia. The ensuing tsunami caused killed 167,540 persons in Indonesia, where most of the damages occurred in Aceh province, including 129,775 deaths and 36,786 people reported missing, i.e., almost 5% of Aceh's population. On the 28th of March, 2005 a magnitude 8.6 earthquake struck off of Nias Island in neighbouring North Sumatra province further displacing many Acehnese. The tsunami also destroyed the local economy, where losses were estimated to be USD\$4.45 billion, or 97% of Aceh's GDP in 2003 (World Bank, 2005). Structurally, one third of roads, schools and health facilities in Aceh were damaged (Athukorala and Resosudarmo, 2005). Lastly, the tsunami killed many local healthcare staff which led to decreased local capacity to care for the large influx of injuries and illnesses caused by the tsunami.

The tsunami also led to some effects that could have been beneficial to child mortality reduction. In response to this human and economic devastation, the international community generated an unprecedented humanitarian response. In total, USD\$7.7 billion was committed for relief and reconstruction by the government, non-governmental organizations and international donors (Masyrafah and McKeon, 2008), which represents the largest influx of aid in history. More specifically, aid was aimed to prevent "second mortality" post disaster through various direct channels such as to prevent communicable diseases outbreak (Athukorala, 2012) and to develop effective policies for sustainable reconstruction. In addition, the devastation was so severe that it further encouraged Aceh's separatists and the Indonesian military to sign a peace agreement that ended a 30-year conflict. At the same time, Aceh strengthened its Islamic identity. Post-tsunami relief efforts ushered in Islamic organizations that did not previously have a presence in Aceh. These organizations helped to intensify the practice of Sharia law and intensified religious zeal (Ichwan, 2011). As a result, the subsequent effects of the tsunami on child mortality may be both positive and negative.

Our paper aims to investigate whether the combination of the different effects of the tsunami translated into an increase in subsequent child mortality the years that followed the catastrophe. Indeed, while international relief organizations played an important role in health services delivery, it is not clear if these efforts were sufficient to prevent subsequent child mortality. To

answer this question, we first conduct a systematic review to identify the multiple short term and longer term effects of the tsunami in Aceh province on child health. Then, we estimate the effect of the tsunami on child mortality the 13 years that followed the natural disaster. To do so, we use non-affected Indonesian provinces to create a synthetic Aceh province using the synthetic control method pioneered by Abadie et al. (2010). Our results show that the tsunami led to a significant increase in under-5 mortality in 2005, the year that followed the catastrophe but did not have any longer term impacts. We however also provide evidence that different age groups were not affected at the same time by this natural disaster in the medium term. More precisely, we show that although children aged 1-4 were negatively affected by the disaster immediately, child mortality for children aged 1-4 decreases in the medium term. Conversely, in addition to the immediate increase in infant mortality, we also observe that mortality of children under-1 also increases 5 years after the tsunami.

The remainder of the paper is organised as follows: Section 2 reviews the literature on the short-term and longer-term effects of the tsunami in Indonesia. Section 3 describes the data and empirical approach used. Section 4 presents the results and robustness checks, while Section 5 discusses findings. Finally, Section 6 concludes.

2 Immediate and longer term effects of the tsunami on child health: a systematic review

The Asian tsunami that hit Aceh was followed by a multitude of events that may have had a combination of negative and positive longer-term effects on child mortality. In order to provide evidence of those transmission channels, we conduct a systematic review. Exact search terms, syntax and database search results are included in Appendix 1. After the review of these search results, a snowballing approach was used to capture articles from reference lists of extracted literature. An additional search of google scholar was conducted to capture grey literature, reports from international relief and governance agencies and unpublished PhD dissertations. Seventy-eight full-text articles written in English met the inclusion criteria and were included in the review. A description of these papers is presented in Appendix 2.

2.1 Negative impacts of the tsunami on child mortality

The tsunami severely damaged health infrastructures. Five of 27 hospitals, 19 of 237 large public health centers and one third of village birth clinics and village health centers in Aceh were destroyed, leaving a limited local capacity to attend to the influx of medical needs (World Bank, 2005). Data from the Study of the Tsunami Aftermath and Recovery (STAR) estimate the disruptions in service provision in 2005 and 2006 in heavily damaged communities to be 64% for community health posts, 49% for village midwives and 63% for public health centers, while emergency primary health care services were only established in 31% of those communities (Frankenberg, 2007). The World Health Organization (2005) reports that of the 497 provincial health staff in Aceh, 57 died and 59 were reported missing after the tsunami. Additionally, 53 of the 244 health facilities were destroyed or incapacitated. Moreover, the proportion of health facility staff who died is estimated to be 22% in heavily damaged communities by the STAR project. Importantly, this lack of health infrastructure prompted a delay in seeking care and increased morbidity since patients were unable to get the immediate care they needed (Guha-Sapir et al., 2007, Pascapurnama et al., 2016, Redwood-Campbell and Riddez, 2012). In addition, there was a decrease in the quality of care reported in public health centres since 17% of affected sub-districts reported a decrease in the quantity of health workers, 20% reported a decrease in supply of pharmaceuticals, and a 18% decrease of equipment, sterile treatment conditions, and inadequacy of waters and toilets. It may be worth noting that the destruction of health infrastructures and the deaths of health workers may have a large detrimental impact on infants and children mortality given that in Indonesia, and more generally in low-and middle income countries, health facilities primarily function as providers of maternal and child care.

The disaster also destroyed vital water and sanitation infrastructure leaving large displaced populations at an increased risk of disease. Post-tsunami, diarrhoea was found to be the second leading cause of morbidity and pointed to the need for improved systems (Gupta et al., 2007).

The tsunami destroyed transportation infrastructure, agricultural production and coastal fishing, which had a dramatic impact on already impoverished communities. The market for fish collapsed because of damage to harbors and public fears of water contamination. Food prices increased because of the destruction of agricultural lands and farm costs rose because of scarce resources and large transportation cost of obtaining new equipment due to the destruction of

roads (Webb, 2005). Thorburn (2009) notes that in the four years before the tsunami, the poverty rate doubled in Aceh to nearly 30% and the tsunami pushed thousands more families into poverty. The study found that although aid programs brought much needed livelihood support and restored many of these families back to work within a year, newly developed enterprises, micro-credit formed businesses and co-operative community development programs could not alleviate pre-existing vulnerability.

Changes to society and culture also occurred after the disaster. Post-tsunami Aceh strengthened its Islamic identity (Shah and Cardozo, 2014). More specifically, Islam was heavily used post-disaster to teach about the relationship between natural phenomenon and faith in order to strengthen religious beliefs (Adiyoso and Kanegae, 2013). Tsunami relief ushered in new, extreme forms of Islamic ideology from radical organizations that developed a presence and a following in the province during their humanitarian aid work (Ichwan, 2011). The increased conservative Islamic values displayed in Aceh after the tsunami may have given rise to further reduction in health seeking behaviours among women and their children.

Finally, the presence of international NGOs' and funding agencies often leads to a lack of local capacity to respond to future sustainability and vulnerability reduction needs. In Aceh, the large influx of organizations overpowered local voices and led to many instances of corruption, unsustainable skyrocketing cost for local materials and wage competition that pushed local labour out of the reconstruction market (Jayasuriya and McCawley, 2010, Jayasuriya and McCawley, 2008). There was no evidence of aid crowding out local government budgets (Athukorala and Resosudarmo, 2005), however, potential shifts in government spending because of earmarked health aid could have had a negative effect on health after aid organizations reduced their local presence and turned over health system management to local staff.

2.2 Positive impacts of the tsunami on child mortality

Within the relief aid effort, USD\$700 million was committed specifically for health-focused work from 135 health NGO's, 16 donors and 152 international actors (Masyrafah and McKeon, 2008). In total there were 330 health projects and 85% of these projects were conducted by NGOs (Masyrafah and McKeon, 2008). The allocation of aid funds took place mainly the four years that followed the tsunami were programmed to be disbursed by 2008. As a matter of

fact, by end 2007, 88 percent (US\$6.8 billions) of committed aid had been allocated to specific projects (Jayasuriya and McCawley, 2010, Jayasuriya and McCawley, 2008). Health aid improved the capacity of the local health system through rebuilding destroyed and damaged health and sanitary infrastructures and training local medical staff (World Health Organization, 2015). Lee et al. (2014) studied the impact of aid to create durable development solutions one and six year post-tsunami and found housing quality, water, sanitation, and perceptions of local and national health services all improved by 2011.

Chang-Seng (2013) argues the tsunami prompted governance change along with rapid decentralization and facilitated the reorganization of government. Indeed, 90% of the capital city, Banda Aceh, was destroyed by the disaster and 40% of its government staff were killed (World Health Organization, 2015). Total destruction of this governance hub allowed for the influence of international actors, with aid and political pressure as tools for incentivizing change, to rebuild systems of governance in partnership with the Indonesian central government. In 2014 universal social health insurance was introduced in order to achieve universal health coverage by 2019 (World Health Organization, 2017). While it is complicated to infer that international scrutiny causes further decentralization and prompted the introduction of social health insurance, one can assume that the increased attention given to Indonesia in the disaster response and recovery effort shifted governance towards improving health systems more than what would have been done in the absence of the tsunami.

Lastly, the “building back better” reconstruction plan focused on sustainable re-development and both rebuilt destroyed capital and made more productive use of capital post-tsunami (Heger, 2016). From 2005-2009 in Banda Aceh, reconstruction doubled built up areas with less dense settlements, enhanced costal development and infrastructure improvements (Achmad et al., 2015). In addition to rebuilding and improving economic systems locally, Aceh province reopened to international investors, which recreated trade connections to Malay and Islamic worlds and generated pathways to future growth (Phelps et al., 2011). Heger (2016) finds strong evidence of a creative-destruction effect of the tsunami that facilitated short and long-term economic growth in Aceh above what was seen in other Indonesian provinces. Economic growth and opportunity is tied to poverty alleviation and could influence many of the social determinants of health that could have lasting effects on population health.

Finally, the tsunami ended an almost 30-year civil conflict that cut off Aceh province from the rest of the country. The civil conflict killed over 15,000 people, shut off access to education and health systems and left nearly 1.4 million people displaced (Worldwatch Institute). The cost of the conflict was estimated at USD\$10.7 billion (World Bank, 2009b). Peace talks had begun in secret prior to the tsunami, however, the tsunami was a catalyst in resuming peace talks in order to help Aceh receive international aid and give the rebel group local political legitimacy in the rebuilding process. Upon signing the 2005 peace agreement, the Free Aceh Movement or *Gerakan Aceh Merdeka* (GAM) gave up their claim for independence and negotiated more autonomy for Aceh in terms of receiving central government funds (Gaillard et al., 2008a). The peace agreement allowed for improvements to local systems and infrastructure, increased international aid and improved local governance (Beardsley and McQuinn, 2009). The ending of the civil conflict undoubtedly had a positive impact on short-term health and it would be expected that improved access to services and outside resources would improve health over time.

2.3 Undetermined impact of the tsunami on child mortality

There is some evidence in the literature that maternal posttraumatic stress disorder is detrimental to child mental health (McFarlane, 1987, Pfefferbaum, 1997). It is clear that the tsunami led to a decline in mental health among survivors, especially in women and young adults (Frankenberg et al., 2008) and that this decline affected long-term health of survivors (Rassekh and Santosham, 2014). However, the tsunami was also a catalyst towards developing a mental health system (Marthoenis et al., 2016). Before the tsunami, there was only one 250-bed mental health hospital available in Aceh and little common knowledge of mental health conditions (De Jong et al., 2005, Meilianda et al., 2017). After the tsunami, intensive training for general practitioners and other aid efforts led to improved capacity, care coordination, and support of mental health services that otherwise would not have been available (Prasetyawan et al., 2006). It is unclear, however, if the tsunami could have had an effect on the mortality of children born from mothers who survived the tsunami through the mental health channel.

