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Forecasting the Impact of Maternal Undernutrition on Child Health Outcomes in Indonesia

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Abstract

Maternal nutrition influences a child's birthweight, which affects the child's growth and subsequent survival. However, the broad consequences of maternal undernutrition and the outcomes of interventions to improve maternal nutrition take years to manifest. To examine the long-term health outcomes of low birthweight infants in response to a maternal nutritional supplementation intervention without this obstacle, we developed the Forecasting Population Progress (FPOP), a microsimulation model. The intervention we assessed was based on the findings of a published clinical trial outcome that reduced the incidence of low birthweight, a known cause of stunting. We implemented the "before intervention" and "after intervention" simulations and generated the difference in outcomes, using a spatially explicit synthetic baseline population of Indonesia generated from a microdata sample of the Indonesian 2010 census. We focused specifically on two provinces—Yogyakarta and Bali—which represent different levels of fertility and mortality but both exhibit significant underweight birth. The baseline scenario represented the current nutritional status of pregnant women in the two Indonesian provinces and projected that implementing a multiple nutrition supplementation intervention would, after 30 years, avert 8 per 1,000 low birthweight births, 3.8 per 1,000 stunted children younger than 5 years of age, and .25 infant deaths per 1,000 births. As our model results demonstrate, improvement in maternal nutrition would reduce infant mortality, but an even greater impact could be the reduction in growth stunting.

Introduction

Maternal nutritional deficiencies at conception and during pregnancy are associated with an increased risk of infant low birthweight and childhood stunting.[1] Globally, approximately 16 percent of all live births, or nearly 22 million newborns, weigh less than 2,500 grams. Low birthweight is the single most important factor influencing neonatal mortality and a significant determinant of infant morbidity and mortality. In Indonesia, the incidence of low birthweight is approximately 9 to 11 percent. Stunting (being more than two standard deviations below the median height for age of the reference population) reduces a child's chance of survival and enhances the risk of complications from infectious disease. Stunting is equally caused by deficiencies in the intrauterine environment of the fetus as well as the child's health and nutrition during early postnatal life.[1] It is estimated that in 1 in 3 children younger than 5 years of age in Indonesia (36 percent) are stunted.[2]

Because maternal undernutrition is a major determinant of both low birthweight and stunting in developing countries, high rates of low birthweight should be interpreted not merely as an indicator of undernutrition, morbidity, and mortality for newborns, but as an public health warning that women of childbearing age are undernourished.[3] Furthermore, research demonstrates that after 2 years of age, it is difficult to reverse the effects of childhood stunting. Over the life cycle, stunted children have a greater likelihood of becoming obese and developing chronic disease later as adults.[4] Consequently, many stunted, impoverished people in low- and middle-income countries will experience rising rates of obesity that are associated with malnutrition and constrained fetal and infant growth.[5] Studying these trends and employing appropriate public health responses is crucial to avoid the consequence of diet-related noncommunicable diseases in which the poorest will suffer the most because they will not be able to afford treatment.[2]

To address the problem of how to examine potential long-term effects of maternal and child undernutrition on low birthweight, stunting, and infant mortality trends in Indonesia in the face of an impending crisis, we developed a geospatial agent-based model (ABM) that simulated the effects of a maternal micronutrient supplement intervention over a period of 30 years. Although programs providing supplemental food and micronutrients to women before, during, and after pregnancy exist, the long-term effects of such programs on child health outcomes have been difficult to assess.[1, 6] We linked the low birthweight model to a platform called Forecasting Population Progress (FPOP). FPOP is a dynamic microsimulation tool to analyze and compare program policies for managing chronic diseases against a backdrop of interacting individuals, causal behaviors, and disease traits.[7, 8] We ran the simulation using synthetic population data from two Indonesian provinces: Yogyakarta and Bali. Although there is no direct connection to patient data, the simulation model processes synthetic populations that have features similar to Indonesian populations.

There are a number of advantages for carrying out a predictive simulation study of the kind presented herein. First, the FPOP model describes a process that would be prohibitively expensive to conduct as a clinical study over a 30-year performance period. Second, the experimental design of a simulation study can implement treatments that do not require review by an overseeing body such as an institutional review board. Consequently, simulation studies can examine scenarios that would be impossible for clinical studies to examine, due to human subject concerns. Third, a clinical study typically includes a recruitment phase that selects appropriate subjects into the study. In many cases, subjects are selected to "fit" the objectives of the study and as a consequence, the selection process biases the study outcomes.[9] Furthermore, recruitment may be affected by any number of issues related to protocol, site, surgeon or referring physician, communication, participants, or funding and reimbursement.[10] The FPOP model examines a subject base that includes the entire population of interest. Therefore, no demographic class or specific participants are precluded from participating in the study.

