Climate Variability and Infant Mortality in Africa

Sarah Baird, George Washington University

Jed Friedman, World Bank

Marc Smitz, World Bank

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Abstract

Changes in heat and precipitation as a result of climate change are expected to have adverse effects on health, particularly among the most vulnerable populations. These changes can affect health both directly, through extreme events and changes in the disease environment, as well as indirectly through its impact on the economic livelihood of the population. In this paper we utilize an extensive dataset of over 400,000 births combined with detailed historical geo-spatial weather data on temperature and rainfall to investigate the impact of extreme weather events on infant survival in Africa. Our results suggest that both extreme heat and extreme rainfall affect the likelihood of infant survival. In particular, we find that excessive heat around the month of birth is predictive of an increased likelihood of death, particularly for neonates but also for older infants. Rainfall during the third trimester of pregnancy increases the likelihood of death for neonates. We also find evidence that excess rainfall can be protective under certain scenarios, most likely as a result of positive income shocks. Utilizing our empirical estimates, we explore four different climate change scenarios that suggest an additional 400 to 900 thousand infant deaths in Africa over the period 2010-2030, due to the impact of increased heat and precipitation change, in the absence of effective adaptation or mitigation efforts.

1. Introduction

It has long been recognized that periods of extreme weather pose risks to human populations and in the history of human development much effort has been devoted to adapt to these risks. Currently, anticipated future climate change presents new potential threats across a variety of dimensions including physical health (US National Research Council 2010). Indeed a recent review considers global climate change to be one of the greatest health threats currently facing the world's population (Lancet 2009). Climate change involves not only increased average temperatures, but also increased variability in weather, including the potential for mounting frequent and severe extreme weather events. These extreme weather events can have a substantial impact, both indirect and direct, on health, particularly for vulnerable populations.

There are three main channels of transmission that are put forth in the literature as key drivers of the impact of weather on health. The first channel is the direct impact of weather. Clearly, tornados, hurricanes and heavy floods can have devastating health impacts, both on physical health and mental health (such as Frankenberg et al. 2008). Extreme heat and cold can also impact health, particularly among the elderly and children (see, for example, Curriero et al. 2002; Keatinge et al. 2000; Yang et al. 2009; Hashizume et al. 2009; O'Neill, Zanobetti, and Schwartz 2003).

Second, weather affects the infectious disease prevalence (Dobson 2005). For example cholera and salmonella replicate more rapidly in warm temperature (Lipp, Huq and Colwell 2002 and Kovats et al. 2004), and malaria and dengue respond to temperature, wind, rainfall and humidity (Rogers and Randolph 2000). A warmer environment increases the pace of reproduction and the length of the active vector season (see, for example, Bayoh and Lindsay 2003; Amstrong and Bransby-Williams 1961; Craig, Snow and le Sueur 1999; Kirby and Lindsay 2004; Epstein 2005). Climate change may open new geographic ranges for diseases to spread—the rise in temperature over the highlands of East Africa is a likely explanation for the appearance of malaria is this previously malaria-free area (Zhou et al. 2004).

Finally, weather indirectly impacts health through its effect on the economic livelihood of the population. Changes in the climatic conditions, as well as extreme events such as flood, drought, cold or heat wave are likely to affect agricultural productivity, and perhaps productivity in other labor intensive sectors as well. In the US, evidence suggests that climate change will have a negative effect on cereal production (Schenkler and Roberts 2009). In drier zones such as West Africa, droughts have been shown to be associated with lower food production and consumption in both the short and long run (Fafchamps, Udry and Czukas 1998; Kazianga and Udry 2006; Dercon 2004). In equatorial zones, an excess of rain, especially in the dry season, negatively impacts soil regeneration and agricultural productivity (Wilkie et al 1999). Although the potential impacts of climate change continue to be debated, the consensus is that the most vulnerable regions in the developing world, which are located in weather sensitive regions and have fewer capacities to adapt, will suffer a decrease in food production as a result of global warming (McMichael 2001; Parry et al. 2004; Naylor et al. 2007; Lobell and Field 2007; Reilly 1999).

There is some empirical evidence on the impact of weather on health from both developed and developing countries. The developed country literature largely focuses on the short run effects of weather utilizing natural experiments, such as the heat wave the struck Europe over the 2003 summer, or the El Niño climatic cycle in Asia and Latin America (CITATIONS).[1] In the developing world, several studies focus on the longer-run impacts of rainfall during key developmental periods on height for age. Maccini and Yang (2008) find that rainfall in early life is associated with increased height, schooling and socio-economic achievement for woman in Indonesia. Droughts and their associated loss in food production in Ethiopia led to lower height for age of children (Yamano et al. 2005), as well as lower height later in life (Porter 2009). Godoy et al. (2005; 2008) find that a rise in rain variability during gestation and early childhood significantly decreases the height-for-age of boys and girls, as well as the adult height of woman. These studies clearly point to the role that weather during in-utero and the first year of life can play in determining health outcomes.

[1] There is also a related literature on air quality and infant mortality that finds that air quality in both the developed and developing country context has a negative impact on infant mortality (Chay and Greenstone 2003; Jayachandran 2009; Currie, Neidell and Schieder 2009).

Given the potential impacts of climate change on health, it is an area where considerably more research is needed, particularly in developing countries where the likely effects of climate change on health will be most strongly felt. In fact, according to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007) "Gaps in information persist on trends in climate, health and environment in low-income countries, where data are limited and other health priorities take precedence for research and policy development. Climate-change-related health impact assessments in low- and middle-income countries will be instrumental in guiding adaptation projects and investments."

This paper attempts to help address this gap in the literature by investigating the relationship between extreme weather events and one key dimension of child health – infant survival – in Africa. In particular this paper addresses two questions. First, does exposure to extreme weather events at or around birth decrease the likelihood of survival? Second, what does this relationship between extreme weather events and mortality predict in terms of the health impacts of anticipated future changes in local mean temperature and precipitation?

In order to answer these questions, this paper utilizes birth level data from the Demographic and Health Survey (DHS) as well as climate data from a number of sources including daily temperature and rain data from the National Oceanographic and Atmospheric Administration (NOAA).[2] The large-scale and detailed dataset allows us to clearly identify the timing of the extreme weather event and the timing of the infant's death thus enabling us to estimate at what stage in development (during pregnancy, neonate, infant, etc.) children under one year are most vulnerable to the impacts of weather.

Overall, our results suggest that mortality in the first year of life is sensitive to both rainfall and temperature. Excess rainfall right before birth increases the likelihood of neonatal death, likely a

[2] Two recent papers explore the same or related questions. Wang, Kanji and Bandyopadhyay (2009) utilize the African Rainfall and Temperature Evaluation System and the DHS to study the relationship between health and temperature. These authors, however, only exploit country level averages leaving them with fewer than 200 observations and dind no impact of weather on IMR. Kim (2009) also utilizes DHS data to investigate the impact of rainfall in West Africa on fertility and child mortality.

result of a change in the disease environment. More precisely, a one standard deviation increase in rain over the local mean increases the likelihood of death by 0.814 deaths per 1000 births. We also find, however, that rainfall can be protective, particularly during the second trimester of pregnancy, likely reflecting an income effect as the gains from elevated precipitation can eventually be translated into higher agricultural yields. Turning to temperature we see almost all the impact coming during exposure to excessive heat in the first quarter of life, with, for example, a one standard deviation increase in temperature during the first month of birth increasing the likelihood of neonatal death by 1.074 deaths per 1000 births. We find no protective effect of extreme temperature at any period. There are some differences in the relationship between weather and death under one year between boys and girls, with girls benefiting more from the protective effect of rain, while being more susceptible to high temperature. We find some interesting differences between rural and urban areas, with urban areas more susceptible to extreme heat, and rainfall seemingly playing more of a protective role in rural areas as would be expected if the protective channel occurs through increased agricultural yields. Robustness checks of our main specification support these findings.

Finally, we utilize the estimates from our analysis to construct a projection of the future impact of climate change on infant death for the countries in our sample, as well as for Africa as a whole, that can arise in the absence of any mitigation or adaptation efforts. Relying on four different climate scenarios and the European Center for Medium-range Weather Forecasting model, we find that the increases in mean temperature and precipitation anticipated under these scenarios will lead to an increase in the infant mortality likelihood of 10 to 25 deaths per 1000 births, or an additional 8 to 18 million infant deaths over the 2010-2030 period. This range of estimates, an average of an additional 385,000 to 920,000 deaths per year, compares to an additional 2,600 infant deaths per year in the US as forecast by Deschenes and Greenstone (2007).

