The future of infant health and mortality in sub-Saharan Africa: Evaluating the relative importance of changes in socio-economics versus climate

Introduction

In pregnancy and child/infant health research (Grace et al. 2014, Grace et al. 2012) we observe the sensitivity of the health of very young children to changes in climate as well as to different measures of development. After considering both areas of scientific inquiry, researchers and policy makers are left with the question: To reduce infant mortality, and given limited resources, is it best to invest in development strategies or in climate mitigation strategies? The goal of this research is to begin to answer that question through the exploration of infant health and mortality in sub-Saharan Africa with attention to the climate and socio-economic scenarios.

Many countries in sub-Saharan Africa report some of the highest IMR in the world (CIA, 2012). Households that have experienced an infant death may face significant social stigma and financial costs. Additionally, because of the theoretical link between high IMR and fertility rates, higher fertility (perhaps owing to "insurance births") may be observed in communities characterized by high IMR. In short, IMR can contribute to stymied individual/household- and community-level development. At the same time, subsistence farming and small-scale farming dominate the economic systems of many sub-Saharan African countries. The majority of subsistence/small-scale African farmers are reliant on rainfall to produce their crops (Morton, 2007). This reliance on rainfed agriculture creates a situation of extreme vulnerability for individuals and communities to unstable weather or climate change (Cooper et al., 2008, Morton, 2007, Jones and Thornton 2003). Finally, sub-Saharan Africa is characterized by low levels of health care access, educational attainment, road-networks, clean water and electricity. In other words, sub-Saharan African ranks low on most indices of development (UNDP 2014). Given the high level of vulnerability of many African communities to climate change, in addition to the low level of development, exploring the relative impacts of each of these factors on infant health and mortality can contribute to improving scientific understanding of the link between population, environment, and development.

To conduct this analysis we rely on 5 shared socioeconomic pathways (SSPs), climate scenarios (specifically rainfall and temperature) and geocoded infant health and mortality data from Demographic and Health Survey (DHS) data from 21 African countries.

Data and Methods

Our first objective is to identify communities characterized by high infant mortality and poor infant health that may lead to significant health challenges (specifically low birth weight). We then explore how infant mortality might increase and infant health might be negatively impacted as a result of anticipated trends in warming and drying. Finally we examine to what extent these changes might be mitigated by socio-economic development. The data required for this analysis are mortality/health, climate and the SSPs.

Health

Our measures of individual physical and socio-economic variables come from Demographic and Health Surveys (DHS). The DHS records contain detailed anthropometric and mortality data on children under 5 years of age at the time of the survey. The DHS provides several measures of individual-, household- and community-level resources and living conditions.

SSPs

Shared socioeconomic pathways (SSPs) describe a set of "plausible alternative trends in the evolution of society and natural systems" and are used in combination with climate scenarios to help identify and describe future society-climate situations (O'Neill et al. 2013). SSPs intentionally contain no information on climate change or climate policies, rather they are focused on population and development to allow flexibility in use with different climate scenarios (O'Neill et al. 2013, Lutz, Butz and KC, forthcoming). Using the SSPs in combination with climate scenarios, researchers have deduced various climate outcomes related to different population and development futures.

Five core shared socio-economic pathways

SSP1 Sustainability
The world shifts gradually, but dramatically, toward a more sustainable path. Management of the global commons slowly improves, educational and health investments accelerate the demographic transition, and concerns with economic growth shift toward the implications for human well-being. Overall energy and resource use is reduced over the longer term, and renewables become more attractive.
SSP 2 Middle of the Road
Development and income growth proceeds unevenly, with only some countries making relatively good progress. Global and national institutions work toward but make slow progress in achieving sustainable development goals. Technological developments proceed apace, but without fundamental breakthroughs. Global population growth is moderate; education investments are not high enough to accelerate the transition to low fertility rates in low-income countries.
SSP 3 Fragmentation
Growing interest in regional identity and concerns about competitiveness and security push countries to increasingly focus on domestic or, at most, regional issues. Policies are oriented toward security, and countries focus on achieving energy and food security goals within their own region, at the expense of broader-based development. Population growth is low in industrialized