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Methods

Overview

Aging the Population

FPOP is a geospatial ABM that ages a synthetic population by linking key life events over time.[11, 12] The life events that affect households and populations include mortality, birth, marriage/union formation and dissolution, and migration. The occurrence of life events for each individual at each time step is stochastically determined using transition probabilities. The model life event probability tables represent hypothetical scenario changes that can be used to test policy intervention effectiveness. For example, interventions affecting low birthweight may modify individual probabilities of mortality and morbidity and, therefore, change the future size, health conditions, and distribution of the synthetic population. Individuals are removed from the model based on mortality and migration rates, and new individuals are added to the population based on fertility and immigration rates.

The Low Birthweight Model

We developed an external model to assign a low birthweight status to each live birth in the synthetic population and to determine participation in the low birthweight intervention. The intervention was based on a maternal nutrition supplementation model,[6] in which females of childbearing age supplement their diets with iron folate and multiple micronutrients. We estimated the likelihood of a mother to participate in the intervention based on her travel distance to a health clinic where hypothetically she would receive services. The model simulates the likelihood of a low birthweight birth based on the mother's demographic and behavioral characteristics, including participation in the intervention program.

Figure 1 represents the high-level operations of the low birthweight model. At the beginning of each user-defined time step, FPOP transitions are determined by individual, household, and spatial traits included in the synthetic population. FPOP retrieves the baseline synthetic subject data, performs the subject aging transitions, and presents these "aged" data and associated demographic characteristics to the low birthweight model for processing. Then, the low birthweight model:

1. determines whether the female subject is of childbearing age (i.e., is 15 to 49 years old);
2. if age indicates childbearing is possible and participation in the intervention is also possible, makes a probability estimate that depends on the woman's age, parity, and distance to clinic and virtually rolls the dice to determine whether the subject participates in the intervention program;
3. determines whether a birth occurs, based on the subject's age, parity, province-level fertility rates, and other factors;
4. if a birth does occur, determines low birthweight status based on the mother's age, region, urban-rural status, birth order, and participation in the intervention;
5. based on the region, low birthweight status, and whether the mother has participated in the intervention, determines whether the child becomes stunted as a direct consequence of a low birthweight; and
6. estimates the probability of the child surviving the first year of life.