3 Methods

3.1 Data

We use the Indonesia Demographic and Health Survey (DHS) data, collected in 1997, 2007, 2012 and 2017. These data come from nationally representative cross-sectional surveys and contain information on child death and on several intermediary child health outcomes. We used birth record from DHS to estimate mortality indicators. This dataset has one record for every child ever born to interviewed women. Essentially, it contains the full birth history of all women interviewed for all children born in the last 5 years ¹. It includes information on year of birth, on whether the child is alive at the time of the interview and if the child is dead, the age at death. As a result, unlike the use of birth and death registers, our measures of child mortality are unlikely to depend on the quality of registration services.. Using information on the province where the household lives and on the date of birth and death, we reconstruct birth cohorts from 258,918 born between 1990 and 2017 (Appendix 3) and estimate indicators per province and year. Among the 258,918 children included in our cohort, 88,164 children are under-5 years old at the time of the interview. We use the cohort of 258,918 children to estimate annual child mortality rates by province (Masset, 2015) and the cohort of the 88,164 children to estimate the effect of the tsunami on main causes to child mortality.

The primary health outcome is under-5 mortality per 1,000 live births, but we also investigate the distribution of under-5 child mortality at different periods: infant (under-1) and 1-4 years. We do so because these different mortality indicators are unlikely influenced by the same factors (Muldoon et al., 2011). Infant mortality is good marker of the quality of care, while mortality of older children is mainly caused by environmental factors such as political and medical infrastructure, poor access to clean drinking water, and lack of sanitation. We also use DHS data in order to estimate the effect of the tsunami on the main factors of child mortality. To identify relevant factors of deaths among children under-5, we use data from the Institute of Health Metrics and Evaluation (IHME)² on the causes of death in Indonesia. Note however that unlike mortality rates, information on intermediary outcomes are only asked for children under-5 hence the period covers ranges from 1992 to 2012 with an interruption between 1997 and 2002.

¹Note that the data set collected in 1997 contains this information for all children born.

²Global of Disease compare tool: <https://vizhub.healthdata.org/gbd-compare/>

Lastly, we present the effect of the tsunami on the other transmission channels identified in the literature review. To do so, we use data from the Indonesia Database for Policy and Economic Research (World Bank, 2015) that contain province-level information ($n=33$)³ on fiscal, economic, infrastructure, social and demographic indicators over the period 1976-2014. The data set combines data from the Indonesian Central Bureau of Statistics, Ministry of Finance, and Central Bureau of Statistics special reports and primarily collected data by the World Bank. Vital system access measures include the percentage of households with access to safe water⁴ and safe sanitation⁵ and were based on the National Socioeconomic Survey. Information was available between 1996 and 2013 but was missing in 2000, 2001, 2002, and 2005.

3.2 Empirical Strategy

A naive analysis consisting of a direct comparison of health outcomes in Aceh to those observed in other Indonesian provinces would be misleading given that Aceh was distinctly different from the rest of Indonesia given its long history of civil conflicts, its limited geographical access and its high poverty level (Fan, 2006). As a result, the rest of Indonesia is not a valid counterfactual as highlighted by the differences in the trend in child mortality Figure 1⁶. However, recreating a synthetic Aceh is an attractive option since other provinces shared similar characteristics. We can see that given the geography of Indonesia, many others provinces are remote. In addition, Aceh has never been the poorest province of Indonesia. Finally, the Indonesian provinces of Maluku, Kalimantan, Central Sulawesi, West Timor and Papua were also been affected by communal conflicts prior 2004.

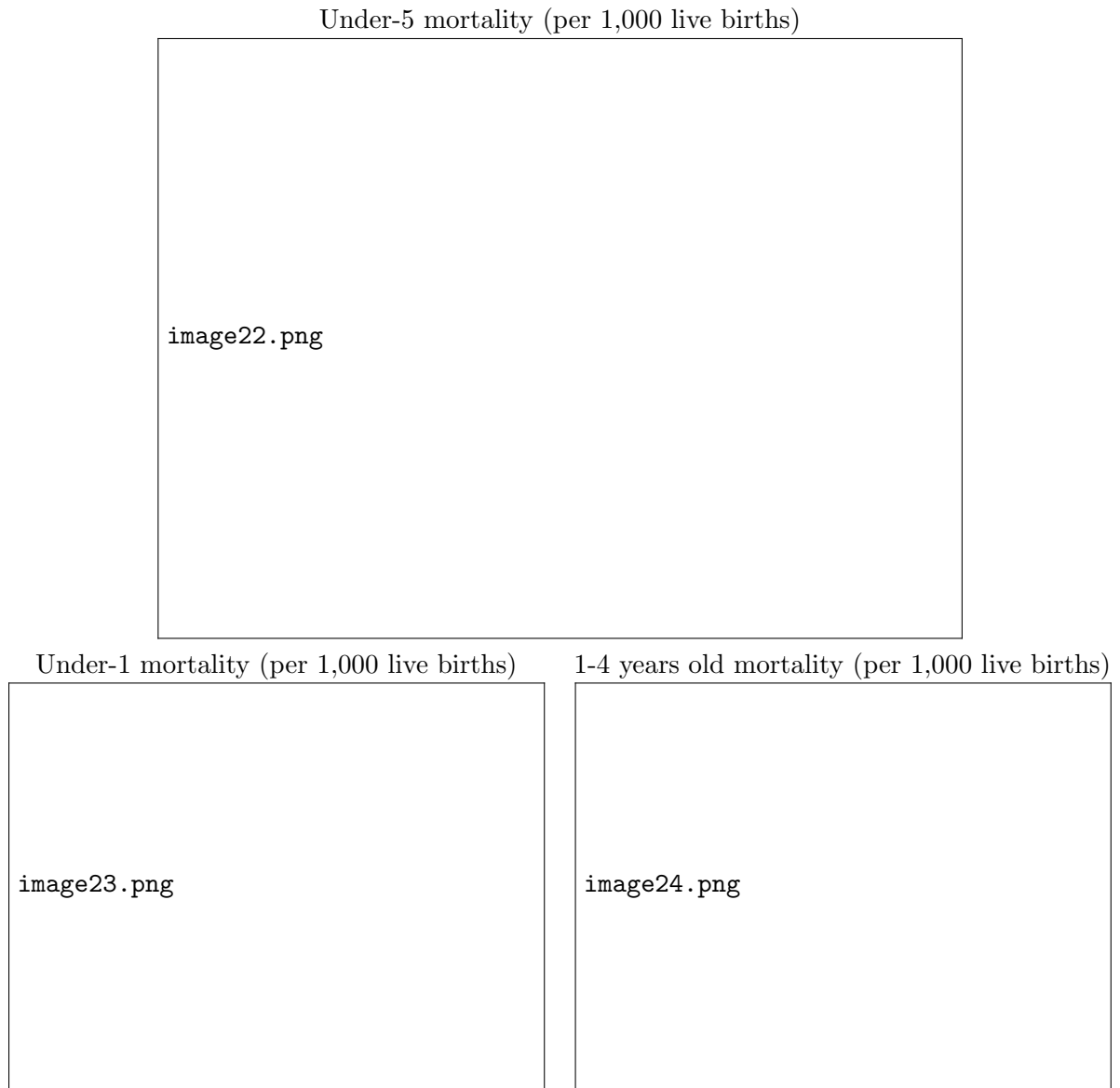
³INDO-DPER lists 34 provinces, however, seven were created after 2000 (Bangka Belitung, Riau islands, Banten, Gorontalo, West Sulawesi, North Maluku, West Papua) and one was created after the period covered by our analysis (Kalimantan Utara). In addition, one province (East Timor) became independent in 1999 and was dropped from DHS 1997.

⁴ Safe water includes access to bottled water, refill water, tap water, protected well more than 10 meters from a septic tank and protected spring located more than 10 meters from a septic tank.

⁵ Safe sanitation means that each household had access to a private toilet and did not use a shared or public toilet.

⁶Note that on the graphs presented, we observe a peak in child mortality in 2001 that is particularly severe for children aged 1-4 years old. This peak in mortality is due to the civil conflict that was taking place in Aceh and that was particularly severe this year (Freeman & Than, 2002)

Figure 1: Trend in child mortality in Aceh and rest of Indonesia



Instead, in order to reconstruct a valid counterfactual we employ the synthetic control method introduced by Abadie and Gardeazabal (2003) and Abadie et al. (2010). The synthetic control method involves constructing a counterfactual, the synthetic control, for the treated province, Aceh, by taking the weighted average of the unaffected provinces that minimises the root mean squared prediction error (RMSPE). For each outcome, a synthetic Aceh is created so that its pre-tsunami outcome trend mimics the one observed in Aceh province. The effect of the tsunami on child mortality is estimated by comparing the level of outcome in Aceh to the one observed in synthetic Aceh post-tsunami.

There are many advantages of the synthetic control method over others quasi-experimental designs. Unlike matching, the synthetic control is a combination of control units, which provides a better comparison group for the treated unit than a single unit alone. Secondly, because the counterfactual is constructed by using all pre-tsunami years, the method, unlike difference-in-differences, accounts for unobserved heterogeneity that is time-varying (Abadie et al., 2010). In addition, the method allows to assess visually the quality of the counterfactual constructed by looking at the actual discrepancy between the treated unit and the combination of untreated units that provides the counterfactual (Abadie, 2019).

In keeping with the Abadie et al. (2010) model, let the observed outcome for province i in year t be defined as Y_{it} . We define the outcome in province i that has been impacted by the tsunami as Y_{it}^I . We define the outcome for province i that have not been impacted by the tsunami as Y_{it}^N . If there are J provinces not affected by the tsunami, potential synthetic controls, W , would be a weighted sum of control provinces such that $(J \times 1)$ weighting $W = (w_2, \dots, w_{J+1})'$, where w_j is the contribution of each control province to the synthetic Aceh with a positive weight. Note that all of the weighted contributions of control provinces sum to 1.

For this analysis we are concerned with the effect of the tsunami on province i at year t which we will identify as α_{it} . Therefore, the effect of the tsunami for province i at year $t > T_0$ can be defined as $\alpha_{it} = Y_{it}^I - Y_{it}^N$ given that T_0 represents all years before and including 2004. Because Y_{it}^I is observed for Aceh, $i=1$, to estimate α_{it} we simply need to estimate Y_{it}^N .

The synthetic control method choses weights of these donor provinces such that the distance between pre-intervention characteristics and outcomes for the treated district, Aceh (X_1), and for the donor districts (X_0) is minimized. Therefore, the synthetic control for unit i is:

$$\hat{Y}_{1t}^N = \sum_{j=2}^{j=j+1} w_j^* Y_{jt} \text{ for } t > T_0$$

And the effect of the tsunami for Aceh, $i = 1$, is $\hat{\alpha}_{1t} = Y_{1t} - \hat{Y}_{1t}^N$.

Since the synthetic control model minimizes the distance between pre-intervention characteristics and outcomes, the optimal vector W^* is chosen such that the distance between X_1 and $X_0 W$ is minimised, where V minimizes the RMSPE denoted $\hat{\xi}_1$:

$$\|X_1 - X_0 W\|_v = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}$$

Sometimes covariates are included in both X_1 and X_0 in order to minimize the RMSPE. In our case, we chose to use all pre-treatment outcomes values without covariates in the main specification since it is the specification that allows us to apply the SCM on the longest time period and to have the largest number of units in the donor pool. While there is no specific recommendation about the variables that should be used in the SCM in Abadie et al. (2010), there is evidence supporting that different specifications used in synthetic control applications may lead to different results and different conclusions (Ferman et al., 2020). We conduct robustness checks in order to prove that different specifications would not affect our conclusion. Following Abadie et al. (2010), we also use three pre-treatment outcome values alongside covariates using two sets of data sets (IDPR and DHS data). Covariates from IDPR data were only available for 19 provinces and 17 years (1996-2012) and DHS data were available for 25 provinces and 26 years (1992-2017). However given that the inclusion of these covariates led to a large reduction of our panel due to missing data and to a larger RMSPE, we chose not to include covariates in the main results presented. We however present the results when including covariates in Appendix 4.

Composition of the donor pool and characteristics of Aceh are presented in Appendix 5.