The following section describes the data and construction of variables. Section 3 discusses the econometric specification and results, while Section 4 projects the impact estimates into various climate change scenarios. Section 5 concludes.

2. Data and construction of variables

The data on births and mortality come from 46 DHS datasets covering 24 countries in Africa. These surveys took place between 1983 and 2006, and we utilize data on over 200,000 mothers linked to over 400,000 births. The list of specific surveys and their sample sizes are given in Table 1. We limit our attention to these surveys from among the larger number of all DHS surveys conducted in Africa (65 and counting) because the selected surveys contain geo-referenced data on each surveyed household thus enabling a direct link to historical weather maps. Table 1 also gives the number of infant deaths recorded in the data. The implied infant mortality rates over the various periods averages 100.4 deaths per 1000 births and varies from a high of 148.7 in the Liberia surveys to a low of 42.1 in Namibia.

The DHS ask women a set of questions about the date of birth, current vital statistics, and date of death (if deceased) of all children ever born. We use the responses to these questions to construct retrospective birth and death histories, closely following Baird, Friedman and Schady (2010). Our measure of infant mortality is an indicator that takes on the value of one if a child died at a reported age of 12 months or younger.[3] We discard information for children born within 12 months of the survey when calculating mortality rates to avoid complications with censored data. In order to avoid recall bias we do not use information on births that occurred more than 10 years prior to the survey.[4] Furthermore, any given survey is representative of women ages 15-49 at the time of the survey, but is not representative of all births and child deaths in earlier years. To see this, note that a woman aged 49 in a survey carried out in 2000 would have been 39 in 1990. If no surveys were carried out between 1990 and 2000 in this country, no data would be available on births to women aged 40 or older in 1990. To avoid this compositional problem, we discard from the sample births to

[3] We use this measure of infant mortality, rather than the standard definition of mortality for children *younger than* 12 months, because of age heaping in reports of mortality. Results are robust to the more restrictive definition of infant mortality.

[4] Although the DHS are a rich source of data, they also have some limitations for our analysis, both of which are related to the use of *retrospective* information in the DHS to construct birth and death histories. These issues of recall bias and representativeness are discussed in detail in Baird, Friedman and Schady (2010).

women age 40 or older. Our analysis therefore provides meaningful estimates of the relationship between weather and infant mortality for women aged 15 to 39.[5] This retrospective construction of births and infant deaths to women aged 15-39 results in series of varying lengths and with varying start periods depending on the number and dates of DHS surveys in each country. Finally, since we geo-spatially link households to local weather data, we exclude a small number of observations that have missing GPS information.[6]

The weather data covering the period 1978 – 2000 comes from NOAA and includes daily measures of temperature and rainfall imputed at a level of 0.5 degrees of longitude/latitude from surrounding weather stations. We normalize our weather variables so that they are reported in terms of standard deviations from the long term mean for each particular calendar month, where the standard deviation and the long term mean are computed using 22 years of climate observations for each geographical cell-month observation. For computational tractability, we define each geo-spatial cell to be a square of 2 degrees of latitude and 2 degrees of longitude, which is about 200 Km square at the equator. Our total sample consists of 305 geographic cells.

3. Econometric specification and results

To estimate the effect of rainfall and temperature on infant mortality we pool all surveys and run regressions of the following form:

$$(1) \qquad \mathrm{D}^{\mathrm{p}}_{\mathrm{imcy}} = \alpha + \sum_{p=-3}^{P} [R_p + T_p + T_p^2]_{mcy} + f_{mc} + t_{cy} + t_{cy}^2 + \varepsilon_{imcy}$$

where D^p_{imcy} is an indicator variable that takes on the value of one if child *i* born in calendar month *m* in geo-spatial cell *c* in year *y* died in the first year of life, and is zero otherwise. The superscript *p* is used to indicate the timing, or phase, of observation in which the death may occur. We divide the periods of weather exposure into the following phases of pregnancy: the first, second, and third

[5] We note, however, that a very small fraction of births in our sample of DHS countries occur to women age 40 or older. We lose a total of 19,617 births by dropping this group, or 4.1% of the total.
[6] This amounts to dropping 7,032 births, 1.4% of total observations.

trimesters of pregnancy, the first month of life (separately as neonatal mortality is a significant contributor to overall infant mortality), the next two months of life, and then the second, third, and fourth quarters of the first year of life. We run separate regressions for each phase to avoid issues of censoring. Rainfall (*R*) and temperature (*T*), measured in millimeters and degrees centigrade respectively, are normalized in terms of standard deviations from their month-cell specific 22 year mean. Rainfall enters the equation linearly, while temperature enters in a quadratic. The specification also includes calendar month-geocell fixed effects (*f*) to control for all time-invariant characteristics at that level (for example infant mortality systematically fluctuates depending on the calendar month, see Lokshin and Radyakin (2009)) as well as quadratic geocell-specific annual time trends (*t*). The cell-specific time trends control for longer run secular gains in infant survival. Standard errors are clustered at the cell level which corrects for autocorrelation in shocks to infant mortality of arbitrary form within cell.

Decisions on the functional form for rainfall and temperature were made based on the non-parametric figures shown in Figures 1a and 1b. These figures relay the expected Infant Mortality Rate as a function of exposure to weather at different periods in pregnancy or post-birth. They are all estimated with locally-weighted least squares and a bandwidth of 1.5 standard deviations of the respective weather variable. Figure 1a reports the associations between temperature and IMR. Large positive deviations in monthly mean temperature from their longer-term average are associated with elevated mortality. The figures in each phase suggest some convex curvature in this relation and even a U-shaped relation between heat exposure in the 2^{nd} and 3^{rd} months of life and subsequent mortality. For this reason we choose to model the temperature relation as a quadratic. Infant mortality associations with precipitation are much less clear – where there is a suggested slope, such as in the second quarter of life, it appears that a linear functional form will suffice.

3.1. Overall Results

Tables 2a and 2b present the results of estimating equation (1) for the overall sample. Table 2a focuses on the rainfall results while Table 2b focuses on the temperature results. The regression coefficients (and standard errors) are multiplied by 1000 so that any result can easily be scaled in terms of an impact on the infant mortality rate. Focusing first on rainfall and neo-natal mortality, we see from Column 1 in Table 2a that a one standard deviation increase in rainfall during the third trimester increases the likelihood of a death during the neonatal period by 0.814 deaths per 1000. The significant positive association with mortality may reflect the direct impact of weather on mortality (perhaps unlikely since the rain shock occurs in the third trimester of pregnancy but death occurs after the (live) birth), or a change in the disease environment soon before birth caused by excess rain. Rainfall during the earlier trimesters of pregnancy appear unrelated to the likelihood of survival to the first month of life. We see no impact of rainfall on the remainder of the first three quarters of life. Interestingly, precipitation again emerges as a determinant of survival in the last quarter (9-12 months after birth) of infant life. However here excess rainfall during the second trimester is protective—a one standard deviation increase in rain decreases the likelihood of infant death by 0.460 deaths per 1000. This protective effect is echoed by rainfall in the 3rd quarter after birth where again a one SD increase in rain decreases the likelihood of death by .449 deaths per 1000 births. This result may reflect a positive income shock as a result of improved crop yields given the delays through which these protective effects are revealed and the seasonal nature of the effect occurring at roughly a 12 month frequency. Additional analysis will explore further with distinctions of rain impact interacted with growing season.

Turning now to the impact of temperature, we see in Table 2b that excess heat during the month of birth increases the possibility of a child dying during the neonatal period. A one standard deviation increase in heat above the mean increases the rate of death by 1.074 deaths per 1000 births, with a p-value of 0.022 on the joint test of the temperature indicators. The quadratic functional form implies that a 2 standard deviation increase in heat for this month raises the likelihood of death by 2.96 deaths per 1000 births. This result likely reflects the direct impact of excess heat on mortality. Temperature during the month of birth has a similar impact on infant mortality for those that die in months two or three of life, indicating some persistence in the effects of early exposure to heat. Temperature during the next two months of life also has a delayed positive and significant impact on infant mortality for those that die in the second or third quarter of life. Given the relative immediacy of the impact of heat – affecting survival either in the same month or in the months immediate following, the influence of heat is likely through a direct weakening of health or a change in the disease environment (or both). We find no relationship between temperature and infant death in the fourth quarter of life, or any impact of temperature during pregnancy.[7]

3.2. Gender

These overall results may conceal important differences in the relationship between extreme weather and infant death depending on the gender of the child. Any difference may simply have to do with biological differences that make one gender more or less susceptible to shocks, but there may also be behavioral differences in the response of households to weather shocks, such as an increased likelihood to protect sons when there is a negative shock. Table 3a investigates the effects of rainfall on death disaggregated by the gender of the child. Looking at neonatal death, we see that a one standard deviation increase in rainfall above the mean during the third trimester increases the likelihood of death for a boy during the first month by 0.825 deaths in 1000 births. The magnitude for girls is similar, although not statistically significant. These results suggest that the change in disease environment around birth affects both boys and girls roughly equally.