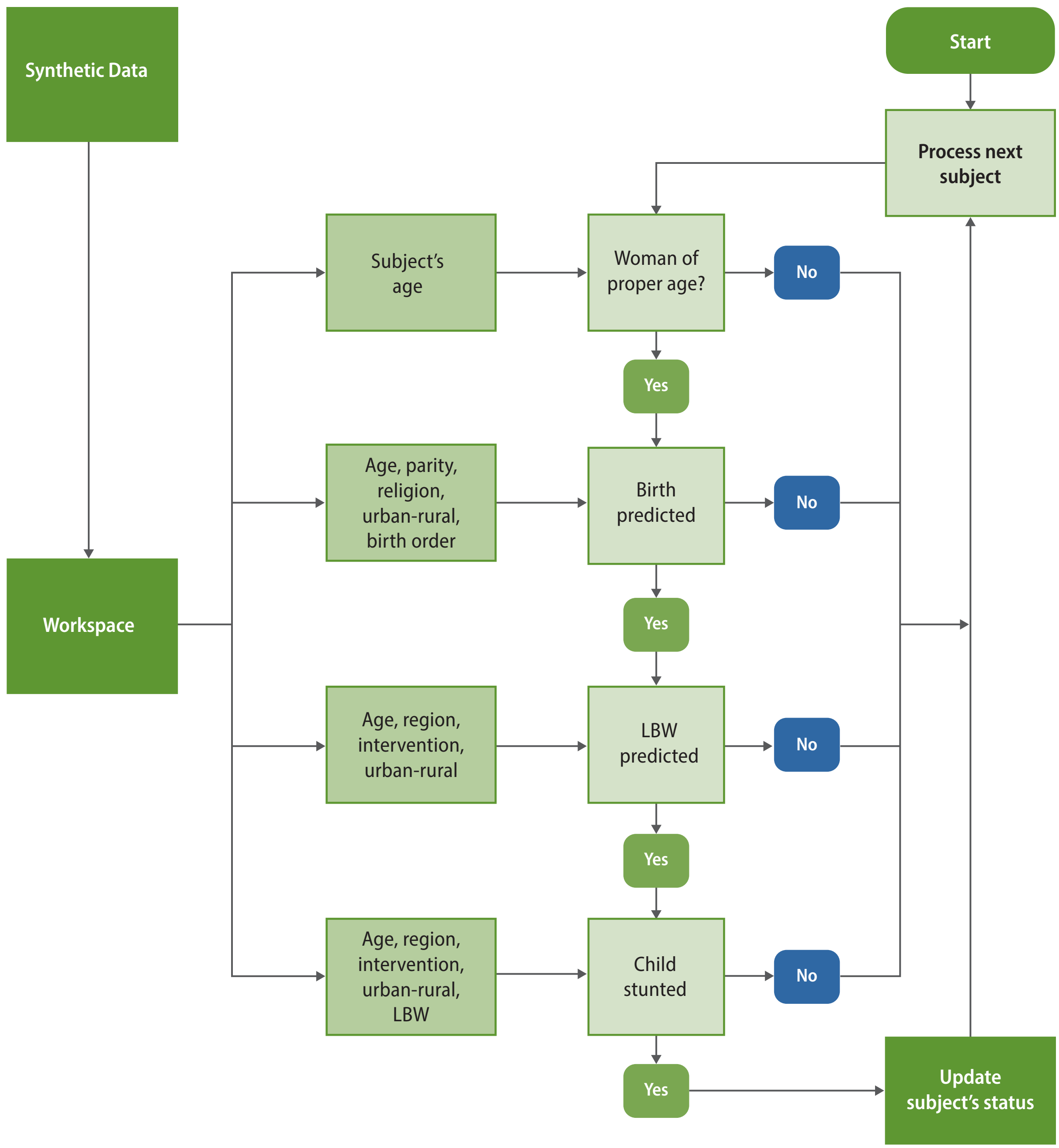
Study Context

We limited our simulations to the Indonesian provinces of Yogyakarta and Bali. Although these two provinces represent different levels of fertility, mortality, and other demographic characteristics, both exhibit significant underweight and overweight patterns among children and adults.

Indonesia's population continues to grow rapidly, expanding by 30 million in the past decade, according to the 2010 population census; however, the population of Yogyakarta Province is shrinking. The 2010 population of Yogyakarta Province was 3,452,390, decreasing 5 percent over the past decade.[13] In contrast, the population of Bali Province, which includes the island of Bali and a few smaller neighboring islands was 3,890,757 and growing rapidly.

These provinces represent a snapshot of a highly diverse country that exhibits heterogeneous regional traits including age structures, fertility, and

Figure 1. Conceptual representation of the low birthweight simulation platform



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undernutrition states see Table 1, which summarizes some of the differences that are also province-specific model parameters.

Model Operations

We chose 2008 as our baseline year because that was consistent with our model parameter data. Using the combined FPOP/low birthweight models with 2008 as our baseline year, we estimated the risk of low birthweight and the proportion of infant deaths and stunting associated with low birthweight by province for a period of 30 years. To model the additional effect of a nutrient supplementation intervention, we reran the model to reflect various levels of participation (estimated from a survey we describe subsequently) in the intervention and its effects on population distribution and child health outcomes. From the model outputs, we computed changes in the number of low birthweight births, the number of infant deaths averted, and the number of children who were stunted as a consequence of their low birthweight event by year and for a cumulative total over 30 years.

Model Parameters

We used the estimates shown in Table 1 for the entire simulation period. An Indonesian population study by Muhidin[14] reported that trends in fertility plateaued in the late 1990s partly due to a severe economic downturn in the Indonesian economy. In 1997, Riskedas reported that the fertility rate in Yogyakarta was 1.85 and increasing (we used 1.94) and further indicated that in Bali it stabilized (see Table 1).[15] The estimate for Bali was 2.12 (we also used 2.12).

Synthetic Data

A spatially explicit synthetic baseline population of Indonesia generated from a microdata sample of the Indonesian 2010 census provides the households and persons whose life events are simulated and projected by FPOP. Each individual in the synthetic population is described by a number of characteristics, including sex, age, race, ethnicity, education, and family type. Table 2 lists the various characteristics that were used by the model to characterize the population, the source of the data characteristics, and geographic level of detail. The product of these data is an initial synthetic population of Indonesia that represents each of the 61.4 million households and 237.6 million people in 2010. Initial transition probabilities simulating births, deaths, and aging derived from census and survey data are applied for each synthetic individual while tracking corresponding changes in household composition, location, and size.

Low Birthweight Model Parameters

Estimating the Incidence of Low Birthweight. A number of external studies determine the data to develop parameters that are used to stratify the Indonesian

Table 1. Summary of population characteristics of the two Indonesian provinces

Indicator	Yogyakarta	Bali	Source
Total population	3,457,491	3,890,757	Riskesdas[15]
Percent urban	66.4	60.2	Riskesdas[15]
Percent population growth rate (2000–2010)	1.04	2.15	Riskesdas[15]
Sex ratio (female to male)	97.7	101.7	Riskesdas[15]
Lifetime net migration (lifetime in-migrants minus lifetime out migrants)	−339,155	137,676	Riskesdas[15]
Total fertility rate (the average number of children that would be born to a woman over her lifetime)	1.94	2.12	Riskesdas[15]
Low birthweight (birthweight < 2,500 grams of a live-born infant)	9.8	9.9	OECD[16]
Infant mortality rate (deaths per 1,000 in children younger than 1 year of age)	16	20	Statistics Indonesia[17]
Younger than 5 mortality rate (deaths per 1,000 in children younger than 5 years of age)	30	33	Statistics Indonesia[17]
Percentage of children younger than 5 years of age stunted (below minus two standard deviations from median height for age of reference population)	28.0	31.0	Riskesdas[18]

OECD = Organization for Economic Co-operation and Development.