In order to test whether the effects obtained are not due to chance, we use placebo tests as defined in Abadie et al. (2010). The placebo tests apply the synthetic control method to each unit of the donor pool. If this distribution in placebo effects denoted $\hat{\alpha}_{1t}^{PL}$ yields gaps as large as the estimated effect of the treated unit, then it is likely that the estimated effect observed in the treated unit was observed by chance. The p-value estimates the proportion of control units that have an estimated effect at least as large as that of the treated unit. The one-sided p-values of post-treatment positive effects are given by $\text{p-value} = \Pr(\hat{\alpha}_{1t}^{PL} \geq \hat{\alpha}_{1t})$. However, it should be noted that placebo effects may be large in the presence of large RMSPE, which will cause p-values to be too conservative. In order to account for this, we adjust $\hat{\alpha}_{1t}$ for the quality of pre-treatment matches. To do this, we divide post-treatment effects by the corresponding pre-treatment match quality \overleftarrow{s}_1 to get a standardized effect measure and report the standardized p-value i.e. the proportion of placebo standardized effects that are at least as large as the main standardized effect for each post-treatment period. Untrimmed placebo tests graphs are

presented in Appendix 6a and trimmed placebo tests graphs in Appendix 6b.

A consideration regarding the composition of the donor pool is its potential contamination. If some units of the donor pool are affected by the tsunami it will lead to an underestimation of its impact and to overestimation of the significance level (p-value). We exclude in all the estimates Aceh's neighbour province, Sumatra Utara, because this province was directly affected by the tsunami as shown in Figure 2 and was indirectly affected by population movement since most Acehnese who left Aceh were displaced to North Sumatra. In addition, one may want to note that at the time of the tsunami, Indonesia had 33 provinces but 7 provinces (West Java, Bangka Belitung, Riau islands, North Sulawesi, South Sulawesi, Maluku and Papua) were created after 2000 i.e. 13 years after the beginning of our child cohort and one province (North Kalimantan) had missing value. This explains why the donor pool contains 24 units.

Figure 2: Number of tsunami related deaths per province

Source: Authors

4 Results

4.1 Descriptive statistics

Descriptive statistics are presented in Table 1. One can note that before the tsunami, child mortality indicators in Aceh were generally lower than in the donor pool. However, in 2005, under-5 mortality in Aceh is as much as twice larger than the one we observe in the donor pool (108 deaths per 1,000 live births in Aceh against 57 in the donor pool). Five years later, we can note that the level of under-5 mortality in Aceh has converged to the level we observe in the donor pool. Average in under-5 mortality rate however hides some important differences in trends between infant and children aged 1-4 years old. Table 1 shows that for children under-1, mortality in Aceh was still greater than the one in the donor pool in 2010 (53 deaths per 1,000 live births in Aceh against 38 in the donor pool) while mortality of children aged 1-4 was lower in Aceh than in the donor pool (0 death per 1,000 live births in Aceh against 14 in the donor pool).

Table 1 also shows a similar pattern observed for causes of mortality than for under-5 mortality.

Namely the fact that before the tsunami, Aceh had lower coverage of assisted delivery, facility-based delivery, tetanus immunisation and access to safe water and sanitation than the donor pool. However, five years after the tsunami, all indicators, except the access to safe sanitation, have converged to the level we observe in the donor pool.

Table 1: Descriptive statistics

	1990		1995		2000		2005		2010		2015	
Indicators	Aceh	Donor pool	Aceh	Donor pool	Aceh	Donor pool	Aceh	Donor pool	Aceh	Donor pool	Aceh	Donor pool
Under-5 mortality per 1,000 live births	65	109	56	73	57	69	108	57	50	47	41	38
Under-1 mortality per 1,000 live births	48	73	34	56	43	49	72	40	48	35	28	27
1-4 year old mortality per 1,000 live births	18	39	22	19	14	20	38	17	1	13	13	12
Assisted delivery from qualified provider (%)	-	-	36	40	-	-	45	51	85	65	87	75
Home-based delivery (%)	-	-	90	78	-	-	78	58	40	44	19	26
Antenatal care from qualified provider (%)	-	-	89	0.91	-	-	88	94	99	95	97	96
Prenatal tetanus injection (%)	-	-	61	73	-	-	41	73	71	74	57	73
Access to safe water (%)	-	-	25	35	27	38	34	46	53	56	63	66
Access to safe sanitation (%)	-	-	46	50	51	55	48	60	59	64	67	73

4.2 Effect on Child mortality

Results of the effect of the tsunami on child mortality are presented in Table 2. The results indicate that the tsunami only led to a significant increase in under-5 mortality in 2004 and in 2005, the year that followed the natural disaster. Results highlight that there is no longer term effect of the tsunami on child mortality.

Results presented in Figure 3 show two distinct peaks in under-5 mortality. The first one that

led to an increase in mortality of 65 deaths per 1,000 live births was observed in 2005 and was explained by an increase in mortality among both under-1 and children aged 1-4.

The second peak, which is of a lower magnitude than the first one, occurred in 2009 and is driven by an increase in mortality of children under-1. Infant mortality increased by 27 deaths per 1,000 live births in 2009 and by 31 deaths per 1,000 live births in 2010. These effects are large since this represents an increase in mortality close to 150% in comparison to its level in 2003. Over the same period, the tsunami is found to have led to a statistically significant reduction in mortality of children aged between 1 and 4 years old. This reduction of 15 deaths per 1000 live births in 2011 represents a reduction of 65% in child mortality in comparison to its level in 2003.

Table 2: Effect of the tsunami on child mortality indicators

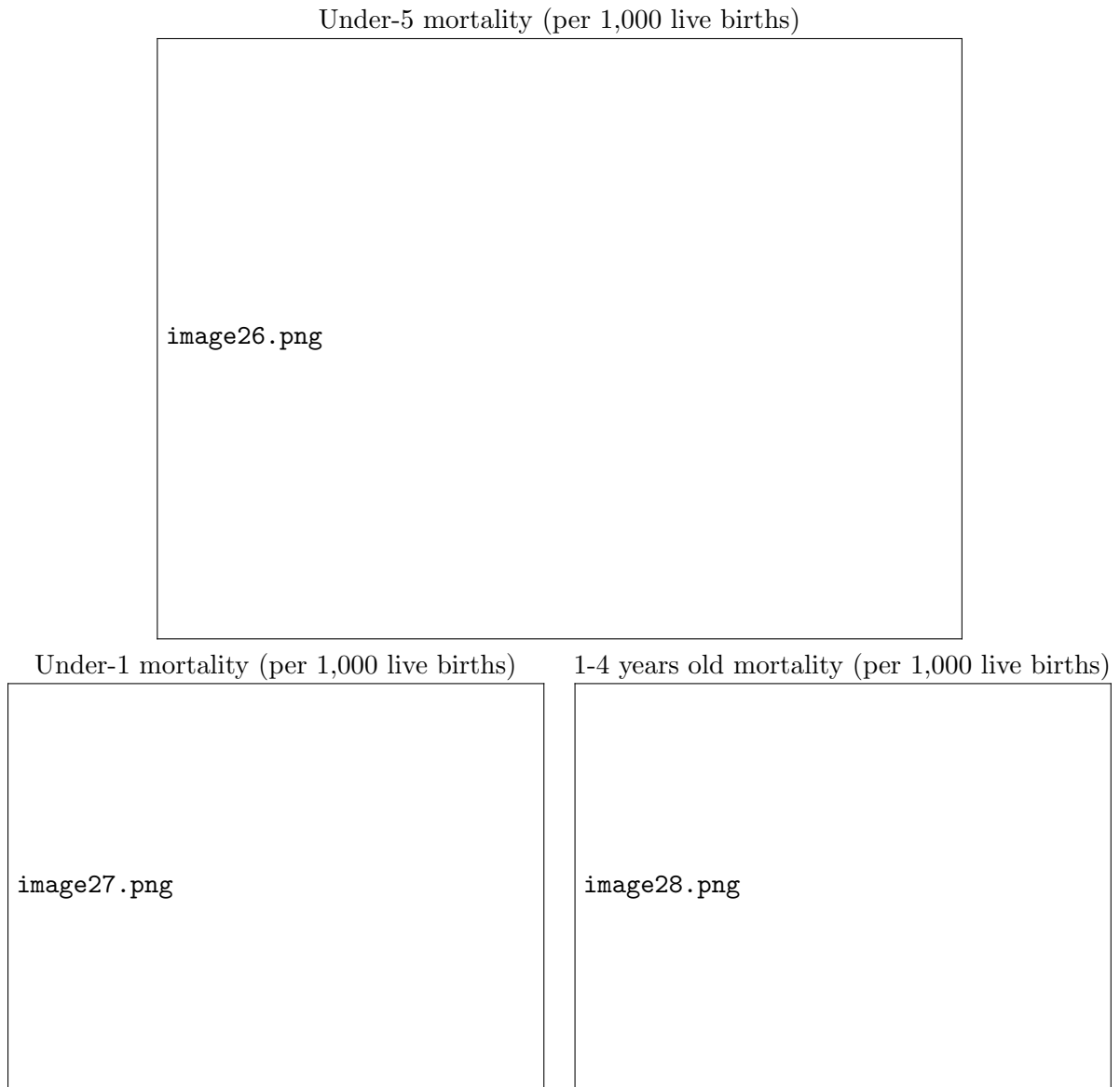
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Under-5 mortality	54.837***	64.969***	16.379	7.181	-11.691	24.508**	9.989	-3.604	3.214	-1.125	-5.212	16.579	-2.026	-9.209
Under-1 mortality	36.249***	45.269***	22.318	15.885	-12.243	27.170***	31.020*	16.612	7.595	5.093	-5.403	12.800	-0.560	11.712
1-4 year old mortality	12.351**	12.189	-0.436	-6.763	-6.362	-11.408	-16.141	-15.439**	-14.367**	-4.314	0.605	-0.564	-2.397	-16.176

Notes: The tables report the effects of the tsunami on child mortality indicators measured by the difference in level in the treated unit and in the synthetic control. P-values are estimated by calculating the proportions of placebo standardized effects that are at least as large as the main standardized effect for each post treatment period.

The donor pool includes 24 provinces.

Donor pool composition and RMSPE are presented in Appendix 5 and placebo test in Appendix 6.

Figure 3: Synthetic control for estimation of the effect of the tsunami on child mortality



4.3 Causes of child mortality

Information collated from IHME on the main causes of death show that in 2005 the main causes of deaths among children under-5 were diarrhoeal diseases and lower respiratory diseases, accounting, respectively, for 19% and 17% of total deaths. In 2009, these two disease groups were also the main causes of deaths among children under-1, accounting, respectively, for 30% and 19% of total deaths. Lower respiratory diseases and diarrhoea are multifactorial diseases that are mainly the result of poor environmental conditions. Conversely, neonatal birth complications were the main cause of death among neonates. In order to investigate the effect of the

tsunami on several causes of child mortality, we estimate its impact on the place and assistance during delivery at birth, antenatal care, prenatal tetanus injection, access to safe water and sanitation.

Results presented in Table 3 and Figure 4 show that overall the tsunami improved intermediary child health indicators in the medium term. For example, there is a significant increase in the proportion of assisted delivery in Aceh from 2007. In addition, there is an increase in antenatal care coverage in the medium term. Results also highlight a large increase in tetanus injection and a reduction in the proportion of mothers who deliver at home, although those effects are not statistically significant.

Conversely, results also highlight the detrimental effect of tsunami on vital systems. We show that the tsunami led to a statistically significant decrease in the access to safe water and sanitation the years that followed the tsunami.

While those results can provide some justifications for the observed short term increase in child mortality and the reduction of child mortality of older children in the medium term, the increase in mortality observed among under-1 in 2009 and 2010 remains unexplained.