For girls, we see that a one standard deviation increase in rainfall during the first trimester of pregnancy increases the likelihood of death during the first month by 0.922 deaths per 1000. This coefficient is about three times as large as that for boys. This may reflect a selection effect where girl fetuses that face a rainfall shock during their first semester are more likely to survive to birth than

[7] These results are of course conditional on live births - temperature during pregnancy may be associated with the gestational health of the fetus which in turn can affect the likelihood of a live birth (Catalano et al. (2008)). Further analysis will explore this matter.

boy fetuses even though they are weakened by it and subsequently at higher risk of mortality.[8] Similar to the overall results, we see very little impact of rain on death during months two and three as well as in the second quarter. We do however see that one additional standard deviation increase in rain during the third quarter increases the likelihood of girls' death by 0.503 deaths per 1000 in the third quarter, with no effect for boys. Finally, we see a strong protective effect for girls of excess rain during the third quarter on the likelihood of death during the fourth quarter—a one standard deviation increase in rain decreases the likelihood of death by 1.179 in 1000 and is significant at the 1% level. Again this result may reflect an income shock where excess rain provides higher crop yields allowing girls access to additional consumption and better nutrition.

Turning now to temperature, we see no impact of temperature on neonate death for boys, but strong impacts on neonate death for girls, both during the second trimester and the month of birth. The second trimester results may be driven by a selection effect (see footnote 7), but the month of birth results could suggest that girl neonates are more sensitive to the consequences of excessive heat. The p-value on the joint effect of temperature during the month of birth is 0.03. When looking at death during months two and three, we again see that girls are more likely to be susceptible to heat during those same months. For boys, the results during the 2nd and 3rd month of life are somewhat unclear with negative effects of temperature during the first trimester, and protective effects during the second trimester. We also see a negative effect of temperature during the month of birth on survival the following two months. We see no effect of temperature on death in either the second or third quarter, but do see a protective effect for girls of excess heat during the first trimester on death in the fourth quarter.

3.3. Urban vs. Rural

[8] In comparison to females, male fetuses have a relatively difficult time surviving pregnancy (see Perls and Fretts, 1998; Mizuno, 2000) and this difference may be exacerbated during hardship periods. Almond et al. (2007) argue that, during the economic chaos associated with the Great Leap Forward in China, the ratio of male to female births fell because of an increase in spontaneous abortions of male fetuses. Given this, the health endowment of girls born may on average then be lower than that of boys, and this may result in higher mortality of girls *after birth*. However, regressions similar to equation (1) that relate the gender of the infant to weather exposure in-utero find no evidence of weather shocks affecting the gender composition of birth, thus casting doubt on this explanation.

There is reason to think that the impact of extreme weather events on infant mortality may differ substantially between urban and rural areas.[9] On the one hand, effects may be exacerbated in rural areas due to the impact on agricultural productivity as well as clean water supplies. On the other hand, heat waves are exacerbated in urban centers due to the heat island effect (Costello et al., 2009). Table 4 presents the results separated by urban and rural areas. One can see in Table 4a that there is no impact of rain on infant death prior to the fourth quarter of life in the first year for either rural or urban areas. (Although the relative magnitude of the precipitation effect in the third trimester is large for both urban and rural areas, it is on longer precisely estimated with the smaller sample sizes than that found in Table 2.) For death during the fourth quarter, rain appears to be somewhat protective in both urban and rural areas. In urban areas, a one standard deviation increase in rainfall during the fourth quarter of life decreases one's likelihood of death by 0.748 in 1000. This result could reflect an improved crop yield (or minimizing drought) or access to cleaner water as a result of increased rain. We see somewhat similar results for rural areas, with the impact coming slightly earlier, with a one standard deviation increase in rainfall during the third quarter of life decreasing one's likelihood of death by 0.571 in 1000. One also sees that rain during the second trimester is protective in rural areas, again a likely reflection of a positive income shock, given the suggested seasonality of the effect and the gender differential of impact.[10]

Turning now to temperature, we see substantial differences between rural and urban areas that appear to confirm the heat island effect – larger adverse consequences from excessive heat occur for urban births. In urban areas, positive deviations in temperature in both the second trimester and month of birth are significantly positively associated with an increased likelihood of infant death. This result could be the result of heat related stress during pregnancy negatively impacting the fetus, as well as malnourishment of the mother leading to less effective breastfeeding. On the other hand, we see no impact of temperature on neonatal mortality in rural areas. The impact of temperature on

[9] The sub-Saharan urban population is projected to double over the 2000 – 2030 period. (UNFPA, 2007).

[10] While many regions in Africa are not commonly known for son preference, Friedman & Schady (2009) find that the infant mortality of girls but not boysis elevated at times of macro-economic shocks in much of sub-Saharan Africa. This suggests that widespread latent son preference may be expressed during times of elevated stress.

infant death in rural areas is focused on deaths in the second and third quarters of life, and is concentrated to heat shocks in the second month of life. For urban infants, death in the third quarter of life is affected by excess during that quarter as well as the two months preceding. We see no impact of temperature on infant death in the fourth quarter in either rural or urban areas.

3.4. Specification robustness

Before turning to projecting the possible impacts of climate change on infant survival in Africa over the medium term, we conduct a number of robustness checks of our basic specification. Variations on the basic specification in equation 1 include (1) utilizing a cubic time trend instead of quadratic, (2) estimating the weather – mortality relation with disaggregated geo-spatial cells (0.5 instead of 2 degrees square) and (3) utilizing an alternative measure of weather severity. This alternative measure norms weather variability to a 5 year moving average rather than the entire 1978-2000 period to control for the possibility of weather trends in that period that can misattribute a trending period effect as a random weather shock. Tables 5a and 5b presents these results, focusing on neonatal death and death during the fourth quarter.[11] Columns one and two replicate the overall results for help with comparison. In Table 5a we focus on rainfall and see that utilizing a cubic trend as opposed to the quadratic trend does not change the results (columns three and four). Turning to the small cell estimation, we do see some minor differences. Looking first at neonatal death, although the signs are the same, we now see that rainfall is negative and significant in the second trimester, while rainfall during the third trimester is now insignificant. The impact on infant death during the fourth quarter of life largely remains the same. Finally, when we look at the alternative weather measure the results are very similar to those in the small cell estimation.

Turning to Table 5b and the impact of temperature, we see that the results are similar across specifications for neonatal death and death during the fourth quarter. Although the magnitudes of the coefficients vary slightly, the results are qualitatively the same. The one coefficient where we see

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[11] We focus on these two columns to help streamline the results. The remaining specifications are available from the authors by request.

slight differences is on the impact of temperature during the second trimester for the small cell and alternative weather specifications, but the joint effect still remains insignificant. In general we conclude that the overall results are robust to alternative secular time trends, the level of geo-spatial aggregation, and weather reference period.[12]

4. Implications for future infant health in Africa

In this final section of analysis we turn to our projections of the anticipated impact of climate change over the medium term 2010-2030. To explore a range of possibilities we utilize four different scenarios combining projections of future population, economic growth, and fossil fuel usage provided by the Tyndall Center of the East Anglia University (Mitchell et al. 2004). The first panel of Table 6 describes the various assumptions made by these scenarios. These scenarios are applied to the European Center for Medium-range Weather Forecasting model. We normalize these projections to the historical weather data from 1978 – 2000 and construct cell level temperature and rainfall predictions for each year-month from 2010-2030. Utilizing these climate values, we then construct a likelihood of mortality for each year-month-cell. A country-month mortality likelihood is then calculated as a weighted average of all cells within the country, where the weights are given by the number of births in each cell in the most recent complete year found in the data. This national level likelihood is then multiplied by the expected number of births for that country-month and year. The birth projections derive from the U.N. World Population Prospects medium variant database (http://esa.un.org/unpp/index.asp) and we apportion births in any given future year across calendar months in the same proportion as observed in the DHS data.