Table 2. Demographic parameters applied to baseline Indonesian synthetic population

Parameter	Source of estimate	Geospatial level of estimate
Synthetic population variables: age, sex, region, urban-rural, household composition (derived from census data)	Statistics Indonesia (Budan Pusat Statistik), (2013, via Minnesota Population Center 2010)[19, 20]	Regency (a political subdivision below the province)
Household location	Oak Ridge National Laboratory[21] and WorldPop[22]	1KM
Birth and death probabilities, partnership formation probability	Riskesdas (Indonesian Ministry of Health)[25]	Province
Height, weight	RAND Corporation[23]	Province

population into women that have low birthweight births, the portion of low birthweight births that are stunted, the portion that die at birth, and the influence of maternal age on birth outcome. We incorporate the results of these studies to make predictions while simultaneously simulating the aging process.

National estimates of the proportion of Indonesian births that are below 2,500 grams are reported by the Organisation for Economic Co-operation and Development/World Health Organization (OECD/WHO).[16] Based on 2009 data,[16] we assume that 11.1 percent of births in Indonesia are low birthweight. Many factors are known to affect low birthweight, including low pregnancy weight gain, maternal infections, as well as mother's socioeconomic background, smoking status, height, and age.

Our baseline synthetic population estimates that 18.6 percent of women of childbearing age were between the ages of 15 and 19, and 81.4 percent were aged 20 to 49. Model estimates of the influence of maternal age (19 years or younger or 20 or older) on the risk of an low birthweight birth were derived from a recent study by Ghimire and colleagues.[24] This study, conducted among mothers in Maharashtra, India, reported births in a rural hospital in 2013–2014; 227 cases were low birthweight births and 486 were normal weight births. Maternal age (19 years or less) was significantly associated with the likelihood of low birthweight (odds ratio [OR] = 1.84, p = .05).

Using the reported odds ratio from Ghimire et al.[24] allows us to estimate that the probability of an low birthweight birth for mothers less than 20 years old is .177 and the probability of a low birthweight given a mother whose age is 20 or higher is .096.

These data were used to adjust the incidence of low birthweight that accounted for maternal birth age. This adjustment lowered the low birthweight in both provinces from the national low birthweight average of 11.1 percent to a rate slightly below 10 percent. This suggests that other (more rural) provinces in Indonesia are likely to have rates of low birthweight higher than 11.1 percent.

Estimating the Incidence of Stunting. Stunting is a serious problem in Indonesia. In 2007, 36.8 percent of all children in Indonesia younger than 5 were considered to be stunted using the new WHO growth standard as a reference.1 To arrive at estimates of stunting given low birthweight in Indonesia, we identified five studies in the literature based on five different developing countries with significant stunting issues. Table 3 identifies the location and year each study was conducted, the odds ratio for risk of stunting given low birthweight, and the reference for the study.

None of these studies were based in Indonesia, so we calculated and average odds ratio for all five studies to produce an estimate of the effects of low birthweight

Table 3. Odds ratios of stunting and low birthweight links, by study

Study country	Year data collected	Odds of stunting*	Source
Nepal	2002–2004	3.40	Vaidya[25]
Southern/ Eastern Asia	2010	2.64	Christian et al.[26]
Brazil	2002	3.49	Vitolo et al.[27]
Uruguay	2007	3.20	Bove et al.[28]
India	2009	3.63	Rehman[29]
Average		3.28	

* Odds of being stunted, given a low birthweight birth.

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on stunting equal to 3.28. Also, a separate study reports that 16.3 percent of the reported stunting prevalence in Brazil is due to low birthweight.[30] We developed province-specific estimates of stunting correlated with low birthweight status to account for the significant differences in low birthweight incidence and fertility between Yogyakarta and Bali.

Overall, stunting is estimated at 28 percent of all children younger than 5 years of age in Yogyakarta and 31 percent in Bali.[1] Thus the probability of stunting coincident with low birthweight (X) plus the probability of stunting observed in children coincident with normal birthweight (Y) can be represented as $.163 * X + .837 * Y = Z$, where $Z = .28$ for Yogyakarta and $Z = .31$ for Bali.

This information supports the estimates in Table 4.

Table 4. Stunting probabilities for birth risk, by region

Parameter	Symbol	Yogyakarta	Bali
Overall stunting rate	Z	Z	31 percent
Pr(Stunted given low birthweight)	Y	Y	.748
Pr(Stunted given normal birthweight)	X	X	.228

Derived from odds ratios (Y/X).[25-29]

Estimating Incidence of Infant Mortality. The infant mortality rate (IMR) is represented in the model as the probability of death within the first year of life. Model parameters are derived from a study of various maternal, clinical, and geographic factors influencing infant mortality in Indonesia using data from the 1997 Indonesia Demographic Health Survey[31] (see Poerwanto et al.[32]). Young maternal age (15 years or younger) at first birth was associated with low birthweight (adjusted OR = 1.84, $p < .001$) and low birthweight births were associated with a higher likelihood of infant death (adjusted OR = 1.13, $p < .001$). A second study based on Indonesian subjects estimates that 19 percent of infant mortality is caused by low birthweight.[3]