Table 3: Effect of the tsunami on the causes of deaths

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Assisted delivery from qualified provider (%)	0.043	0.021	0.007	0.151*	0.134	0.269**	0.242***	0.156	0.167	0.123	0.138	0.126	0.063	0.155
Home delivery (%)	0.063	0.033	-0.006	-0.082	-0.0871	-0.072	-0.149	-0.059	-0.143	-0.098	-0.086	-0.151	-0.233	-0.211
Antenatal care from qualified provider(%)	-0.050*	-0.034**	0.038*	0.024	0.043	0.071***	0.084**	0.044*	0.084**	-0.005	-0.005	0.045**	0.041*	0.062*
Prenatal tetanus injection (%)	-0.050	-0.200*	0.013	-0.070	0.132	0.153	0.153	0.167	0.108	0.103	0.019	-0.013	0.064	0.092
Access to safe water (%)	0.054	-0.045	-0.051	-0.074	-0.067	-0.008	0.005	0.043	0.026	0.030	0.004	0.024	0.041	0.051
Access to safe sanitation (%)	0.028	-0.085*	-0.110***	-0.066	-0.019	-0.017	-0.018	-0.029	-0.030	-0.047	-0.042	-0.051	-0.044	-0.044

Notes: The tables report the effects of the tsunami on intermediary health indicators measured by the difference in level in the treated unit and in the synthetic control. P-values are estimated by calculating the proportions of placebo standardized effects that are at least as large as the main standardized effect for each post treatment period.

Figure 4: Synthetic control for estimation of the effect of the tsunami on causes of child mortality

Assisted delivery at birth (%)	Received antenatal care (%)
Home-based delivery (%)	Tetanus immunisation before birth (%)
Access to sanitation (%)	Access to safe water (%)

4.4 Robustness checks

We conduct several robustness checks. Firstly, we remove DI Yogyakarta from the donor pool given that this province was affected by an earthquake in 2006.⁷ By doing so we obtained close results but the quality of the synthetic control constructed was not as good given that this unit accounts for a large weight for several child mortality outcomes.

Gray et al. (2014) estimate that two-thirds of individuals who were living in severely affected area at the time of the disaster moved in the four months that followed the tsunami. Population displacement and returns may affect per capita health outcomes in the donor pool, hence it is important to ensure that effects on child mortality are not driven by migration patterns. We show in Table 4 that our results are not driven by changes in the population growth in the donor pool. More specifically, Figure 5 shows that the increase in population growth that occurred after the tsunami was not attributable to displaced populations coming back to Aceh, since there was an increase in population growth in the rest of the country. In addition, it is apparent that since 2007 population growth remains steady in both Aceh and its synthetic control.

The changes in government spending allocations may also potentially have been caused by the large influx in aid to central government and might have resulted in a reallocation of funds from other provinces towards Aceh. It is crucial to argue that an absence of effect is explained by Aceh's resilience rather than by a degradation in outcomes in the donor pool. We further identify in Table 4 and Figure 6 that although there was a noteworthy increase of per capita health and infrastructure function expenditure in Aceh, this did not occur at the expense of other Indonesian provinces. One may want to note that the increase in function expenditure did not come from aid relief because deconcentration funds, emergency funds, and reintegration of

⁷ Results are available from authors upon request.

GAM funds were first channelled through Indonesian National Board for Disaster Management before being channelled through the Rehabilitation and Reconstruction Agency and do not seem to have been recorded in regional budgets.

The peace accord provided Aceh special autonomy status and new legislation on the governing of Aceh which provided additional revenue from central government general allocation funds and an increased share of own source revenue from a change in the revenue-sharing arrangements of oil and gas revenue (World Bank 2009, World Bank 2008, World Bank 2006). These additional funds were meant to increase revenue and public spending in order to improve infrastructure, education, health and social programs. Additionally, Aceh saw an increase in their province tax revenue with the ending of violence, which previously had prohibited local government from collecting taxes and “increased economic activity generated by the influx of tsunami aid money into the local economy” (World Bank, 2006). Hence, this result suggests that the peace accord and subsequent changes to local government budgets led to an increase in government spending but did not take away central funding received by non-affected provinces.

In addition we provide a series of purely methodological robustness tests as suggested in Abadie, 2019. We first test the absence of anticipation effect by running our estimation while backdating the tsunami 5 years before its actual date (1999) and present results in Appendix 7a. The fact that the estimated effect of the tsunami appears after 2003 even when the event is artificially backdated in the data provides credibility to the synthetic control estimator of the tsunami and confirm absence of anticipation effect. In addition, we investigate how results are influenced by the choice of units in the donor pool. To do this, we conduct leave-one-out re-analysis taking from the sample one-at-a-time each of the Indonesian provinces that contribute to the synthetic control. Results of the leave-one-out re-analysis are presented in Appendix 7b and show that all leave-one-out estimates closely follow mortality indicators before the tsunami. The results are all consistent with results produced using the full donor pool.

Table 4: Long-term effect of the tsunami on population growth, health and infrastructures spending

	2004	2005	2006	2007	2008	2009	2010	2011	2012
Population growth (%)	-0.037	-0.034	-0.012	0.000	-0.001	-0.001	-0.001	0.006	0.004
Health Function expenditure per capita in IDR ⁸	-5,365	-7,287	-9,318	5,957	30,570	75,066*	88,958	105,950	104,419
Infrastructure Function expenditure per capita in IDR	5,491	-15,004	-2,053	71,589	355,985**	558,843***	386,903***	277,323*	305,956*

*Notes:*The tables report the effects of the tsunami on indicators measured by the difference in level in the treated unit and in the synthetic control. P-values are estimated by calculating the proportions of placebo standardized effects that are at least as large as the main standardized effect for each post treatment period.

Figure 5: Pre- and post-tsunami trends in Aceh and its synthetic control for population growth

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Figure 6: Pre- and post-tsunami trends in Aceh and its synthetic control for government expenditures per capita

Health function expenditure (IDR)

Infrastructure function expenditure (IDR)

5 Discussion

Our paper makes use of the inability to forecast earthquakes and the existence of a large control group to reconstruct a valid counterfactual using the synthetic control method to estimate the effect of the 2004 tsunami on child mortality in Aceh province. We find that while there was no long term effect of the Indian Ocean tsunami on child mortality, it affected all children the year that followed the tsunami. Our results however highlight different patterns of mortality for different age groups. We find that the tsunami reduced mortality among children 1-4 years old in the medium term but increased mortality of younger children over the same period.

We showed that the increase in child mortality in 2005 is likely to be explained by a degradation in access to safe water and sanitation. In contrast, the investigation of the causes of mortality for children under-1 observed in 2009 and 2010 did not provide a clear explanation of the causes of death since there was no evidence of any deterioration in prenatal care and delivery. Selection into childbearing could also have longer term impact on child mortality. For instance it has been shown that the increase in fertility observed after the tsunami was driven by women who lost a child in the disaster and by women who did not have any children before the disaster (Nobles et al. 2014). While there is no available evidence regarding the characteristics of the second group, it has been shown that socio-economic factors did not explain much the probability of dying among women of childbearing age (Frankenberg et al., 2011). As a result, it is unlikely that the second peak in mortality observed among infants post-tsunami is due to selection into childbearing. While we cannot explicitly test for the reason of the delayed increased in mortality among the youngest children, the timing coincides with the end of aid relief. The results highlight that despite increase in assisted delivery, antenatal care and tetanus immunisation, there was an increase in infant mortality when international reconstruction projects ended. The World Bank 2009 reports highlights the effect on the end of aid on macroeconomic indicators by stating that “growth in Aceh’s non-oil and gas declined sharply in 2008 as the reconstruction efforts winds down. As many reconstruction actors (NGOs, GOI) wind down or significantly scale down their operation in the province, sectors linked to the reconstruction effort that had led to growth in Aceh since 2005 registered low or negative growth” (World Bank, 2009a). Hence, the most likely explanation for the increase in mortality among infants in the medium term is the decrease in quality of care resulting from the end of aid projects.

The decrease in mortality among older children in the medium term coincides with improvement in environmental factors. However, this result could also be explained by an ‘harvesting’ effect, namely the fact that if the tsunami killed the most vulnerable children before the age of 1, this selection in mortality may lead to a decrease in mortality later on among children of this age cohort and could explain the decrease in mortality observed later on among children aged between 1 and 4 years old.

The main limitation of our analysis relates to the potential contamination of the donor pool due to misplaced populations. For instance, if those with high morbidity were more likely to leave Aceh because of the tsunami, the effect of tsunami on morbidity would be underestimated. However, Gray et al. (2014) finds that a small proportion of total Acehnese families left their pre-tsunami home by April 2005 and that few were displaced from their community to Sumatra Utara, which we have excluded from the donor pool. Additionally, the analysis of population shows little difference in population between Aceh and the counterfactual over time and that there was no large increase in population in the counterfactual post-tsunami, which would have signalled a migration effect away from Aceh to donor pool provinces.

There is also little concern of aid funds contaminating the donor pool since many international relief agencies directly provided services in Aceh instead of funnelling aid through the local or national government. In fact, the Aceh government created a non-political body which was responsible for coordinating local reconstruction efforts with the help the Multi-Donor Fund to channel aid funds. This effort was revered as highly successful at retaining aid commitments and ensuring their effective local use (Masyrafah and McKeon, 2008). Furthermore, the analysis shows that the counterfactual, consisting of the donor provinces, did not have an abnormally large increase in government expenditure after the tsunami. This suggests that aid did not create an exogenous increase in government health budget across donor provinces.

The final hypothesized limitation of our findings is the possibility that the results are overestimated given the potential of a shift in central government funding due to the 2005 peace accord. More specifically, the peace accord gave Aceh province a larger percentage of its oil and gas revenues, previously kept by the central government (World Bank, 2009b, Shah and Cardozo, 2014). This dramatically increased Aceh’s local government budget, which was used for investment in local services (Shah and Cardozo, 2014). If the central government previously

dispersed these oil revenue funds to other provinces, and then post-peace accord may have taken these funds away from the donor provinces, so that the shift in donor province budgets would degrade the donor pool health function expenditure and possibly influence health outcomes. If a change in donor province government budgets is not exogenous, but targeted and reallocated from donor provinces to Aceh province, then the tsunami treatment effects would be overestimated.

Another limitation is the fact that information on child mortality is reported by the mother in DHS. It is likely that mothers who had children who died during the tsunami also died and this could explain why our results should not be used to estimate the number of children who died during the tsunami in 2004.

6 Conclusion

Each year there are over 300 natural disasters globally, resulting in millions of victims and economic losses near USD\$100 billion. With the increase incidence in climate variation and intensity of natural disasters, understanding the impact of these shocks on population health is vital to improve resilience of health systems. We investigate the effect of one the deadliest natural disasters in history and find that the disaster increased child mortality immediately after the tsunami. However, we show mixed evidence of the combined effect of such disaster on child mortality in the medium term since children were affected differently depending on their age. Our systematic literature review identified several transmission channels in the Indonesian context through which the tsunami may have impacted child health. While we were not able to disentangle these impacts empirically, the review confirmed that the response to this disaster was complex and that the coordinated international aid played an important role in the reconstruction process in Aceh.

6.1 Appendix 1: Literature review method

The literature search focused on two elements, searches that would return articles that focused on direct health outcomes post-tsunami and articles that would illuminate hypothesized pathways to longer-term health effects. Below are the search strings and results of each of the two searches.

Table 5: Search strategy: short term effect

Health outcomes search string		
Health AND	Tsunami AND	Indonesia
health OR sanitation OR water quality OR assisted deliver* OR birth OR morbidity OR mortality OR health expenditure OR health ADJ2 spending OR mental health OR medicine OR health ADJ2 outcome* OR access to care OR health ADJ2 impact* OR health seeking behaviour OR health seeking be- havior OR hospital* OR nurse* OR out of pocket payment	tsunami OR earth- quake OR natural disaster* AND 2004	Indonesia* OR Aceh OR Sumatra OR Sumatera Utara OR Nanggroe OR Banda Aceh
Health Outcomes Database Search Results		
Database	Date	No. Results
Medline/PubMed	June 2017	26
EMBASE	June 2017	31
Global Health	June 2017	12
Scopus	June 2017	5
Web of Science: Core Collection	June 2017	151
IBSS	June 2017	22
Social Policy and Practice	April 2017	0

Table 6: Search strategy: medium and long term effect

Pathways to long-term health outcomes search string		
Factors of Interest AND	Tsunami AND	Indonesia
religion OR Islam OR civil-war OR conflict OR aid OR donation OR govern* OR economy OR economics OR society OR welfare OR development OR growth OR innovation OR re-construction OR investment OR relief OR corruption OR trauma OR poverty	tsunami OR earthquake OR natural disaster* AND 2004	Indonesia* OR Aceh OR Sumatra OR Sumatera Utara OR Nanggroe OR Banda Aceh
Pathways to Long-Term Health Outcomes Database Search Results		
Database	Date	No. Results
Medline/PubMed	June 2017	73
EMBASE	June 2017	82
Global Health	June 2017	37
Scopus	June 2017	18
Web of Science: Core Collection	June 2017	531
IBSS	June 2017	170
Social Policy and Practice	April 2017	4

Once the articles were collected from the two searches they were subjected to title and abstract review from which it was decided that if they met inclusion criteria they would be kept in the review. Once articles were selected for inclusion only those that were able to be accessed in full text were used for the review.