Our birth level microdata covers 24 African countries, so we present the total excess death calculation for these same 24 countries. According the medium variant of the U.N. World Population Prospects, these 24 countries are expected to contribute 69% of all births in Africa over

[12] We also investigate an additional alternative weather specification. Instead of heat or rainfall expressed in terms of units of standard deviation from the long term mean for that spatial cell and calendar month, we adopt an absolute measure and count the number of days in a given period where the heat exceeds 35 degrees Celsius or the daily rainfall exceeds the 95th percentile (in millimeters) for that spatial cell and calendar month. Results, available upon request, are largely consistent with that reported here – the number of hot days is predictive of mortality in the period it occurs for neonates and infants 9-12 months old. Within-period rainfall also increases mortality for infants within every period, but is protective of mortality if it occurs in the 2nd trimester of life.

2010-2030, so to estimate a continent wide excess death figures we scale the excess death estimates for the 24 countries by 1/0.69.

This exercise produces a range of estimated excess deaths depending on the scenario. The lowest excess death estimate – 387,000 – derives from fragmented projected fossil energy use and slow projected rates of global economic growth. The greatest excess death estimate – 925,000 – arises from intensive projected fossil energy use and rapid material focused economic growth. To help contextualize these excess death estimates, the U.N. medium variant projection estimates 756 million births in all of Africa over 2010-2030, thus the mortality impacts of these climate change scenarios would raise the projected Infant Mortality Rate over this period from 0.51 to 1.22 additional deaths per 1000 live births.

While these excess death estimates appear large they of course do not attempt to account for possible global efforts to mitigate the severity of future climate change or local efforts to adapt to the rises in temperature and changes in precipitation. Indeed there is presumably much scope for local adaptation in terms of public health measures that mitigate the health consequences of excessive heat and precipitation including information campaigns and heat early warning systems. Additional activities include the adoption of protective designs for homes and communities, as well as increased household ability to regulate the indoor climate as incomes rise. Progress on either or both of mitigation and adaptation can hopefully avoid the most alarming forecasts summarized in Table 6.

5. Conclusion

Climate change is expected to have a substantial impact, both direct and indirect, on health, particularly for vulnerable populations. Changes in heat and precipitation can directly impact health through increased devastating events such as hurricanes and floods, as well as through changes in the disease environment. These changes can also have an indirect impact on health through its effect on the economic livelihood of populations.

This paper focused on one particular vulnerable population, infants in Africa, and utilized a dataset of over 400,000 births from the DHS to investigate the effect of extreme rainfall and temperature on death within the first year of life. The results suggested that both extreme temperature and rainfall impact the likelihood of dying during the first year of life. Excess rainfall is both detrimental and protective depending on the timing in which it occurs. Excess rainfall soon before birth increases the likelihood of neonatal death, likely the result of a change in the disease environment. On the other hand, rainfall during the second trimester appears protective of death if the infant survives to the fourth quarter of her first year, likely due to an income effect. The impact of rainfall is fairly similar for boys and girls, with the exception of strong protective effects during the third quarter of life on the likelihood of death during the fourth quarter for girls. We also find similar results for urban and rural areas, with rainfall being slightly more protective in rural areas.

Extreme temperature, on the other hand, is always detrimental, particularly during the first quarter of the first year. This result is true for the overall population and particularly for girls and infants of both sexes born in urban areas. We see no evidence of a counteracting positive effect of extreme temperature across specifications or sub-groups.

When we utilize these estimates to predict the number of excess deaths due to climate change between 2010 and 2030 we estimate an additional 400 to 900 thousand infant deaths throughout the continent. These estimates assume no effective attempt on the part of governments or populations to mitigate or adapt to the projected climate changes. Successful efforts for global mitigation or local adaptation can help to substantially avoid this human cost.

Without such efforts, the human toll may be severe. Numerous countries in Africa have made significant recent gains in their reduction of infant mortality and future progress can be threatened to some extent by anticipated climate change. To place the magnitude of this climate risk in context with regards to the standard interventions that governments implement to improve infant survival, we illustratively calculate the association between infant mortality and a variety of characteristics of mothers and children in the DHS known to be protective of infant health, and then compare these associations with the anticipated effects of climate change. This exercise suggests that the anticipated increase in infant mortality likelihood is comparable in magnitude to a 0.13 to 0.32 year's reduction in average mother's schooling, to an 40 to 100 gram reduction in average birth weight, or to roughly a two to four percentage point decline in the coverage of tetanus shots for pregnant women.[13] If African nations expected a future event to reduce maternal schooling, birth-weight, or tetanus coverage by this magnitude, national efforts, perhaps with donor support, to counteract this effect would likely be easily mobilized. The challenge to national policy makers is to identify the activities and interventions that can most effectively mitigate the anticipated adverse consequences for infant survival.

[13] Note that these associations should not be interpreted as *causal* effects because of their likely endogeneity. For example, mothers with more years of schooling are likely to have other (unmeasured) characteristics which make it less likely that their children die. In this case, the association we report is likely higher than the true causal effect. We report these associations simply as a way of contextualizing the magnitude of the anticipated effects of climate change.

6. References

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Figure 1a: Non-Parametric relationship between the Infant Mortality Rate and Temperature during pregnancy and the first year of life (bandwidth=1.5)

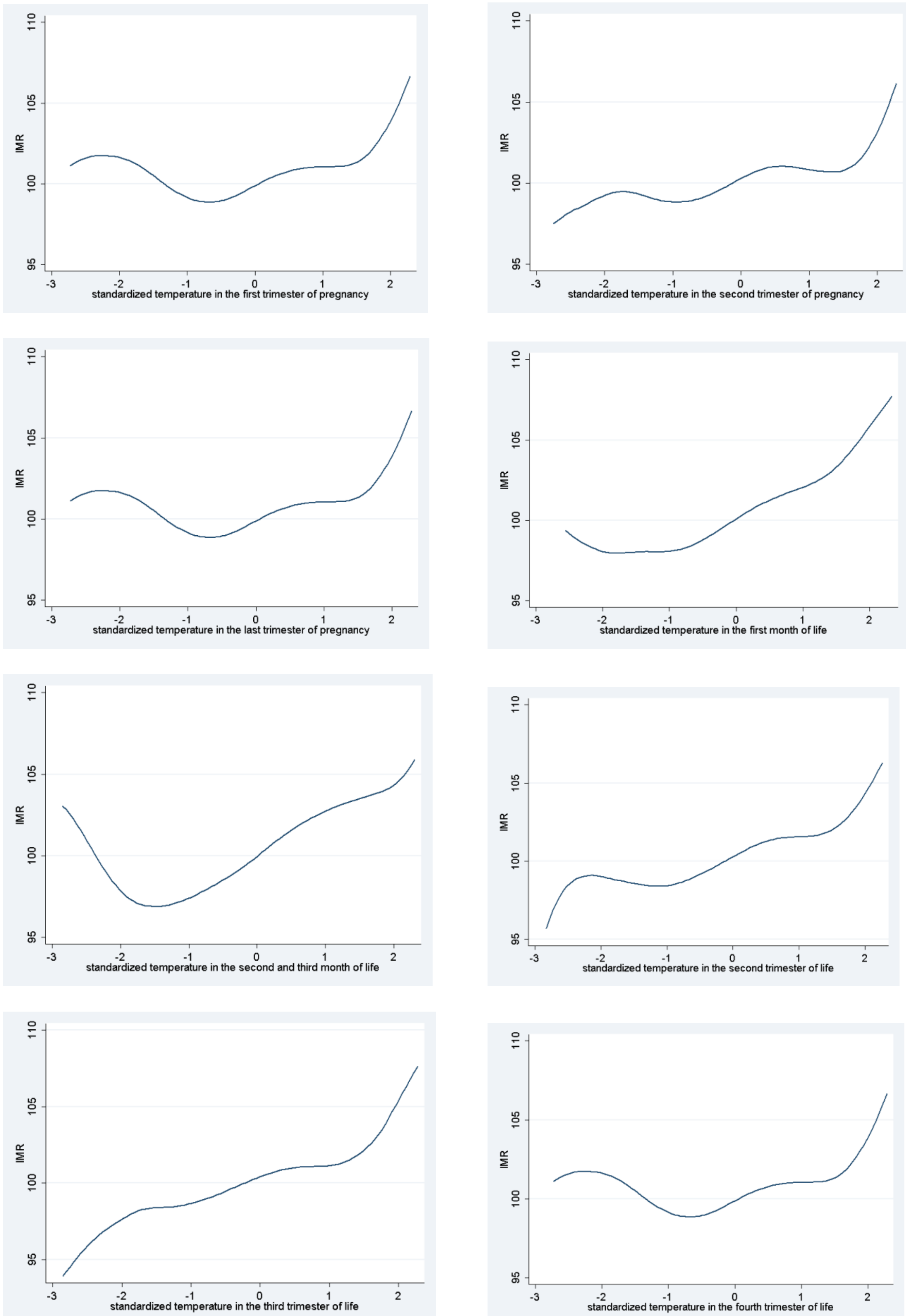

Figure 1b: Non-Parametric relationship between the Infant Mortality Rate and rainfall during pregnancy and the first year of life (bandwidth=1.5)