These results collectively provide the means to estimate the influence of low birthweight on infant mortality according to the following logic:

X = probability of infant death (ID) given low birthweight, and Y = probability of ID given non–low birthweight. From the definition of the odds ratio, we have $X/Y = 1.13$. If we use the value provided by Lee that attributes 19 percent of the infant mortality rate risk to low birthweight, then we can define Z as the weighted infant mortality rate average due to low birthweight and other (non–low birthweight) causes or $.19X + .81Y = Z$. By solving the two equations, we find that

$$Y = Z/1.0247 \text{ and}$$
$$X = Z * 1.10276.$$

The province-specific values for infant mortality rate(Z) are available from Statistics Indonesia (Badan Pusat Statistik)[17]: $Z = .025$ for Yogyakarta and $Z = .029$ for Bali. Table 5 shows the province-adjusted IMRs.

Thus, the death of a low birthweight infant within the first year of life can be attributable to multiple causes (e.g., infection, injury, inadequate nutrition), but these are all considered low birthweight deaths because the infant weighed less than 2,500 grams at birth. The low birthweight infant mortality rate (X) refers to all deaths of infants before 1 year of age who weighed less than 2,500 grams at birth, regardless of the cause of death.

Table 5. Infant mortality for low birthweight risk, by region

Parameter	Symbol	Yogyakarta	Bali
Overall infant mortality	Z	.025	.029
Pr(infant death given low birthweight)	Y	.0276	.0320
Pr(infant death given normal birthweight)	X	.0244	.0283

Derived from odds ratio (Y/X).[14]

Intervention Effects. The focus of the intervention was to prevent the incidence of low birthweight because it is a cause of stunting. Other causes of stunting (maternal height and education) are not amenable to change at least in the short term. We reviewed The Cochrane Library (ISSN 1465–1858), which is a collection of six databases that contain different types of high-quality, independent evidence to inform health care decision-making. The results from these sources have been published in a landmark series of papers on maternal and child undernutrition in *Lancet*.[6] These papers bring to bear evidence on the critical role of early nutrition in the health of children, making clear that the golden period of intervention for nutrition is between pregnancy and 24 months. One set of clinical studies reported findings of trials in India and Tanzania involving multiple micronutrient supplements and iron folate in pregnancy to reduce the rate of low-birthweight babies. This study, described by Bhutta et al.[6] reports that the intervention reduced the risk of low birthweight at term by 16 percent. Accordingly, we adopted this estimate to simulate a 16 percent reduction in low birthweight incidence as a result of women's participation in the study. However, the voluntary participation in this type of study is not known. To support this assessment, we developed and implemented a survey to determine the characteristics of the women that would participate in the intervention.

Estimating Participation Rates. Health policy approaches to address low birthweight deliveries include changing behaviors (such as providing nutrition awareness and food choice awareness training) and improving the availability and quality of food (such as programs providing food supplements). The effectiveness of these interventions depends not only on whether diagnostic, preventive, and treatment services are made available by the health care system, but also on individuals' willingness to use those services and participate in health programs.

To assess mothers' willingness to participate in a nutrition program, we conducted a preference survey and asked respondents about their own willingness to participate in a hypothetical food supplementation program at a variety of specified one-way travel times.[33] We identified a food supplementation program from the "What works? Interventions for maternal and child undernutrition and survival" array on intervention[34] found to be effective in reducing the risk of low birthweight deliveries.[6]

The study conducted 200 household interviews in eight enumeration areas located in two provinces from Java. The provinces were Central Java and DI Yogyakarta. The sample was stratified by urban/rural status. Households were selected from lists of households with children younger than 2 and mothers aged between 18 and 38 years acquired from each selected village. The response rate was more than 98 percent.

The hypothetical food supplementation program was described to survey respondents as a 1-year program involving monthly visits to a specialized health center to receive a month's supply of daily food supplements and to meet with a health worker for nutrition advice. The program would be provided at no cost, although participants would be responsible for covering their own travel expenses to and from the health center. A probit regression analysis of the survey data identified maternal age, number of prior children, and clinic location as the major determinants of participation.

Estimating Travel Time to Nearest Health Facility. The 2011 Village Potential Statistics (PODES) survey was used as the source of health facilities location information.[35] The PODES data include counts of health facilities by type to the village level of geography but do not include locations of individual facilities. We developed a dasymetric procedure based on population density data to create an estimated location of each health facility. The distance from each synthetic household to each synthetic health facility was calculated and a time-of-travel value was estimated using a constant speed of 35 kilometers per hour. Table 6 was developed by this process.[33]

Table 6. Probability of participation in food supplementation programs, by mother's age and travel time to clinic

Age of mother	10 minutes of travel	30 minutes of travel	60 minutes of travel	120 minutes of travel
18–19 years	0.9997	0.9986	0.9884	0.7945
20–24 years	0.9855	0.9554	0.8356	0.3190
25–29 years	0.9959	0.9845	0.9243	0.4949
30–34 years	0.9649	0.9078	0.7271	0.1996
35–38 years	0.9856	0.9558	0.8366	0.3204
Total in sample	52	52	52	52

Cell entries are the probability of participating in the intervention given mother's age and travel time to the clinic.