Figure 7: Study flow diagram

6.2 Appendix 2: Literature review results

6.2.1 Negative effect

Author/ Add institution	Study Type	Method	Population/ Study Size	Modifying Factor	Outcome of Interest	Correlation or causal effect
Guha-Sapir et al. (2007)	Peer reviewed analysis of patterns of disease after tsunami	Cross-sectional record study of Red-Cross field hospital	1,188 Aceh resident records January 15-31	Limited care seeking behaviour	Morbidity	Odds of chronic vs acute disease increased by 16.4% per day (95%CI 7.8-25.6) until the 23 rd and decreased 13.1% after (95%CI 6.6-19.1) signalling a delay in care for acute conditions that have negative implications for long-term health
De Jong et al. (2005) Written for Medecins Sans Frontieres	Field report in peer reviewed journal	Observations from field workers	Medical, logistical, water/sanitation and mental health teams using rapid assessments	Cultural views of mental health	Morbidity	Negative association
Doocy et al. (2009)	Peer reviewed demographic survey collection and analysis	Surveys of mortality and injury impact	Three surveys across districts in Aceh with 7310 households	Location, demographics	Injury, morbidity, mortality, care seeking behaviour	Odds of mortality 1.41% (95%CI 1.27-1.58) times greater for women, Odds of injury 0.81(95%CI 0.61-0.96) for women. Highest mortality 23.6% (95% CI 17.8-29.4 in west coast versus 5.3% (95% CI 1.3-8.0 east coast.
Jeremijenko et al. (2007)	Peer reviewed tetanus outbreak summary	Standard reporting and active case finding report	Clinical review in 8 hospitals in Aceh	Limited immunization, illness, poor access to care	Morbidity, mortality, child health	Mortality rate 19%, projection that limited care was a result of inability to reach a hospital leading to negative morbidity/mortality outcomes
Pascapurnama et al. (2016)	Peer reviewed systematic literature review of tetanus outbreaks	Systematic literature review of PubMed, WHO website and books	16 publications reviewed	Poor access to care and low vaccination	Morbidity, mortality	Positive association between limited access to health care facilities and case fatality ration (18.9%)
Redwood-Campbell and Riddez (2012)	Peer reviewed description of post-disaster illness and casualty	Prospective reporting of depression and Post-traumatic Stress Disorder screening in Red Cross field hospital	5 day review of 271 patients registered in ICRC hospital in Banda Aceh	Limited access to mental health care	Morbidity	24% of patients had at least 4/7 depression/PTSD symptoms yet 1.4% received mental health diagnosis. Study authors report that there is a need for better assessment and mental health response
Gupta et al. (2007)	Peer reviewed study of factors associated with water contamination	Water quality sampling and survey to households about water storage	Survey of 1,127 households in Aceh Besar, Simeulue and Nias	Poor water quality and sanitation	Morbidity	Found improved water sources and handling was associated with decreased risk of contamination. Author notes relationship between water quality and morbidity but does not test morbidity
Patunru (2015)	Peer reviewed analysis of Indonesian progress towards meeting millennium development goals	Multivariate logistic regression analysis of WHO and UNICEF data	N/A	Poor water quality and lack of improved sanitation infrastructure	Morbidity	Individuals without access to improved sanitation infrastructure have 1.27 [CI 1.25; 1.29] times the risk (27 percent higher chance) of having diarrhoea

Athukorala and Re-sosudarmo (2005)	Peer reviewed economic impact and disaster management report	Review of past disasters and response, Impact assessment of 2004 tsunami		Socio-political instability, constrained information sharing, poor infrastructure	Limited disaster response, morbidity	Suggested association
Webb (2005)	Peer reviewed account of food and nutrition assessment teams experience in Aceh	Emergency needs assessment conducted by UN agencies with the Indonesian Government	Non-statistically representative of population, 30 locations reviewed	Poor nutrition access	Morbidity, mortality	Authors suggest that “there was a danger of major loss of life in the absence of [food] interventions”
Agustini et al. (2011)	Peer reviewed analysis of association between trauma exposure and persistence of PTSD symptoms	Child Post-Traumatic Stress Reaction Index survey & Traumatic Exposure Severity Scale	482 11-19 year old tsunami survivors in Aceh	Trauma exposure, mental health, parental mortality	Morbidity	Positive association between trauma exposure and persistence of PTSD symptoms 4.5 years later
Frankenberg et al. (2008)	Peer reviewed analysis of correlation between PTSR and tsunami exposure intensity	Survey analysis of Post-Traumatic Stress Reactivity interviews before and after tsunami	20,500 adults from Aceh and North Sumatra 5 to 17 months after tsunami	Tsunami exposure	Morbidity (mental health)	As distance from coast increased, PTSR scores decreased indicating better mental health. Distance from coast (KM) -.02 in PTSR score (95%CI -.03-.01)
Frankenberg et al. (2013a)	Unpublished manuscript investigating the effect of tsunami on child height	Multivariate linear regression comparing height of cohorts in utero at tsunami to an older cohort	4,170 children in Aceh	Tsunami exposure	Morbidity (child height)	Children exposed to tsunami in utero have a lower height of one third than children born 3-4 years earlier.
Frankenberg et al. (2012)	Peer reviewed analysis of traumatic stress	Multilevel linear regression model with satellite mapping and informant interviews	27,624 STAR respondents from Aceh and North Sumatra. Additional 16,709 of these were interviewed.	Community destruction	Morbidity (post-traumatic stress)	1-point increase in exposure to tsunami is associated with .81 increase in PTSR score. Community destruction worsens stress reaction.
(Frankenberg, 2007)	Peer reviewed analysis of the condition of public services after the tsunami	Descriptive statistics	Community and facility characteristics located in the 591 villages targeted by STAR	Tsunami exposure	Morbidity (health services)	High destruction of health services after the tsunami.
Irmansyah et al. (2010)	Peer reviewed analysis of determinants of psychological morbidity after tsunami	Multiple linear regression analysis of self-reported questionnaire of disaster exposure and measure of resilience	783 people in Aceh both displaced and non-displaced.	Displacement, tsunami exposure	Morbidity (mental health)	Each increase in impact level had .416 increase in predicted SRQ-20 score of post-traumatic stress symptoms IDP status had .324 increase in predicted score.
Lee et al. (2015)	Peer reviewed analysis of causes of impairment in tsunami-exposed children	Multivariate linear modelling of predictors of impairment using Brief Impairment Scale	138 displaced and non-displaced Acehnese children	Displacement distance	Morbidity (mental health)	Displacement distance predicted impairment, one KM of displacement increased interpersonal subscale score by .213 points (.0335-.393, p=.026) and impairment by .149 points (.015-0.282, p=.033)

Guha-Sapir and van Panhuis (2009)	Peer reviewed analysis of infection disease and injury consequences of tsunami	Epidemiological profile of disease survey before and after tsunami using field hospital records and historic records		Illness	Morbidity	Negative association observed between increased instance of wounds mixed with lack of vaccination in Aceh against tetanus and tetanus infections leading to increased morbidity
Schwab et al. (2016)	Peer reviewed assessment of preterm deliveries associated with infection	Wet mount microscopy	159 women screened from Banda Aceh in February-June of 2005 post-disaster	Stress, demographics	Morbidity	Study found higher than normal pre-term delivery in this population which they suspect high levels of stress was a risk factor in negative birth outcome
Urlainis et al. (2014)	Peer reviewed literature review of extreme weather events	Literature Review of extreme events impact on critical infrastructure and review of strategies and their implementation	8 events, including the 2004 Indian Ocean tsunami	Lack of pre-warning system	Morbidity	Author states that appropriate disaster alert systems and preparation could have reduced loss of life and that critical infrastructure was destroyed because of poor design and consideration of tsunami possibility
Hayat and Amaratunga (2014)	Peer reviewed analysis of political factors influencing governance and road development post-disaster	Semi-structured interviews with infrastructure stakeholders	Road infrastructure stakeholders (n=28) in 4 districts in Aceh	Corruption and governance	Road maintenance and infrastructure	Perceived negative impact of corruption and governance on infrastructure repair
James (2006)	Australian National University report on corruption: discussion paper	Discussion		Corruption in aid, weak governance, rapid decentralization, civil conflict	Infrastructure	Theorizes negative association
Jayasuriya and McCawley (2008) for Asian Development Bank	Working paper examining aid delivery and reconstruction after tsunami	Comments on aid delivery arrangements and challenges of designing reconstruction program with recommendations		Poor aid quality leading to increased cost of labour, cost increase in construction goods, lack of local participation in reconstruction	Infrastructure, poverty alleviation	Discussed negative association (hypothesized?)
Jayasuriya and McCawley (2010).	Book reviews tsunami situation and aftermath for Asian Development Bank	Literature review of disaster policy response and economic theory		Aid coordination, labour market changes, local participation in reconstruction, weak governance	Infrastructure	Theory of negative association

World Bank (2005)	Situation report conducted by BAPPENAS, the Indonesian Government and international donors	Collection of reports	N/A	Tsunami Impact	Mortality, infrastructure, health systems	Negative impact on mortality, health system capacity, infrastructure (exact detail reported throughout text of paper)
World Health Organization (2005)	WHO news release	Situation analysis of tsunami recovery process		Tsunami impact	Infrastructure and health system capacity	Negative impact observed (details reported throughout text of paper)
Ichwan (2011)	Peer reviewed analysis of Islamic Law in Aceh	Authors analysis of legal proceedings and political process		Influx of aid	Culture	Author finds that the introduction of new religious groups via aid efforts changed local religious interpretations of Islam
Adiyoso and Kane-gae (2013)	Peer reviewed qualitative study	In-depth interviews and direct observation	6 Students and 8 community members from Banda Aceh	Religious education, culture and disaster education	Disaster preparedness : Mortality	N/A
Chang-Seng (2013)	Peer reviewed institutional-oriented analysis framework	Analysis of institutions and governance related to development of a tsunami early warning system		Civil conflict, rapid decentralization in governance, culture	Disaster preparedness and response—mortality	Suggested association weak institutions were a result of civil conflict and decentralization of government which lead to limited disaster response capacity
Grayman (2014)	Peer reviewed ethnographic case study	Analysis of email archives between aid organization and medical staff		Poor aid quality and poor communication between aid and health staff (culture)	Health system quality	Author hypothesizes negative association between use of electronic communication and patient outcome
Ismail et al. (2016)	Peer reviewed assessment of disaster preparedness	Household descriptive survey	Surveyed 827 random households in Aceh province	Disaster preparedness, culture	Mortality	26% of participants had good knowledge of disaster preparedness after the tsunami, far below the 70% target which is hypothesized to have had a negative effect on tsunami outcomes
Lovholt et al. (2014)	Peer reviewed analysis of tsunami risk reduction 10 years after the tsunami	Vulnerability assessment	Indonesia and Sri Lanka	Culture and disaster preparedness governance (tsunami awareness, income and employment, ethnic group)	Mortality	Concludes that improvements in preparedness have been made implying that previously cultural and governance factors hindered prevention