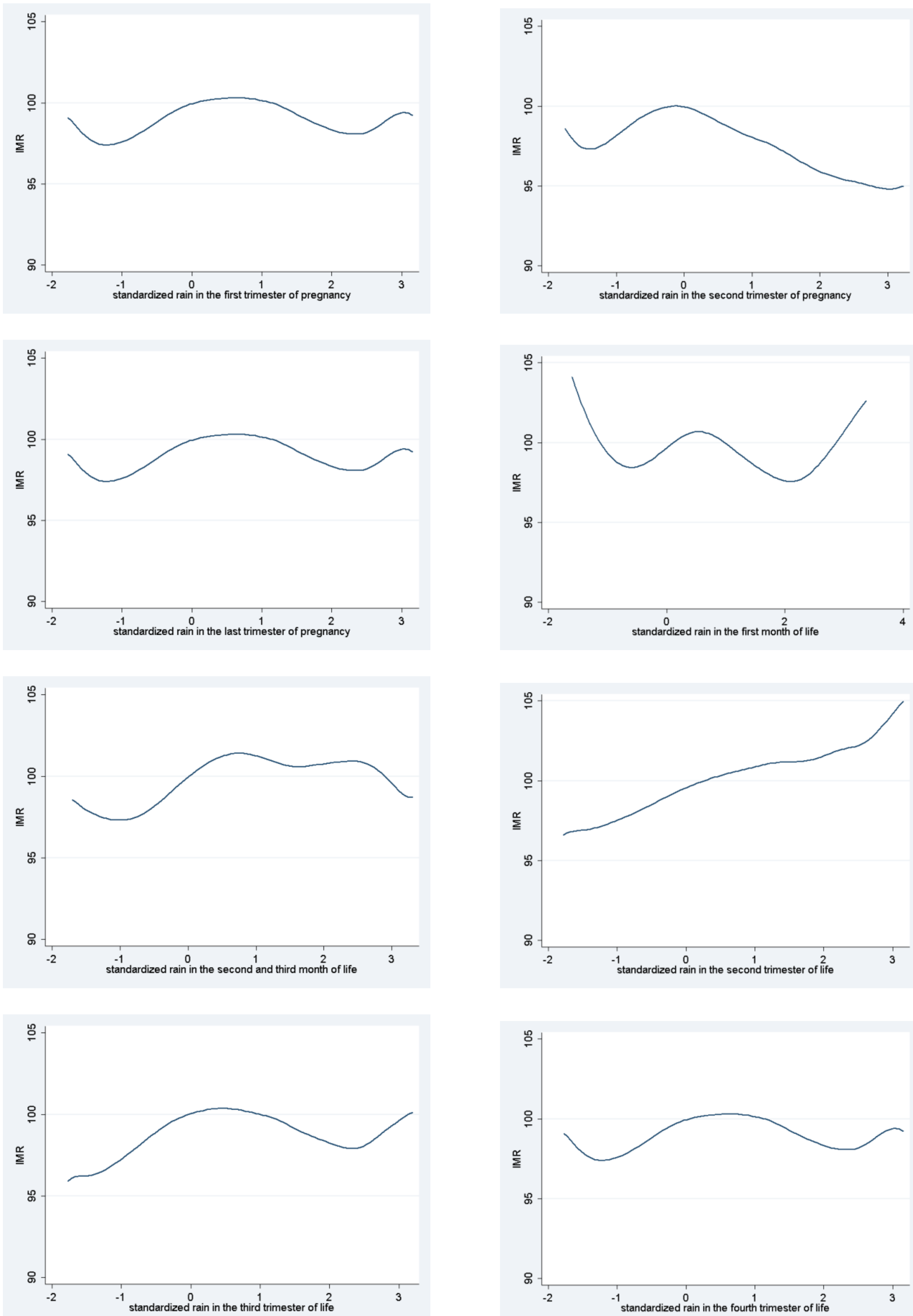

Table 1: List of DHS datasets used in the analysis, including information on country, year of survey, number of mothers, and number of births, and number of infant deaths.

Country	Survey Years	Total Mothers	Total Births	Total Deaths
Benin	1996, 2001	7,354	16,840	1,770
Burkino Faso	1993, 1999, 2003	15,366	32,837	3,785
Central African Republic	1995	3,460	8,009	824
Cameroon	1991, 1998, 2004	9,829	20,121	1,643
Cote d'Ivoire	1994, 1999	6,761	15,120	1,445
Egypt	1993, 1996, 2000	27,526	58,447	4,382
Ethiopia	2000	8,244	18,764	2,239
Ghana	1994, 1999, 2003	8,450	16,209	1,216
Guinea	1999, 2005	8,471	16,667	2,064
Kenya	1998, 2003	6,175	11,856	877
Lesotho	2005	2,301	3,108	246
Liberia	1986, 2007	5,545	9,153	1,361
Madagascar	1997	4,160	9,632	962
Malawi	2000, 2005	14,071	27,479	3,230
Mali	1996, 2001, 2006	21,837	47,766	6,719
Morocco	2004	5,175	7,868	372
Namibia	2000, 2007	6,074	9,262	390
Niger	1992, 1998, 2006	13,927	31,704	4,110
Nigeria	1990	5,490	13,523	1,346
Senegal	1993, 1997, 2005	14,664	31,034	2,549
Tanzania	1999	2,354	5,231	583
Togo	1988, 1998	7,522	17,070	1,428
Uganda	2001	4,144	10,139	895
Zimbabwe	1999, 2006	6,416	9,755	491
Total		215,316	447,594	44,927

Table 2a: Impact of rainfall on likelihood of death at different ages under one year

	Neonatal Death	Death During Months Two and Three	Death During Second Quarter	Death During Third Quarter	Death During Fourth Quarter
Rainfall - first trimester	0.618	0.049	-0.143	-0.106	0.004
	(0.404)	(0.182)	(0.213)	(0.200)	(0.227)
Rainfall - second trimester	-0.566	0.140	0.187	-0.227	-0.460**
	(0.392)	(0.190)	(0.249)	(0.230)	(0.220)
Rainfall - third trimester	0.814**	0.083	0.099	-0.145	0.021
	(0.372)	(0.197)	(0.271)	(0.225)	(0.239)
Rainfall - month of birth	0.180	0.050	0.158	0.270	-0.374
	(0.344)	(0.201)	(0.210)	(0.201)	(0.247)
Rainfall - next two months		0.196	0.214	-0.042	0.263
		(0.185)	(0.200)	(0.211)	(0.260)
Rainfall - second quarter of life			-0.088	0.111	-0.253
			(0.217)	(0.226)	(0.219)
Rainfall - third quarter of life				0.170	-0.449*
				(0.197)	(0.236)
Rainfall - fourth quarter of life					-0.345
					(0.229)
Number of observations	447,590	427,571	422,468	416,310	410,221

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel A also includes explanatory variables in Panel B.