Figure 2. Births and deaths, by year and province

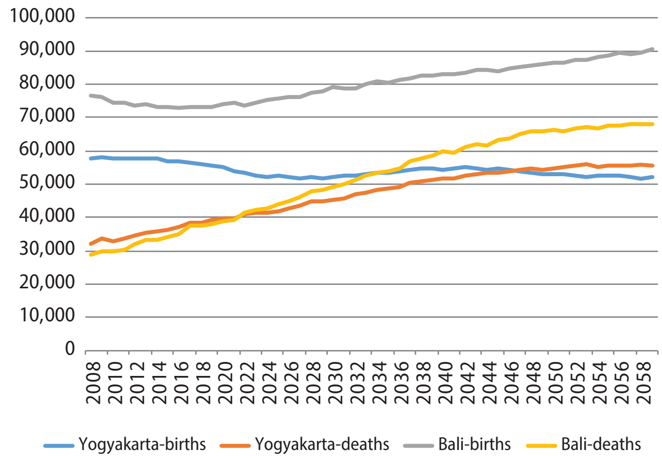
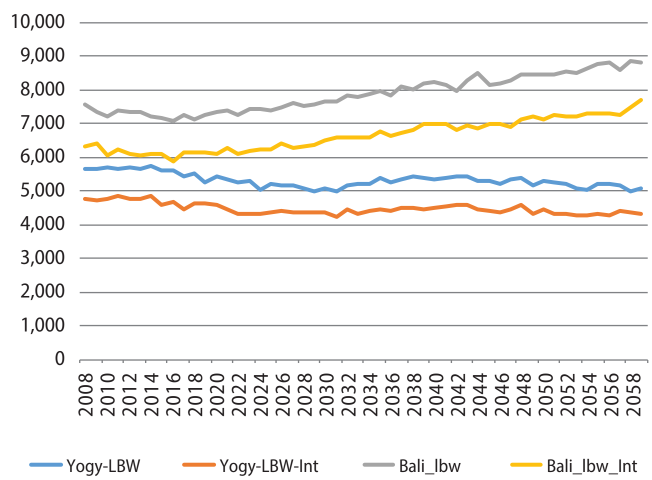


Figure 3. Low birthweight births, by year and province



Results

Low Birthweight Trends

We ran the model for 30 simulated years. We made two sets of runs: one run with and one run without the nutrient intervention in effect. The major assumption behind the runs is that past history continues 30 years into the future. This, of course, is unrealistic but we have no additional future insight that we feel is more sanguine. The major parameter that drives the results is the province fertility rate. These are 2010 estimates that are reported in Riskesdas.[15]

Figure 2 presents the estimated change in the number of annual births and deaths by province. Although births in Yogyakarta slightly decline over the 30-year period, deaths show a steady increase. Both births and deaths in Bali, however, continue to increase. Consequently, estimated population growth in Bali is relatively high over the projected time period—approximately 30 to 40 percent—whereas in Yogyakarta, overall population growth is less (14 percent), reflecting differences in the age structure and fertility rates in the two provinces.

As Figure 2 shows, the fertility rate in Yogyakarta is declining and, if trends continue, deaths will exceed births by midcentury. The fertility in Bali continues to rise, however, and although Bali's deaths are also increasing and they likely will not surpasses births in the near future.

Figure 3 presents trends in low birthweight incidence by province and time. Solid lines are baseline (no intervention) results and broken lines are intervention results (discussed below). As anticipated, the low birthweight incidence does not change appreciably over the time period and closely tracks the trends in overall births. However, the number of low birthweight births per year is higher in Bali, reflecting Bali's higher fertility rate, whereas the low birthweight trend in Yogyakarta is substantially lower, reflecting rates of fertility near replacement level.

Infant Mortality Trends

As indicated by Lee et al.,[36] 19 percent of infant mortality is associated with low birthweight births. The total infant mortality rate from all causes in 2012 was 25 per thousand in Yogyakarta and 29 per thousand in Bali.[17] Figure 4 displays infant mortality that is a consequence of low birthweight only.

Stunting Results

Figure 5 shows total stunting trends by province. Once again, trends are similar to the fertility trends shown in Figure 2. Accordingly, Bali stunting trends are slightly increasing, and Yogyakarta trends are slightly decreasing.