Marthoenis et al. (2016)	Peer reviewed literature review of mental health services in Aceh	Review of published and unpublished literature pertaining to mental health in Aceh.	Medline search, limited results prompted use of media reports and google scholar	Cultural views of mental health, limited access to care, lack of political will to develop mental health services	Mental health	Mental health systems have improved since before the tsunami, implying these factors limited mental health system capacity and infrastructure leading to poor tsunami outcomes. Stigma, limited access to care and political fluctuations still hinder mental health system development.
McNicol (2011)	Peer reviewed historical account of conflict, economics, demographics and culture's influence on development in Indonesia vs. Nigeria.	N/A		Culture	Understanding of illness, infertility and health seeking-behaviour	Primordial beliefs have negative impact on health seeking-behaviour, yet this is waning as acceptance of clinical medicine has spread over time
Meilianda et al. (2017)	Peer reviewed analysis of perceptions of recovery efforts	Qualitative analysis of focus group discussions using mind mapping analysis	Beneficiaries and actors involved in rehabilitation in Banda Aceh with 5 sessions of 80 different participants	Community perceptions of the tsunami recovery process and aid (culture?)	Mental health	Participants felt that aid and revitalization improved mental health infrastructure and programs since very little was available pre-tsunami and they felt recovery efforts improved governments attention to improving mental health infrastructure and programing.
Shah and Cardozo (2014)	Peer reviewed analysis of educational system and social transformation in Aceh	Cultural, political and economic framework analysis	N/A	Shifts in government budgets and decentralization following peace agreement	Culture	Peace accord brought changes to budget for education and lead to islamafication of local education
Smith (2015)	Peer reviewed personal account and survey summary	Ethnographic semi-structured interviews	Author's connections in Aceh	Perceptions of health system quality due to civil conflict (culture)	Care seeking behaviour	Author finds association between mistrust of local doctors because of civil conflict and care seeking behaviours of Acehnese
Daly (2015)	Peer reviewed qualitative interviews	Semi-structured in person qualitative survey and interview	20 aid workers in Aceh both international and Acehnese	Religion, cultural practices, lack of capacity of local institutions from civil conflict, poor engagement of local institutions by external agency	Effectiveness of aid	Negative association was perceived

Thorburn (2009)	Peer reviewed analysis of recovery program impact	Program evaluation	N/A	Aid	Household income, economic re-development	Almost three years after tsunami, many households returned to pre-tsunami income levels which the author attributes to food aid and subsidies, work programs and livelihood assistance programs. Conversely, many business start-up programs and agriculture programs had mixed results as the author observes that economic development program was supply-driven, not needs based.
Doocy (2007) for the World Health Organization	Tsunami mortality report	Two-stage cluster survey of tsunami-displaced households	Surveys of 1653 households across Aceh	Location, demographics	Mortality, population	Highest mortality in 0-9yo and 70+yo, mortality highest in the west vs. east
Frankenberg et al. (2011)	Peer reviewed analysis of correlates of survival	Analysis of population level survey data with measure of damage by location	43,606 respondents living in Aceh and North Sumatra before and after tsunami	Demographics, location	Mortality	Children, older adults and females least likely to survive. Mortality highest in those living within 5KM of coast (1 in 20 died), within 1KM of coast (1-2 children and females (15-44yo) died and (7 of 10 older women died). Men 15-44yo (1 in 4 died).
Rofi et al. (2006)	Peer reviewed analysis of demographic impacts of tsunami and assessment of displaced households	Household survey clustered by internally displaced person households and multivariate regression model for risk of death analysis	Survey of 20 clusters across Aceh Barat and Naga Raya including 388 households	Location, demographic characteristics	Mortality	Mortality risk of females 1.9 [CI 1.5-3.0] times greater than males, children under 10 and adults over 60 had 2.3 [1.6-3.4] and 3.1 [1.9-4.9] times the risk of mortality, fisheries based households were 2.2 [1.2-11.4] times more likely to have a household member die, of those IDP household who settled, 91.7% [88.6-94.2] remained in the same district
Rassekh and Santosham (2014)	Peer reviewed assessment of care-seeking practices in IDP's living in barracks and non-IDP's living in their homes	Cross-sectional cluster sampling with stratification and multiple logistic regression analysis	31 clusters of barracks and non-IDP neighbourhoods with 1295 observations	Maternal mortality and displacement status	Care seeking behaviour, child health	Mother caretakers had 1.88 [CI 1.04; 3.40] times the odds of seeking formal care for their sick children and those who were not displaced had 2.7 [CI 1.38; 5.44] times the odds of seeking formal care for their sick children
Du et al. (2012)	Peer reviewed analysis of children's' fears and psychological experience since the tsunami	Multivariate logistical regression analysis of interviews with displaced families	155 child and parent dyads from barracks and comparison village within 1KM of barrack	Displacement and residence in barracks	Mental health	Children from barracks were three times more likely to report fear than children from villages Odds ratio of 2.97(95% CI 1.00-8.85).
Fan (2006) for the World Bank	Analysis of land rights policy			Governance, religion	Housing quality and poverty disparities	Perception that unequal land rights because of cultural, religious, and legal precedents has a negative impact on economic development, poverty and infrastructure

6.2.2 Positive effect

Author	Study Type	Method	Population/ Study Size	Modifying Factor	Outcome of Interest	Correlation or causal effect
Chan et al. (2010)	Peer reviewed field report published in WHO bulletin	A balanced scorecard was created and used to identify and assess performance targets	7 clinics and 9 accommodation centres across Aceh in 2007	Aid quality and assessment	Quality of health infrastructure	Positive association
De Pee et al. (2007)	Peer reviewed program evaluation in bulletin of UN university	Descriptive analysis and program evaluation	104,691 children 0-12 in transitional camps in Aceh in Nias between January 2005 and April 2006	Food aid	Nutritional status and health status of children	Authors correlate food aid to reduced anaemia and diarrhoea prevalence
Doocy et al. (2006) for Mercy Corp	Peer reviewed description and discussion of program evaluation	Review of monitoring data and staff exit interviews	1,428 randomly selected Cash-for-Work program participants in Banda Aceh and Meulaboh	Cash for work programs (aid)	Household economics and post-disaster economic recovery	Positive association
Heger (2016)	PhD dissertation	Synthetic control analysis of economic outcomes post-tsunami	Analysis range in number of districts in Aceh used	Capital investment and aid	Economic Development	GDP in districts with the most aid surpassed the counterfactual across all models even after aid ended signalling creative destruction effect
Lee et al. (2014)	Peer reviewed impact assessment of aid	Cluster community survey; multiple linear regression analysis	598 households in Banda Aceh and Meulaboh surveyed	Aid	Development-vulnerability reduction, poverty	Standard of living, education and health facility satisfaction increased significantly after tsunami believed to be a result of receiving aid
Masyrafah and McKeon (2008) for Brookings Institute	Aid effectiveness report	Analysis of types of aid given, amounts of aid, pledged vs. dispersed	N/A	Aid	Development-vulnerability reduction	Aid has positive impact on sanitation, health facilities, resource repair
Prasetyawan et al. (2006)	Peer reviewed description and commentary on proliferation of mental health training	Description and commentary on the reach of mental health programing	Program administered to 168 GP's and 277 nurses in Aceh and Sumatra Utara	Professional development programs administered after the tsunami, aid	Improved diagnostic and treatment practices for mental health	Author notes lack of mental health services pre-tsunami and the positive results of professional development and mental health capacity improvement to improve mental health care
World Health Organization (2015)	Book of lessons learned and strategic planning for the future of South East Asia	Compilation of various reports and findings post-tsunami	N/A	Disaster response, aid	Long-term recovery	Book emphasizes the importance of health on long-term disaster recovery and highlights positive responses and lessons learned
Chang-Seng (2013)	Peer reviewed analysis of disaster risk preparedness	Governance concept and framework conditions institutional analysis	N/A	Improved disaster governance	Improved tsunami resilience	Author concludes that learning from the tsunami has changed disaster governance structures which will improve future resilience

Syamsidik et al. (2017)	Peer reviewed review of disaster governance 10 years after the tsunami	Survey of government employees and legislation	245 respondents from Aceh based organizations	Governance strengthening	Vulnerability reduction	New guidance around disaster preparedness and improved confidence of local stakeholder in policy has improved integration of disaster risk maps with development planning for future risk reduction
Beardsley and Mc-Quinn (2009)	Peer reviewed model for understanding insurgent groups motivation and use of conflict	New typology proposed	Indonesia and Sri Lanka	Estimated return on investment, dependence on foreign relief aid	Behaviour of GAM, civil conflict	GAM was incentivized to foster peace and end conflict for their perceived longevity
Gaillard et al. (2008a)	Peer reviewed framework analysis of factors to securing peace	Review of disasters, conflicts and diplomatic responses	Aceh and other country case studies	Tsunami, pressure from international aid organizations	Conflict resolution	The disaster played a positive role in encouraging peace talks, author proposes that aid and international pressure were an even greater catalyst for the ending of civil conflict for the GAM
Achmad et al. (2015)	Peer review analysis of change and factor effecting land use	Land use geo-spacial mapping	Banda Aceh 2005-2009	Population density and location of business center	City growth	Built up areas in Banda Aceh increased 90% and were positively impacted by population density and business center growth
Cas et al. (2014)	Peer reviewed analysis of correlation between parental death and children's wellbeing	Ordinary least squares regression with fixed effects	9-17 year olds living in coastal communities n=737	Parental mortality	Child wellbeing	If both parents died, 9-14yo girls were 58% less likely to still be enrolled in school 5 years later and girls 15-17 were 55% less likely to be enrolled in school 5 years later
Frankenberg et al. (2013b)	Peer reviewed analysis of the impact of socioeconomic status on resilience after natural disaster	Multivariate regression analysis of population-representative longitudinal study	3,813 adults in areas heavily damaged by tsunami	Education	Morbidity, mental health	Education above primary level has some protective effect for men, immediately after tsunami education did have positive effect on spending vulnerability
Phelps et al. (2011)	Peer reviewed commentary on opening of Aceh post disaster	Authors commentary based on field work in Aceh and Jakarta	N/A	Ending of civil conflict	International investment	Author argues that ending of the civil conflict reopened trade routes, encouraged investment and united Aceh
Nobles et al. (2015)	Peer reviewed analysis of fertility response to natural disaster shock	Multiple linear regression analysis	Nearly 300 communities across Aceh	Fertility	Population	For each one percentage point increase in community mortality there is a 1.2 percentage point increase in probability of birth
Srinivas and Nakagawa (2008)	Peer reviewed environmental analysis	Observations of environmental impact of tsunami	Indonesia	Conservation and ecological preservation pre-disaster	Development-housing, poverty	Author notes that damage from natural disasters destroys infrastructure, livelihoods and sanitation systems and notes that in coastal areas that were protected and where development was not close to the shore line did better, recommends improved eco-sustainable development practices

6.2.3 Undetermined effect

Author	Study Type	Method	Population/ Study Size	Modifying Factor	Outcome of Interest	Correlation or causal effect
Gaillard et al. (2008b)	Peer reviewed discussion of ethnic groups customs and disaster experiences	Community surveys and framework analysis	120 Face to face interviews	Culture	Mortality	Mortality varied dramatically by ethnic group, survival depended on historical experience and education of disasters, location to coast and relative freedoms of women
Jauhola (2010)	Peer reviewed analysis of gender mainstreaming policies and advocacy	Analysis and framework of gender normativity in Aceh		Gender roles, religion, government	Advocacy capacity	Author argues that gender advocacy needs to include economic and political oppression in its interpretation of gender biases and violence
Kenny (2007)	Peer reviewed analysis of types of capacity building available post-tsunami	Author offers different frameworks through which to view capacity building	N/A	Aid	Community development, training, reconstruction	Author offers mixed reviews of capacity building to meet outcomes of interest
Muriuki et al. (2012) for Mentor Initiative	Peer reviewed research report of malaria prevalence	Malaria prevalence surveys	11,763 individuals in 5 coastal districts of Aceh	Malaria	Morbidity	Study finds an epidemic did not occur, but given that pre-tsunami data is not available study can not draw a conclusion about tsunami effect
Oktari et al. (2017)	Peer reviewed analysis of disaster management budget post-tsunami	Literature review and budget analysis based on recommendations from interviewed stakeholders	Banda Aceh local budgets from 2007-2015	Government budgets	Vulnerability reduction	Legal frameworks have improved, disaster management budgets have improved, yet study cannot draw conclusion on quality of investments
Régnier et al. (2008)	Peer reviewed investigation into livelihood recovery	Case study analysis	Aceh v. Tamil Nadu India	Aid	Economic recovery	Only a few organizations could deliver economic recovery and most were chaotic unorganized aid efforts
Steinberg (2007)	Peer reviewed report on housing reconstruction	Review of experience of implementing housing programs	Aceh and Nias	Aid	Housing redevelopment	Building back better initiative will take more time to incorporate the views of effected communities and has both benefits and drawbacks
Sudomo et al. (2010)	Peer reviewed report of malaria prevalence	Village and school-based surveys of malaria prevalence	Simeulue	Malaria	Morbidity	Malaria may have been endemic before tsunami, aid efforts helped to control malaria and island remains on its way to eradication. Study does not offer evidence on change in morbidity
Thormar et al. (2014)	Peer reviewed analysis of longitudinal study of PTSD in relief volunteers	Impact of Event Scale survey conducted at 6 and 18 months post-tsunami	506 Indonesian Red Cross volunteers	Volunteering	Morbidity	Finds some evidence that volunteers have higher PTSD prevalence than professional workers, but notes that methodological differences hinder this association
Uscher-Pines (2009)	Peer review systematic literature review of health effects of relocation	Systematic literature review	24 articles reviewed from 5 databases plus google	Relocation	Morbidity	Literature review finds mixed evidence of the impact of relocation on health and health seeking behaviour