Table 2b: Impact of temperature on likelihood of death at different ages under one year

	Neonatal Death	Death During Months Two and Three	Death During Second Quarter	Death During Third Quarter	Death During Fourth Quarter
Temperature- first trimester	0.042	0.131	0.146	0.001	0.343
	(0.427)	(0.195)	(0.198)	(0.277)	(0.285)
Temperature - first trimester ^ 2	0.260	0.130	-0.058	0.086	-0.106
	(0.224)	(0.115)	(0.110)	(0.115)	(0.159)
Temperature - second trimester	0.591	0.245	0.111	-0.030	-0.190
	(0.424)	(0.190)	(0.188)	(0.229)	(0.268)
Temperature - second trimester ^ 2	0.332	-0.145	-0.047	0.019	0.015
	(0.218)	(0.115)	(0.151)	(0.121)	(0.118)
Temperature - third trimester	0.015	-0.019	0.077	-0.030	-0.166
	(0.439)	(0.203)	(0.235)	(0.242)	(0.299)
Temperature - third trimester ^ 2	-0.243	-0.007	-0.047	-0.230**	-0.117
	(0.231)	(0.098)	(0.120)	(0.113)	(0.128)
Temperature - month of birth	0.660*	0.450**	-0.092	0.072	0.288
	(0.387)	(0.207)	(0.264)	(0.252)	(0.296)
Temperature - month of birth ^ 2	0.414**	0.061	-0.092	-0.023	-0.091
	(0.184)	(0.106)	(0.120)	(0.109)	(0.132)
Temperature - next two months		0.245	0.384	0.629**	0.291
		(0.216)	(0.254)	(0.246)	(0.269)
Temperature - next two months ^ 2		-0.112	0.287**	0.216**	0.182
		(0.129)	(0.146)	(0.104)	(0.142)
Temperature - second quarter of life			0.379*	0.079	0.217
			(0.214)	(0.230)	(0.273)
Temperature - second quarter of life ^ 2			0.054	0.019	-0.061
			(0.109)	(0.118)	(0.137)
Temperature - third quarter				0.263	-0.220
				(0.226)	(0.295)
Temperature - third quarter ^ 2				-0.054	-0.041
				(0.133)	(0.129)
Temperature - fourth quarter					0.126
					(0.291)
Temperature - fourth quarter ^ 2					0.159
					(0.169)
Joint Effect First trimester (p-value)	0.510	0.462	0.605	0.753	0.308
Joint Effect Second trimester (p-value)	0.179	0.131	0.800	0.974	0.769
Joint Effect Third trimester (p-value)	0.558	0.994	0.870	0.119	0.587
Joint Effect Month of Birth (p-value)	0.022	0.093	0.744	0.915	0.354
Joint Effect Next Two Months (p-value)		0.143	0.044	0.022	0.326
Joint Effect Second Quarter (p-value)			0.209	0.938	0.634
Joint Effect Third Quarter (p-value)				0.353	0.754
Joint Effect Fourth Quarter (p-value)					0.630
Number of observations	447,590	427,571	422,468	416,310	410,221

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel B also includes explanatory variables in Panel A.

Table 3a: Gender differences in impact of rainfall on likelihood of death at different ages under one year

	Neonatal Death (Boys)	Neonatal Death (Girls)	Death During Months Two and Three (Boys)	Death During Months Two and Three (Girls)	Death During Second Quarter (Boys)	Death During Second Quarter (Girls)	Death During Third Quarter (Boys)	Death During Third Quarter (Girls)	Death During Fourth Quarter (Boys)	Death During Fourth Quarter (Girls)
Rainfall - first trimester	0.372	0.922*	0.453*	-0.338	0.114	-0.425	0.066	-0.328	0.264	-0.316
	(0.580)	(0.528)	(0.270)	(0.295)	(0.305)	(0.279)	(0.288)	(0.303)	(0.326)	(0.298)
Rainfall - second trimester	-0.511	-0.644	0.315	-0.030	0.470	-0.064	0.130	-0.564*	-0.484	-0.382
	(0.553)	(0.487)	(0.276)	(0.268)	(0.318)	(0.316)	(0.332)	(0.309)	(0.306)	(0.327)
Rainfall - third trimester	0.825*	0.744	0.263	-0.115	0.295	-0.119	-0.181	-0.025	0.042	-0.063
	(0.504)	(0.570)	(0.275)	(0.251)	(0.329)	(0.335)	(0.269)	(0.329)	(0.336)	(0.366)
Rainfall - month of birth	-0.008	0.384	0.043	0.090	0.037	0.268	0.311	0.224	-0.371	-0.329
	(0.534)	(0.448)	(0.278)	(0.300)	(0.290)	(0.345)	(0.250)	(0.316)	(0.329)	(0.316)
Rainfall - next two months			0.131	0.308	0.127	0.314	-0.042	-0.049	0.183	0.463
			(0.293)	(0.234)	(0.311)	(0.269)	(0.332)	(0.285)	(0.363)	(0.355)
Rainfall - second quarter of life					-0.103	-0.020	0.185	0.069	-0.179	-0.363
					(0.289)	(0.328)	(0.316)	(0.338)	(0.318)	(0.312)
Rainfall - third quarter of life							-0.149	0.503**	0.263	-1.179***
							(0.321)	(0.261)	(0.374)	(0.330)
Rainfall - fourth quarter of life									-0.597*	-0.076
									(0.334)	(0.344)
Number of observations	227,394	220,196	215,859	211,712	213,162	209,306	210,058	206,252	207,060	203,161

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel A also includes explanatory variables in Panel B.

Table 3b: Gender differences in impact of temperature on likelihood of death at different ages under one year

	Neonatal Death (Boys)	Neonatal Death (Girls)	Death During Months Two and Three (Boys)	Death During Months Two and Three (Girls)	Death During Second Quarter (Boys)	Death During Second Quarter (Girls)	Death During Third Quarter (Boys)	Death During Third Quarter (Girls)	Death During Fourth Quarter (Boys)	Death During Fourth Quarter (Girls)
Temperature - first trimester	0.704	-0.634	0.178	0.087	0.130	0.149	-0.035	0.009	0.569	0.070
	(0.592)	(0.577)	(0.313)	(0.236)	(0.286)	(0.308)	(0.374)	(0.331)	(0.373)	(0.400)
Temperature - first trimester ^ 2	0.100	0.370	0.425**	-0.155	-0.056	-0.062	0.114	0.080	0.251	-0.505**
	(0.339)	(0.282)	(0.170)	(0.136)	(0.175)	(0.172)	(0.163)	(0.170)	(0.201)	(0.225)
Temperature - second trimester	0.128	1.124**	0.138	0.365	0.108	0.115	0.452	-0.539	-0.206	-0.129
	(0.537)	(0.569)	(0.297)	(0.255)	(0.332)	(0.344)	(0.326)	(0.388)	(0.350)	(0.406)
Temperature - second trimester ^ 2	0.156	0.479*	-0.319**	0.027	-0.163	0.073	0.020	0.032	0.006	0.034
	(0.331)	(0.273)	(0.145)	(0.154)	(0.177)	(0.223)	(0.171)	(0.157)	(0.155)	(0.180)
Temperature - third trimester	0.194	-0.163	-0.133	0.088	-0.264	0.374	-0.295	0.219	-0.257	-0.147
	(0.633)	(0.537)	(0.292)	(0.248)	(0.353)	(0.363)	(0.318)	(0.352)	(0.378)	(0.447)
Temperature - third trimester ^ 2	-0.386	-0.069	0.014	-0.014	-0.242	0.136	-0.254	-0.191	-0.169	-0.041
	(0.326)	(0.293)	(0.161)	(0.136)	(0.171)	(0.168)	(0.190)	(0.163)	(0.164)	(0.185)
Temperature - month of birth	0.539	0.812*	0.659**	0.229	0.167	-0.355	0.354	-0.122	0.561	0.096
	(0.561)	(0.507)	(0.309)	(0.286)	(0.346)	(0.373)	(0.351)	(0.397)	(0.380)	(0.410)
Temperature - month of birth ^ 2	0.330	0.518**	0.100	0.034	0.083	-0.293**	0.081	-0.104	-0.120	-0.045
	(0.280)	(0.209)	(0.170)	(0.133)	(0.184)	(0.143)	(0.144)	(0.134)	(0.195)	(0.192)
Temperature - next two months			-0.118	0.642**	0.336	0.381	0.611*	0.639*	0.227	0.344
			(0.347)	(0.295)	(0.374)	(0.329)	(0.336)	(0.360)	(0.412)	(0.409)
Temperature - next two months ^ 2			-0.080	-0.127	0.311	0.289	0.152	0.328*	0.198	0.205
			(0.154)	(0.168)	(0.214)	(0.183)	(0.158)	(0.162)	(0.192)	(0.200)
Temperature - second quarter of life					0.236	0.595**	-0.244	0.408	0.029	0.418
					(0.301)	(0.289)	(0.362)	(0.330)	(0.362)	(0.463)
Temperature - second quarter of life ^ 2					0.030	0.046	-0.299**	0.364**	-0.100	-0.056
					(0.178)	(0.176)	(0.140)	(0.175)	(0.188)	(0.199)
Temperature - third quarter							-0.010	0.613*	0.013	-0.473
							(0.324)	(0.332)	(0.405)	(0.431)
Temperature - third quarter ^ 2							-0.274	0.173	-0.040	-0.021
							(0.182)	(0.200)	(0.170)	(0.183)
Temperature - fourth quarter									-0.021	0.238
									(0.488)	(0.387)
Temperature - fourth quarter ^ 2									0.381*	-0.081
									(0.222)	(0.228)
Joint Effect First trimester (p-value)	0.482	0.169	0.044	0.450	0.775	0.798	0.780	0.896	0.164	0.072
Joint Effect Second trimester (p-value)	0.892	0.065	0.069	0.361	0.603	0.899	0.371	0.360	0.835	0.920
Joint Effect Third trimester (p-value)	0.401	0.942	0.870	0.923	0.351	0.446	0.356	0.318	0.516	0.940
Joint Effect Month of Birth (p-value)	0.326	0.030	0.099	0.720	0.857	0.113	0.554	0.738	0.225	0.930
Joint Effect Next Two Months (p-value)			0.870	0.044	0.270	0.167	0.148	0.073	0.492	0.514
Joint Effect Second Quarter (p-value)					0.736	0.114	0.104	0.074	0.864	0.521
Joint Effect Third Quarter (p-value)							0.301	0.180	0.970	0.532
Joint Effect Fourth Quarter (p-value)									0.195	0.678
Number of observations	227,394	220,196	215,859	211,712	213,162	209,306	210,058	206,252	207,060	203,161