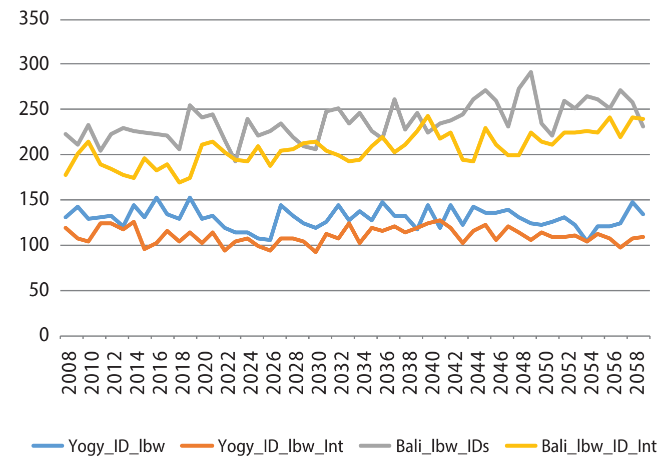
Intervention Effects

We present results illustrating the effects of maternal participation in the supplementation intervention on the reduction of low birthweight for each province.

Figure 3 provides annual counts of the number of low birthweight births at baseline (no intervention) as well as and the number of low birthweight births given participation in the low birthweight intervention. The cumulative effect on low birthweight prevalence resulting from the low birthweight intervention is shown in Figure 6 for a period of 30 years (2010 to 2040). The figure shows the difference in low birthweight births with and without the multiple micronutrient supplementation intervention (as shown in figure 3) accumulated over 30 years for each province. The results indicate that the intervention averts more than 38,000 low birthweight births in Bali and 27,000 low birthweight births in Yogyakarta.

The benefit of the intervention is not limited to the low birthweight births avoided. Because low birthweight births also associate with infant mortality and stunting, we present figures for infant mortality (Figures 4 and 7) and stunting (Figures 5 and 8) that show the impact over the 30-year period. Figure 7 shows the infant deaths

Figure 4. Infant mortality linked to low birthweight, by province



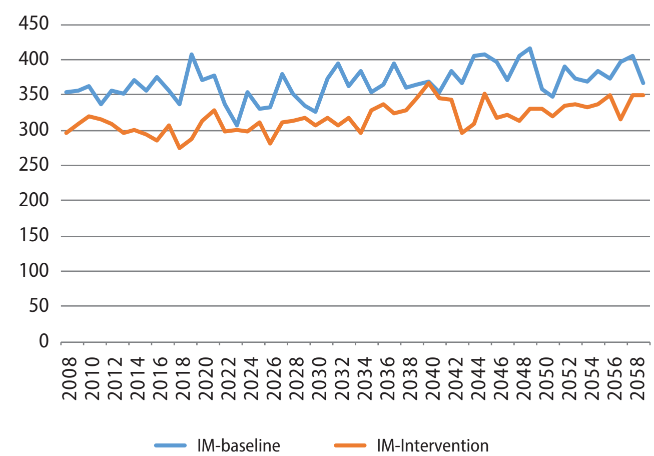


Figure 5. Stunting trends, by province

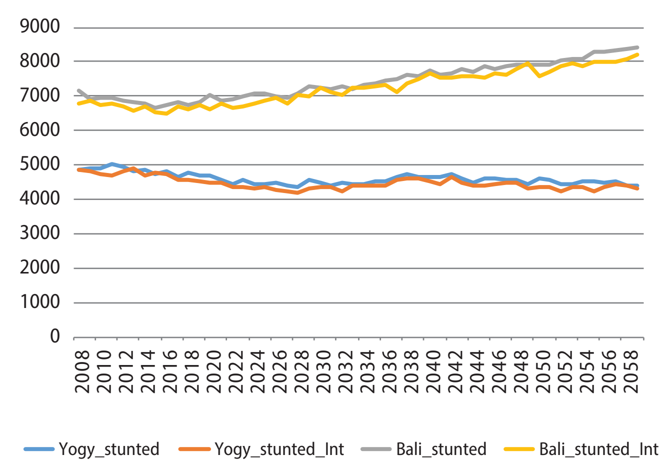


Figure 6. Cumulative low birthweight births avoided by the intervention, by province