Waizenegger and Hyndman (2010)	Peer reviewed analysis of peace process for multiple stakeholders	Interviews and in-field research	Field work in Aceh and unidentified number of interview with stakeholders, interview of 14 ex-combatants	Aid	Civil conflict	Aid to tsunami survivors was greater than for conflict survivors which could hinder future peace
Zeccola (2011)	Peer reviewed analysis of humanitarian action	Authors commentary from working in Aceh		Aid, civil conflict, governance	Reconstruction	Author argues need for donor flexibility in changing humanitarian contexts as changing context poses new challenges for aid delivery amid political contexts

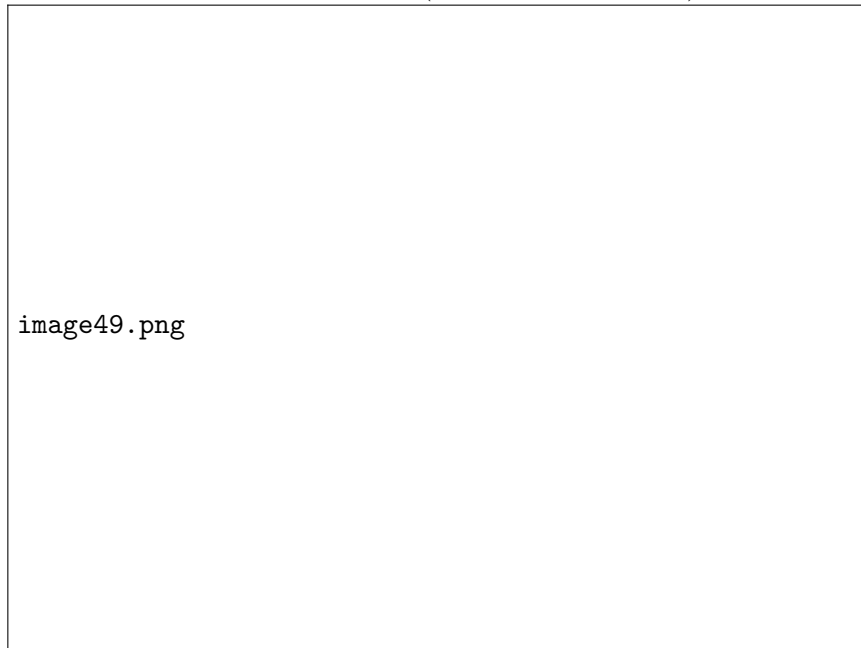
6.3 Appendix 3: Sample of the DHS and estimation of mortality

Year	Number of children
1990	9,364
1991	9,235
1992	10,307
1993	10,324
1994	10,753
1995	11,987
1996	12,578
1997	11,697
1998	12,084
1999	13,178
2000	15,024
2001	13,664
2002	13,485
2003	11,353
2004	10,899
2005	10,831
2006	11,127
2007	9,592
2008	7,355
2009	7,268
2010	7,324
2011	7,564
2012	5,177
2013	3,674
2014	3,550
2015	3,552
2016	3,671
2017	2,301
Total	258,918

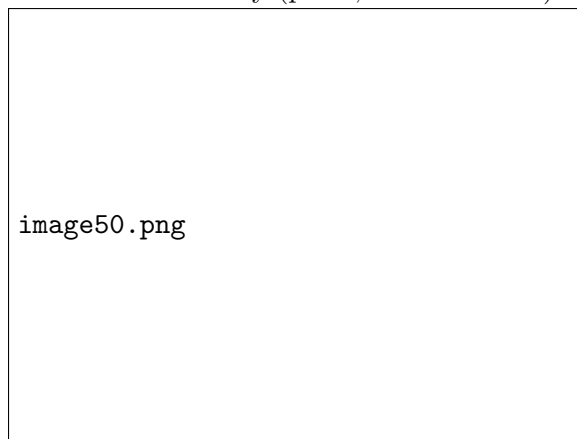
6.4 Appendix 4: Inclusion of covariates

Using IDRP data: Covariates include the proportion of births attended by skilled health worker, the GDP on construction sector, access to safe water, access to safe sanitation, net enrolment ratio, total GDP, total population and total revenue of the province. The data set contains a total of 19 provinces (18 donor provinces) and 17 years including 8 pre-treatment years. We conduct the synthetic control by including the level of pre-treatment outcomes in 1996, 1999 and 2003.

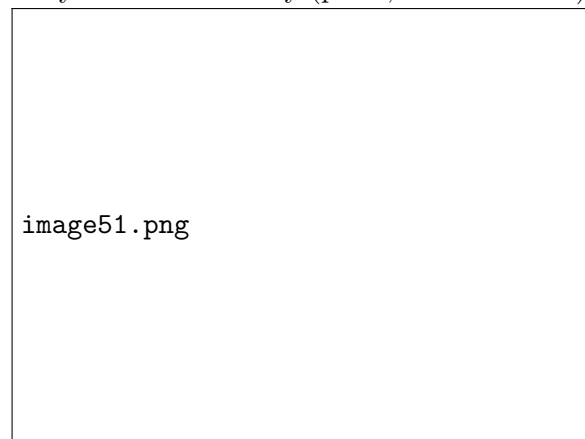
Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)

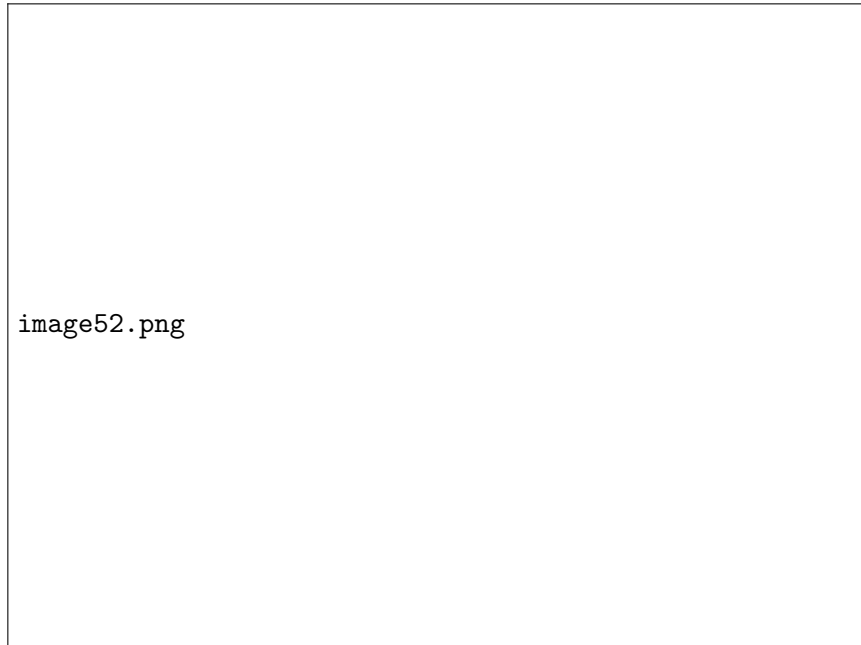


1-4 years old mortality (per 1,000 live births)

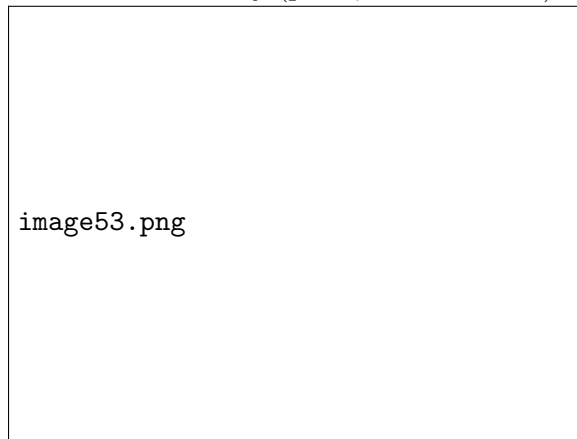


Using DHS data: Covariates include the access to drinking water, antenatal care, births attended by skilled health worker, tetanus immunisation coverage, home delivery. Data cover the period of 1992-2017 and 25 provinces (24 donor provinces). We conduct the synthetic control by including the level of pre-treatment outcomes in 1992, 1997 and 2003.

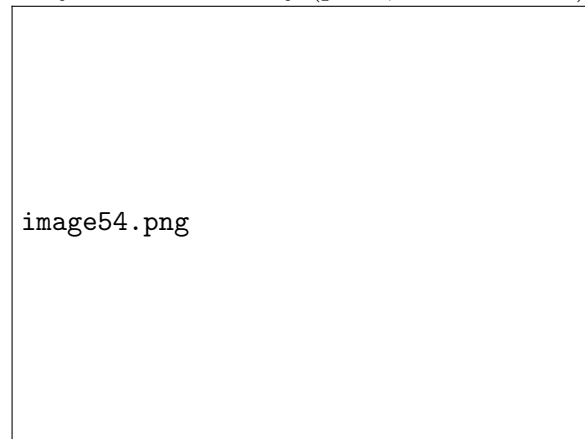
Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)



1-4 years old mortality (per 1,000 live births)