and high in developing countries. Inequities are high, especially in developing countries. There is growing resource intensity and fossil fuel dependency along with difficulty in achieving international cooperation.
SSP 4 Inequality
In this world, inequalities increase, both between and within countries. Vulnerable groups are largely outside the mainstream globalized economic system and have little representation in national and global institutions, which emphasize international competitiveness. This is a world with low social cohesion, and regularly in social conflict and unrest. Power becomes more concentrated in a relatively small political and business elite, even in democratic societies. Energy companies diversify their energy sources to hedge against price fluctuations, investing in carbon-intensive fuels such as coal and unconventional oil, but also low-carbon energy sources.
SSP 5 Conventional Development
Driven by the economic success of industrialized and emerging economies, this world places increasing faith in competitive markets, innovation, and participatory societies to produce rapid technological progress and development of human capital as the path to sustainable development. Global markets are increasingly integrated, and there are strong investments in health, education, and institutions to enhance human and social capital. At the same time, the push for economic and social development is coupled with the exploitation of abundant fossil fuel resources and the adoption of resource and energy intensive lifestyle around the world.

Source: Based on initial drafts of narratives in O'Neill et al. *2012a*, to be updated in O'Neill et al. (under review) and Hunter and O'Neill (2014).

Climate Variables

Precipitation: The precipitation data is observed monthly at 0.05 degree spatial resolution (~5km). Each grid cell records the total precipitation (in mm) for a given month at that location. Precipitation records for each child are generated by averaging grid cells from a 10 km radius around the child's sampling cluster. This is done separately for every month one year before the child's birth date. Monthly precipitation values are then summed over trimesters to create a measure of total precipitation during each 3 month period one year before the child's birth. Additionally, using the FEWS NET growing calendar information, we sum the rain per trimester that falls within the growing season. For example, if the first trimester of the pregnancy contains only one month of the prime rainy season for that region then only the precipitation during that rainy season month is counted. In this way, we can examine relationship between rain and birth weight with attention to the needs of subsistence farmers.

Temperature: Our objective is to measure heat stress occurring prior to and during the pregnancy as well as during the child's life (when we are observing infant mortality). Our primary measure is the count of days in each trimester where the maximum daytime temperature exceeds the long term average maximum daytime temperature for that calendar day.

To obtain this measure we first calculate the long-term average maximum daily temperature (tmax) for a given calendar day (d) and grid cell (g), over 28 years (y) of observations. We then subtract that mean from each corresponding grid cell and calendar day to create a field of maximum temperature anomalies:

$$\overline{tmax}_{(d,g)} = \frac{1}{Y}\sum_{y=1}^{Y} tmax_{(y,d,g)}$$

$$\widetilde{tmax}_{(y,d,g)} = tmax_{(y,d,g)} - \overline{tmax}_{(d,g)}$$

The anomaly values are then joined to the cluster locations based on the 12 months before the child's birth and a 10 km radius surrounding the sample cluster location. We then count the number of days in each birth month where the grid cell values exceeded the average maximum daily temperature:

$$tcount_{(y,d,g)} = \begin{cases} 1 & \text{if } \widetilde{tmax}_{(y,d,g)} \geq 0 \\ 0 & \text{if } \widetilde{tmax}_{(y,d,g)} < 0 \end{cases}$$

These are then summed over trimesters to get a count of hot days during each trimester.

Methodological Approach

Our approach centers on evaluating the out of sample prediction accuracy from several statistical models that have the same inputs but are estimated in different ways. We will use regression analysis as well as classification trees to identify the correlates of infant mortality and health. We then use the models with the best predictive performance to examine how outcomes change given a particular combination of climate and SSPs.