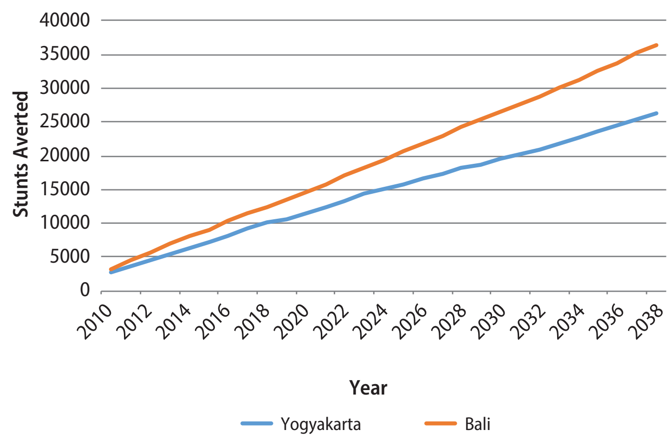


Figure 7. Infant deaths averted by the low birthweight intervention, by province

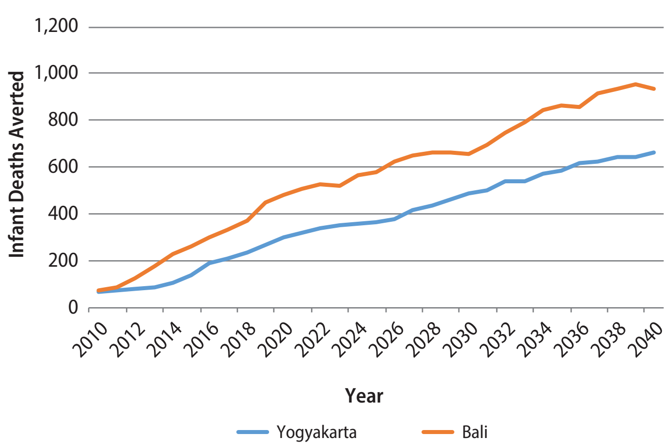
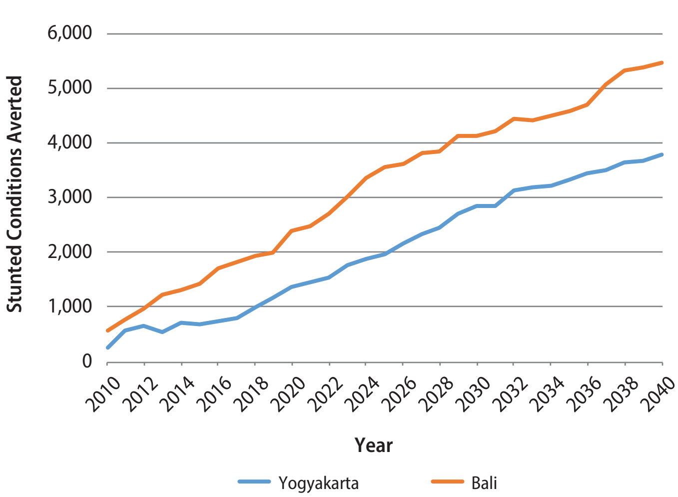


Figure 8. Cumulative stunted conditions averted by the low birthweight intervention, by province



averted by the intervention and Figure 8 shows the number of stunting conditions specifically averted by the low birthweight intervention. The results present cumulative differences in stunting cases averted and estimate that approximately 18,000 cases in Bali and 12,000 cases in Yogyakarta would be prevented by the intervention over a 30-year simulation period.

The results in both Figures 7 and 8 depict annual differences between the infant mortality projections with and without the intervention, accumulated over a 30-year period. For infant deaths avoided, the estimates predicted by the model are modest. This estimate is a consequence of the product of the proportion of infant deaths that are linked to low birthweight (19 percent) and the anticipated impact of the micronutrient supplementation intervention (16 percent) on lowering the incidence of low birthweight.

The cumulative stunting projections presented in Figure 8 show stunting trends from all causes including low birthweight births. The impact of the intervention is modest; nevertheless, introducing the intervention avoids more than 300 stunting cases per year.

In summary, the low birthweight model described in this manuscript was designed to illustrate future patterns and trends in child health outcomes in two provinces of Indonesia. The outcomes are geospatial projections of a population undergoing changes due to aging, disease, and disease interventions that represent hypothetical changes in public health policy. The outcome of this simulation model suggests that an intervention targeting pregnant women to prevent low birthweight births, with an effectiveness rate of a modest 16 percent fosters a small reduction in infant mortality and a more significant impact on the incidence of stunting. Under our model scenario, we estimate that over a 30-year period, more than 30,000 cases of childhood stunting in the two provinces of Bali and Yogyakarta could be avoided.

Discussion

Traditionally, with respect to child mortality and undernutrition reaching the remote, the poorest and most-in-need children has been considered by policymakers as too costly, time-consuming and difficult to pursue with the limited purses of international aid and public finance. Carrera and colleagues reviewed this premise using a mathematical-modelling approach to compare cost-effectiveness (in terms of child deaths and stunting events) averted between two approaches (from 2011–2015 in 14 countries).[37] The first approach was an equity-focused approach that prioritized the most deprived communities. The second was a mainstream approach representing current strategies. Their findings support the view that child mortality and undernutrition continue with higher concentrations of child deaths and undernutrition in the most deprived communities. However, they further indicate that higher effects for averting both child mortality and stunting are possible by prioritizing the poorest and most marginalized populations.

We propose that applying our model can pave the way for improving the health of children and adults of future generations for Indonesians by examining specific regional intervention policies. Poor infant nutrition is a major risk factor for chronic diseases, in particular abdominal obesity, type 2 diabetes, hypertension, and cardiovascular disease.[36] Our model can identify policies for preventing LBW and stunting, across the diverse Indonesian landscape. Furthermore, by targeting health-deprived populations, we can identify region-specific approaches with higher cost-effectiveness, while reducing inequities in effective intervention coverage, health outcomes, and out-of-pocket spending between the most and least deprived groups—a necessity for a country with limited resources and a decentralized health care system.

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