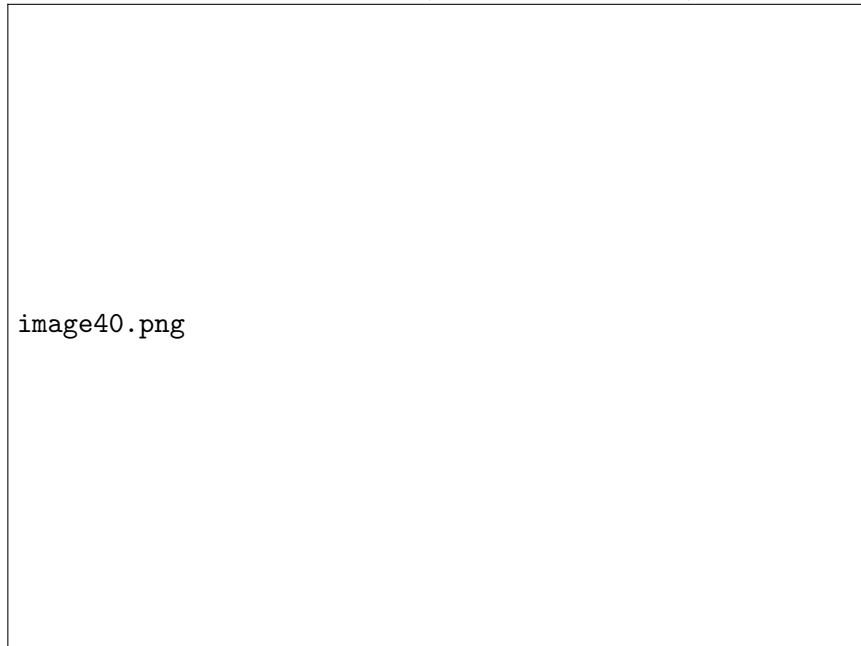


6.5 Appendix 5: Donor Pool Weights and RMSPE Tables

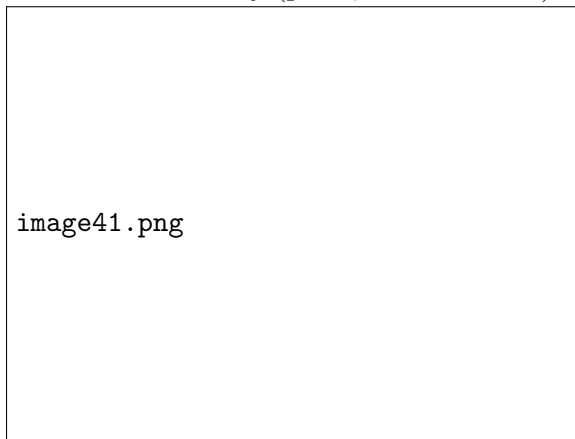
	Under-5 mortality	Under-1 mortality	1-4 year old mortality
West sumatra	0	0	0
Riau	0	.134	0
Jambi	0	.165	.359
South sumatra	0	0	0
Bengkulu	.09	0	0
Lampung	0	0	0
Jakarta	0	.281	0
Central java	0	0	0
Yogyakarta	.363	.189	0
East java	0	0	0
Banten	0	0	0
Bali	.148	0	.249
West nusa tenggara	0	0	0
East nusa tenggara	0	0	0
West kalimantan	0	0	0
Central kalimantan	.015	0	.091
South kalimantan	0	.019	0
East kalimantan	.25	.212	0
Central sulawesi	0	0	0
Southeast sulawesi	0	0	0
Gorontalo	.023	0	0
West sulawesi	0	0	0
North maluku	0	0	.118
West papua	.111	0	.183
Total	1	1	1
RMSPE	7.140	8.045	4.163

6.6 Appendix 6a: Placebo Test Graphs (untrimmed)

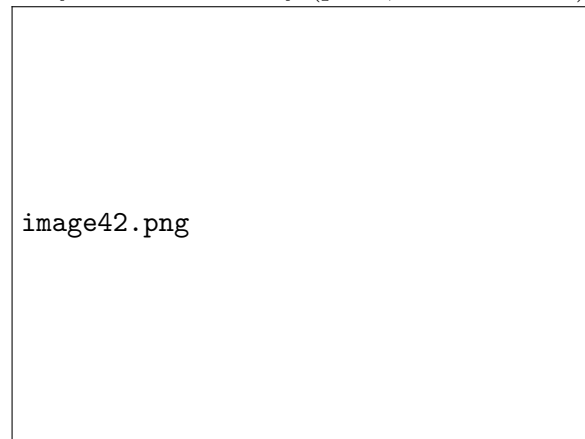
Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)

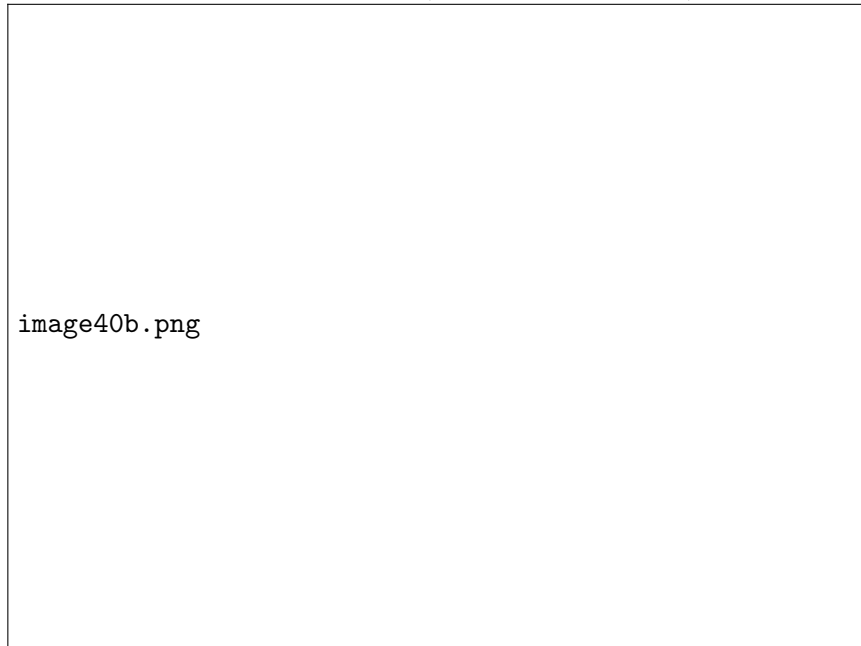


1-4 years old mortality (per 1,000 live births)



6.7 Appendix 6b: Placebo Test Graphs (trimmed)

Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)

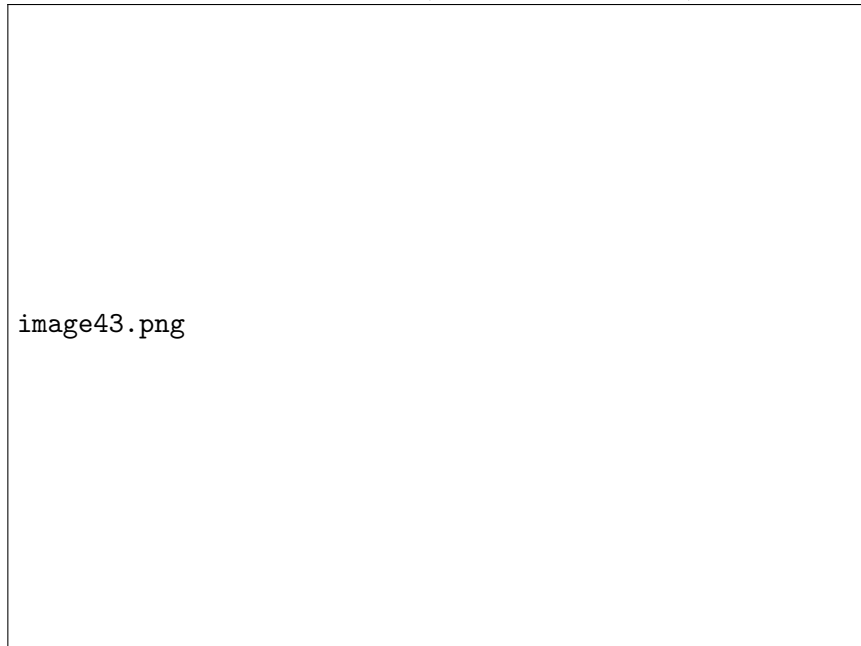


1-4 years old mortality (per 1,000 live births)

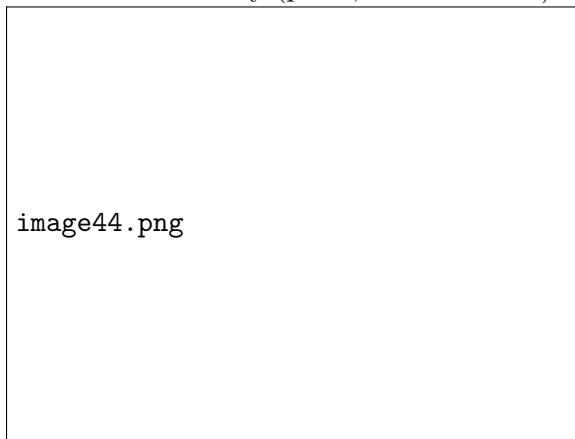


6.8 Appendix 7a: Backdating analyses

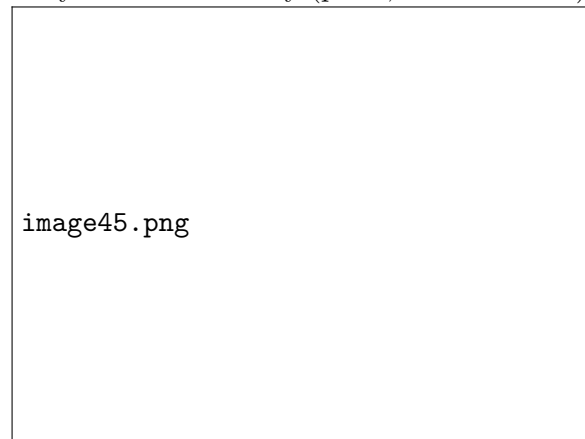
Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)

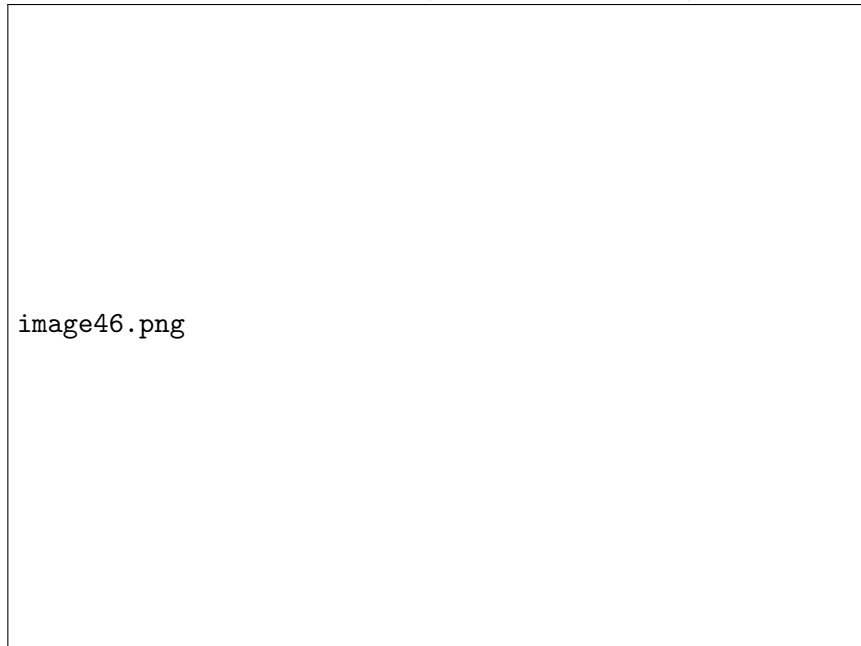


1-4 years old mortality (per 1,000 live births)

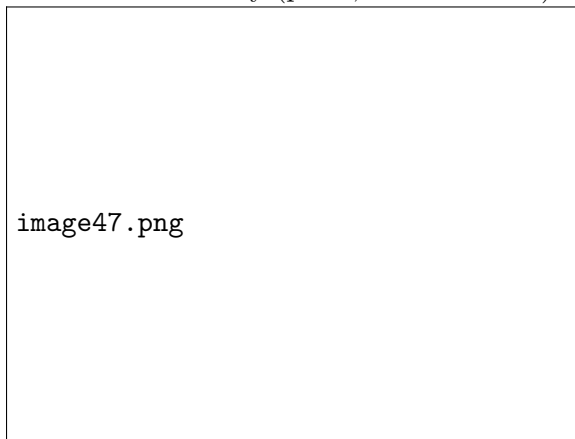


6.9 Appendix 7b: Leave-out analyses

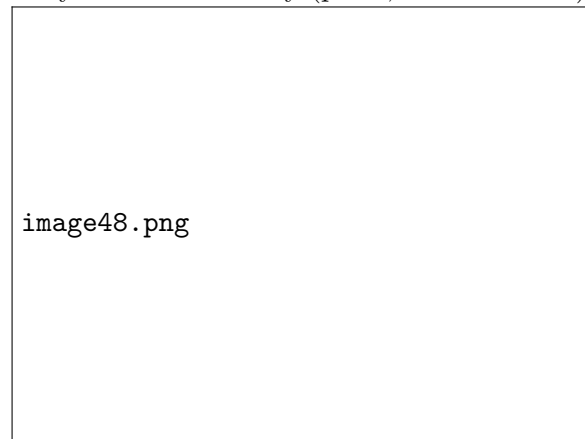
Under-5 mortality (per 1,000 live births)



Under-1 mortality (per 1,000 live births)



1-4 years old mortality (per 1,000 live births)



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