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel A also includes explanatory variables in Panel B.

Table 4a: Urban/Rural differences in impact of rainfall on likelihood of death at different ages under one year

	Neonatal Death (Urban)	Neonatal Death (Rural)	Death During Months Two and Three (Urban)	Death During Months Two and Three (Rural)	Death During Second Quarter (Urban)	Death During Second Quarter (Rural)	Death During Third Quarter (Urban)	Death During Third Quarter (Rural)	Death During Fourth Quarter (Urban)	Death During Fourth Quarter (Rural)
Rainfall - first trimester	0.172	0.580	0.218	-0.026	0.418	-0.451	-0.210	-0.162	0.430	-0.257
	(0.676)	(0.507)	(0.292)	(0.232)	(0.290)	(0.281)	(0.322)	(0.273)	(0.335)	(0.300)
Rainfall - second trimester	0.031	-0.839	0.114	0.047	-0.212	0.353	-0.364	-0.159	-0.177	-0.601**
	(0.609)	(0.531)	(0.333)	(0.236)	(0.365)	(0.300)	(0.323)	(0.289)	(0.323)	(0.287)
Rainfall - third trimester	0.872	0.732	-0.090	0.127	0.521	-0.087	-0.037	-0.223	0.113	0.010
	(0.545)	(0.470)	(0.287)	(0.249)	(0.383)	(0.309)	(0.304)	(0.309)	(0.436)	(0.281)
Rainfall - month of birth	-0.263	0.348	-0.091	0.080	-0.101	0.279	-0.122	0.397	-0.160	-0.500
	(0.511)	(0.442)	(0.299)	(0.264)	(0.347)	(0.254)	(0.324)	(0.283)	(0.343)	(0.317)
Rainfall - next two months			0.286	0.123	-0.322	0.383	-0.265	0.025	0.390	0.164
			(0.287)	(0.223)	(0.305)	(0.269)	(0.290)	(0.274)	(0.393)	(0.325)
Rainfall - second quarter of life					-0.136	-0.084	-0.246	0.233	-0.646*	-0.150
					(0.329)	(0.284)	(0.315)	(0.261)	(0.362)	(0.303)
Rainfall - third quarter of life							0.323	0.154	-0.312	-0.571**
							(0.318)	(0.255)	(0.391)	(0.282)
Rainfall - fourth quarter of life									-0.748**	-0.282
									(0.340)	(0.274)
Number of observations	129,681	317,909	125,177	302,394	124,184	298,284	122,961	293,394	121,715	288,506

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel A also includes explanatory variables in Panel B.

Table 4b: Urban/Rural differences in impact of temperature on likelihood of death at different ages under one year

	Neonatal Death (Urban)	Neonatal Death (Rural)	Death During Months Two and Three (Urban)	Death During Months Two and Three (Rural)	Death During Second Quarter (Urban)	Death During Second Quarter (Rural)	Death During Third Quarter (Urban)	Death During Third Quarter (Rural)	Death During Fourth Quarter (Urban)	Death During Fourth Quarter (Rural)
Temperature- first trimester	0.440	-0.202	-0.167	0.245	0.432	-0.015	0.104	-0.065	0.262	0.346
	(0.641)	(0.494)	(0.342)	(0.261)	(0.331)	(0.283)	(0.376)	(0.332)	(0.405)	(0.420)
Temperature - first trimester ^ 2	-0.014	0.306	0.308	0.044	0.138	-0.160	-0.023	0.116	-0.147	-0.137
	(0.378)	(0.269)	(0.190)	(0.127)	(0.163)	(0.144)	(0.203)	(0.159)	(0.205)	(0.195)
Temperature - second trimester	0.310	0.626	0.670**	0.116	0.049	0.051	0.174	-0.117	-0.037	-0.268
	(0.717)	(0.483)	(0.295)	(0.259)	(0.359)	(0.254)	(0.333)	(0.293)	(0.446)	(0.336)
Temperature - second trimester ^ 2	1.117**	-0.040	0.084	-0.241*	-0.084	-0.040	0.213	-0.063	-0.065	0.021
	(0.469)	(0.242)	(0.175)	(0.143)	(0.173)	(0.187)	(0.173)	(0.163)	(0.217)	(0.155)
Temperature - third trimester	-1.003	0.312	0.667**	-0.286	0.403	-0.089	0.080	-0.129	-0.387	-0.012
	(0.710)	(0.570)	(0.308)	(0.274)	(0.445)	(0.275)	(0.348)	(0.322)	(0.429)	(0.352)
Temperature - third trimester ^ 2	-0.498	-0.177	-0.155	0.099	-0.088	-0.051	-0.385*	-0.188	0.084	-0.262
	(0.397)	(0.284)	(0.156)	(0.134)	(0.166)	(0.148)	(0.197)	(0.136)	(0.210)	(0.166)
Temperature - month of birth	0.138	0.818	0.375	0.408	-0.296	-0.039	-0.513	0.361	0.725	0.040
	(0.585)	(0.518)	(0.340)	(0.253)	(0.373)	(0.298)	(0.344)	(0.310)	(0.445)	(0.357)
Temperature - month of birth ^ 2	0.808**	0.244	-0.019	0.088	0.060	-0.168	0.033	-0.040	-0.020	-0.113
	(0.318)	(0.225)	(0.153)	(0.139)	(0.134)	(0.162)	(0.222)	(0.131)	(0.181)	(0.164)
Temperature - next two months			-0.222	0.400	0.674*	0.250	0.590*	0.530*	0.117	0.337
			(0.352)	(0.264)	(0.355)	(0.319)	(0.352)	(0.288)	(0.505)	(0.341)
Temperature - next two months ^ 2			-0.129	-0.105	-0.050	0.459**	-0.049	0.339**	-0.079	0.284
			(0.173)	(0.162)	(0.166)	(0.183)	(0.174)	(0.140)	(0.235)	(0.187)
Temperature - second quarter of life					-0.111	0.460	-0.445	0.244	-0.323	0.356
					(0.354)	(0.295)	(0.340)	(0.288)	(0.500)	(0.287)
Temperature - second quarter of life ^ 2					-0.094	0.077	0.411**	-0.207	-0.271	-0.020
					(0.200)	(0.144)	(0.205)	(0.157)	(0.205)	(0.177)
Temperature - third quarter							0.736*	0.015	-0.491	-0.189
							(0.381)	(0.283)	(0.454)	(0.374)
Temperature - third quarter ^ 2							-0.268	0.024	0.247	-0.161
							(0.214)	(0.159)	(0.205)	(0.172)
Temperature - fourth quarter									0.143	-0.014
									(0.427)	(0.368)
Temperature - fourth quarter ^ 2									-0.051	0.236
									(0.269)	(0.210)
Joint Effect First trimester (p-value)	0.772	0.488	0.197	0.639	0.393	0.538	0.948	0.756	0.518	0.500
Joint Effect Second trimester (p-value)	0.060	0.379	0.075	0.184	0.864	0.962	0.432	0.873	0.956	0.713
Joint Effect Third trimester (p-value)	0.245	0.656	0.007	0.356	0.410	0.890	0.108	0.374	0.555	0.289
Joint Effect Month of Birth (p-value)	0.041	0.202	0.498	0.248	0.579	0.560	0.246	0.417	0.121	0.762
Joint Effect Next Two Months (p-value)			0.731	0.106	0.086	0.023	0.122	0.028	0.890	0.271
Joint Effect Second Quarter (p-value)					0.686	0.272	0.032	0.256	0.406	0.426
Joint Effect Third Quarter (p-value)							0.014	0.989	0.155	0.635
Joint Effect Fourth Quarter (p-value)									0.898	0.505
Number of observations	129,681	317,909	125,177	302,394	124,184	298,284	122,961	293,394	121,715	288,506

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level. Specification in Panel B also includes explanatory variables in Panel A.