Our starting point is a multi-level regression model of infant birth weight as dependent on climate and household socio-development factors. We also construct a similar model for infant mortality. These models are specified based on theory and prior empirical work with the goal of identifying marginal effects of precipitation and temperature on birth-weight. The purpose of the model is to produce a parsimonious model to identify conditional population means. However several restrictions on the model can be relaxed to improve the overall predictive power. Specifically we will fit flexible models, allowing the coefficients to vary by spatial location and across domain of the temperature and precipitation variables.

We will assess model fit through a series of 'leave-one-out' cross-validation exercises. To assess the ability of the model to predict spatial gaps, we will iteratively remove all observations within a given region, re-estimate the model, and predict birthweight values for the observations that were removed. We will conduct a similar exercise where we remove all observations from a given year. The models with the smallest prediction errors in these exercises will be used to conduct the scenario analysis.

The first set of scenarios will examine the impacts of predicted climate trends on low birthweight and infant mortality. A recent preliminary analysis conducted by one of the authors suggests that the coastal regions of east Africa will become 15% dryer and warmer by 2030 but that some of the inland regions will remain unchanged. Using these inputs we will re-run the selected models and produce a map of the resulting changes in birthweight.

We will then couple these scenarios with observed trends of key socioeconomic variables as presented in the SSP framework. For example, in preliminary research we found access to electricity had a positive impact on child birthweight. Using country specific data on electricity access with the SSP framework indicating different development scenarios we will examine to what extent the potential negative impacts of climate change can be mitigated if a certain percentage of the population without electricity has access. We will also attempt to evaluate these impacts at the subnational level. A household without electricity will be 'given' electricity with a probability based on the number of households in the region that that currently have electricity. We will run similar scenarios with other key SSP variables including water access and the mother's education.

The end result will be a map that highlights populations that are at risk of decreased birthweigtht resulting from climate change and also shows where these risks can be potentially mitigated with increased access to key infrastructure and resources.

Preliminary results

We have conducted a preliminary analysis evaluating birth weight and making basic changes to education and electricity status. To gauge the potential impact of increased drying we reduced the amount of precipitation received by 100 mm in all trimesters where the estimate of rainfall was statistically significant. To simulate the effects associated with an increase in temperatures, we increased the number of warm days by 45[1], again focusing only on the statistically significant trimesters. Finally because warming and drying trends tend to be correlated we combined the two scenarios and compare differences in predicted values when rainfall decreases and temperature increases.

[1] We did not allow the total number of warm days to exceed 90 or precipitation to fall below 0 mm.

We found that that the ‘dry’ (less rain) scenario leads to average decrease in birthweight of 9g , a ‘warm’ scenario leads to an average loss of 23g, and the combined (dry+warm) scenario leads to an average loss of 32g.

We also explore how the effects of warming and drying might be mitigated by increased access to electricity and education. We randomly selected ½ of the woman who report having no education and change there education status to ‘primary’. We also randomly select ½ the households that have no electricity and changed the status to having electricity. Re-running the models with the modified data (higher education and more electricity) increased the average birth weight by 19g. Finally we combined all the scenarios (dryer, warmer, more education and more electricity) and found that average birthweight decreased by 13g, about 1/3 the loss on the dryer-warmer scenario.

The scenario exercise illustrates some simple points. Substantial changes in rainfall or temperature can have as large an impact on birth weights as key societal indicators such as educational attainment and access to electricity. In addition improvements in education and basic infrastructure may mitigate against the detrimental effects of a warmer, dryer climate.

Birth weight scenarios analysis

	Mean Predicted Birthweight (using standard regression model)	Mean Predicted Birthweight (using scenario)	Percent Change in Birthweight
Temperature Increase**	3217.37 g	3208.16 g	-.29
Precipitation Decrease*	3217.37 g	3193.97 g	-.73
Precipitation Decrease x Temperature Increase	3217.37 g	3184.66 g	-1.02
Increase Education and Add Electricity	3217.37 g	3236.49 g	.59
Increase Education, Add Electricity, Temperature Increase x Precipitation Decrease	3217.37 g	3203.78 g	-.42

*Represented by a 100 mm decline in trimester 0.
**Represented by a 45 day increase in trimester 0.

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