Table 5a: Robustness checks, impact of rainfall on likelihood of death at different ages under one year

	Original		Cubic Time Trends		Small Cell		Alternative Weather	
	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter
Rainfall - first trimester	0.618	0.004	0.615	0.115	0.564	-0.095	0.394	-0.115
	(0.404)	(0.227)	(0.418)	(0.232)	(0.377)	(0.240)	(0.318)	(0.231)
Rainfall - second trimester	-0.566	-0.460**	-0.547	-0.415*	-0.763*	-0.521**	-0.546*	-0.493**
	(0.392)	(0.220)	(0.397)	(0.224)	(0.403)	(0.250)	(0.357)	(0.192)
Rainfall - third trimester	0.814**	0.021	0.830**	0.048	0.547	0.067	0.599	-0.117
	(0.372)	(0.239)	(0.381)	(0.239)	(0.358)	(0.243)	(0.318)	(0.202)
Rainfall - month of birth	0.180	-0.374	0.180	-0.343	0.392	-0.328	0.428	-0.258
	(0.344)	(0.247)	(0.340)	(0.247)	(0.337)	(0.259)	(0.310)	(0.215)
Rainfall - next two months		0.263		0.303		0.096		0.110
		(0.260)		(0.264)		(0.251)		(0.227)
Rainfall - second quarter of life		-0.253		-0.226		-0.254		-0.199
		(0.219)		(0.220)		(0.249)		(0.197)
Rainfall - third quarter of life		-0.449*		-0.445*		-0.529**		-0.436**
		(0.236)		(0.238)		(0.254)		(0.217)
Rainfall - fourth quarter of life		-0.345		-0.368		-0.423*		-0.447*
		(0.229)		(0.233)		(0.236)		(0.207)
Number of observations	447,590	410,221	447,590	410,221	447,439	410,089	447,590	410,221

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends except in the Cubic specification which includes a cubic time trend. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level, except for the Alternative Weather specification which normalizes monthly weather against a 5 year moving average. The Small Cell specification adopts a 0.5 degree square goe-spatial cell as opposed to a 2- degree square cell. Specification in Panel A also includes explanatory variables in Panel B.

Table 5b: Robustness checks, impact of temperature on likelihood of death at different ages under one year

	Original		Cubic		Small Cell		Alternative Weather	
	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter	Neonatal Death	Death During Fourth Quarter
Temperature- first trimester	0.042	0.343	-0.032	0.332	0.077	0.435	-0.016	0.367
	(0.427)	(0.285)	(0.422)	(0.294)	(0.390)	(0.285)	(0.420)	(0.288)
Temperature - first trimester ^ 2	0.260	-0.106	0.223	-0.117	0.179	0.043	0.257	-0.103
	(0.224)	(0.159)	(0.225)	(0.158)	(0.218)	(0.143)	(0.223)	(0.161)
Temperature - second trimester	0.591	-0.190	0.592	-0.175	0.740*	-0.136	0.599*	-0.152
	(0.424)	(0.268)	(0.423)	(0.272)	(0.442)	(0.282)	(0.418)	(0.265)
Temperature - second trimester ^ 2	0.332	0.015	0.315	0.007	0.165	-0.004	0.320	0.010
	(0.218)	(0.118)	(0.219)	(0.120)	(0.225)	(0.136)	(0.219)	(0.118)
Temperature - third trimester	0.015	-0.166	0.047	-0.161	0.025	0.038	-0.096	-0.171
	(0.439)	(0.299)	(0.444)	(0.298)	(0.426)	(0.266)	(0.438)	(0.291)
Temperature - third trimester ^ 2	-0.243	-0.117	-0.275	-0.139	-0.237	-0.132	-0.246	-0.121
	(0.231)	(0.128)	(0.233)	(0.128)	(0.208)	(0.140)	(0.233)	(0.129)
Temperature - month of birth	0.660*	0.288	0.684*	0.275	0.781*	0.323	0.711*	0.337
	(0.387)	(0.296)	(0.386)	(0.298)	(0.423)	(0.293)	(0.384)	(0.293)
Temperature - month of birth ^ 2	0.414**	-0.091	0.405**	-0.100	0.379*	-0.054	0.433*	-0.079
	(0.184)	(0.132)	(0.184)	(0.131)	(0.201)	(0.126)	(0.183)	(0.131)
Temperature - next two months		0.291		0.298		0.257		0.263
		(0.269)		(0.268)		(0.296)		(0.270)
Temperature - next two months ^ 2		0.182		0.168		0.099		0.186
		(0.142)		(0.145)		(0.131)		(0.143)
Temperature - second quarter of life		0.217		0.204		0.140		0.247
		(0.273)		(0.268)		(0.264)		(0.267)
Temperature - second quarter of life ^ 2		-0.061		-0.073		-0.176		-0.054
		(0.137)		(0.138)		(0.140)		(0.139)
Temperature - third quarter		-0.220		-0.226		-0.302		-0.165
		(0.295)		(0.300)		(0.284)		(0.297)
Temperature - third quarter ^ 2		-0.041		-0.071		-0.155		-0.052
		(0.129)		(0.133)		(0.134)		(0.132)
Temperature - fourth quarter		0.126		0.105		0.080		0.143
		(0.291)		(0.291)		(0.273)		(0.292)
Temperature - fourth quarter ^ 2		0.159		0.139		0.106		0.146
		(0.169)		(0.171)		(0.134)		(0.168)
Joint Effect First trimester (p-value)	0.510	0.308	0.606	0.315	0.703	0.312	0.513	0.284
Joint Effect Second trimester (p-value)	0.179	0.769	0.198	0.812	0.214	0.890	0.182	0.844
Joint Effect Third trimester (p-value)	0.558	0.587	0.468	0.502	0.469	0.614	0.573	0.564
Joint Effect Month of Birth (p-value)	0.022	0.354	0.020	0.334	0.051	0.420	0.013	0.308
Joint Effect Next Two Months (p-value)		0.326		0.359		0.606		0.344
Joint Effect Second Quarter (p-value)		0.634		0.619		0.347		0.583
Joint Effect Third Quarter (p-value)		0.754		0.720		0.352		0.838
Joint Effect Fourth Quarter (p-value)		0.630		0.710		0.727		0.662
Number of observations	447,590	410,221	447,590	410,221	410,089	447,439	447,590	410,221

Notes: *** p<0.01, ** p<0.05, * p<0.1. Standard errors are clustered at the geo-spatial cell level. All regressions include calendar month of birth - geo-spatial cell fixed effects, as well as geo-spatial cell quadratic time trends except in the Cubic specification which includes a cubic time trend. Monthly weather measures are normalized in terms of standard deviations from the 1978 - 2000 mean at the calendar month- geo-spatial cell level, except for the Alternative Weather specification which normalizes monthly weather against a 5 year moving average. The Small Cell specification adopts a 0.5 degree square goe-spatial cell as opposed to a 2- degree square cell. Specification in Panel B also includes explanatory variables in Panel A.

Table 6. Projected excess infant deaths in Africa over 2010-2030 as a result of different climate change scenarios

Scenario Description				Predictions		
Scenario Name	Projected fossil energy use	Projected rate of population increase	Projected rate and type of economic growth	Excess deaths for 24 countries in analysis	Excess deaths for all of Africa	Increase in IMR due to projected climate changes
A2	Fragmented	Fast	Slow	266,713	386,540	0.51
B2	Fragmented	Slow	Intermediate	495,511	718,131	0.95
B1	Clean	Fast	Rapid - services focused	535,626	776,270	1.03
A1FI	Intensive	Fast	Rapid - material focused	638,508	925,374	1.22

Note: Predictions based on coefficients from Table 2, climate projections from European Center for Medium-range Weather Forecasting model, and birth projections from U.N. World Population Prospects database.