Examining the relationship between temperature, rainfall and low birth weight: Evidence from 21 African Countries

Abstract: This paper examines the relationship between low birth weight and rainfall and precipitation in 21 African countries. We match recorded birth weights from the Demographic and Health Survey (DHS) from 1986 through 2011 with gridded monthly precipitation and temperature data derived from satellite and ground based weather stations. Observed weather patterns during various stages of pregnancy are also observed to determine the effect of increasing temperature and decreasing rainfall on birth weight outcomes. In our empirical model we also allow the effect of weather factors to vary by the dominant food production strategy (livelihood zone) in a given region as well as by household wealth, mother's education and birth season. This allows us to determine if certain populations are more or less vulnerable to unexpected weather changes even after adjusting for known covariates. Finally we measure effect size by observing differences in birth weight outcomes in women who have one low birth weight experience and (at least) one healthy birth weight baby.

Introduction

There is increasing attention on the impact that climate change will have on agricultural production and what these changes mean for health issues related to food insecurity (Jones and Thorton 2003; Juli and Duchin 2007; Fraser 2006). However, the link between weather and health remains controversial and somewhat convoluted in part because of the difficulties inherent in analyzing data with complicated temporal and spatial scales. In this research, we explore the link between one health outcome – birth weight – and weather in 21 African countries, (Figure 1). Our study countries include some of the poorest and most climatically sensitive areas in the world. Because of the narrow time frame of pregnancy, dramatic changes in temperature or rainfall can be matched to a birth outcome and the resulting impact on birth weight can be observed and analyzed. We focus on low birth weight outcomes because they are costly for individuals, households and communities. Prior research suggests strong links between low birth weight and future health problems, educational attainment, and income (Walker et al., 2007; Victora et al., 2008). Increasing understanding of the link between low birth weight and variation in climate may help to mitigate against these effects.

A number of researchers have noted the complex relationship between heat stress/heat-waves, rainfall and birth weight (Wells and Cole, 2002; McGrath et al. 2005; Strand et al., 2011). Yet, no study of African households using fine resolution rainfall and temperature data has been undertaken. Additionally, because weather may be linked to local food production, we argue that in food insecure countries, it is important to also account for food production strategy (livelihood zone). This consideration is particularly important for the countries in our study because they are subsistence-based economies where food producers rely on rainfall for to grow their crops. While we are interested in the relationship between local food production and low birth weight, we are primarily interested in exploring the impact of temperature and precipitation apart from food production to contribute to a better understanding of the link between heat, rain and low birth weight.

Our overarching goal is to examine the link between community-level rainfall and temperature variations and low birth weight. We seek to answer the following question: Do increasing temperature and decreasing rainfall result in an increased likelihood of low birth weight – even after adjusting for variations in food production strategy, and household- and individual-level factors? The data for this study comes from retrospective birth records included in the Demographic and Health Survey (DHS). The data are then combined with elevation, mean satellite observed rainfall, mean satellite observed land surface temperatures, and mean satellite-observed brightness infrared temperatures to create a 0.1 degree grid that covers the entire region (Funk et. al 2012). Recorded live birth weights are temporally and spatially matched to community-level rainfall and temperature data. Recorded live birth weights are therefore temporally and spatially matched to community-level rainfall and temperature data. To account for the variation in low birth weight that may be associated with food production we use livelihood zone data collected by the US Agency for International Development's Famine Early Warning System (FEWS NET) program.

Background

Low Birth Weight

When babies are born weighing less than 2500 grams, the international standard for low birth weight (LBW), their mortality rates are higher than those of their normal birth weight counterparts (Walker et al., 2007). If an LBW baby does survive, her future is grimmer than that of a normal birth weight baby. Educational rates and income levels are lower among children who are born with LBW and if a mother was herself characterized as LBW then she is more likely to produce LBW children (especially girls) (Victora et al., 2008). LBW babies are therefore less likely to grow into healthy and economically productive members of society.

The weight of an infant at birth is the result of a multitude of interrelated biological (e.g. maternal height) and socio-environmental (e.g. environmental factors, socioeconomic status, health care, maternal age, time since previous birth) factors (Mwabu, 2008; Abu-Saad and Frasier, 2010; also see Kramer, 1987 for an extensive discussion). Among the most prominent of the environmental factors, is maternal nutrition (Kramer, 1987; Keen, 2003; Wu et al., 2004; Cetin et al., 2010). Studies of interventions related to maternal nutrition have produced a variety of results identifying the impacts of different types of vitamins, minerals and eating habits on the birth weight of a newborn. And while results of successful interventions are not always consistent across human studies, the positive influence of maternal nutrition on the birth weight of an infant in animal studies is undeniable (Wu et al., 2004).

One component of maternal nutrition relevant in a food insecure context is appropriate caloric intake and weight gain, which are directly linked to food availability and accessibility. Therefore, while LBW is an indicator of future health of the child it is also represents nutritional deficiencies of the mother (Young, 2001). In highly food insecure communities - where adequate food supply is limited or food is costly (see the UNICEF framework, 1990) - the potential for women to intake an adequate amount of nutritional food is unlikely, and could possibly increasing the risk of a woman delivering an LBW baby (Young, 2001). We therefore theorize that women who experience reduced access to food (as indicated by high temperatures and low rainfall during a pregnancy) would not gain the proper amount of weight or consume the needed calories for healthy in- utero growth, resulting in a LBW infant.

The component of low birth weight that is of prime interest to our study, however is heat stress and drought. The seasonality of birth outcomes (weights, stillbirths, heights) has been studied for some time, however the results are not conclusive. In some cases low temperatures are linked to lower birth weights and in other cases, heat waves are linked to lower birth weights (see, for example, Torche and Corvalan, 2010; Strand et al., 2011). The impact of rainfall, drought and floods has also been studied and also produced inconsistent results (Bantje and Neimeyer, 1984; Hoddinott and Kinsey, 2001). In our analysis, by examining a large number of births over a 25 year period and after adjusting for food production (a measure of weather dependency in developing countries) we will expand this area of research and ultimately improve understanding of the factors impacting birth weight in the developing world.

Data and Measures

An infant's birth weight is the result of both biological and socio-environmental features. To use models to explain variation in LBW, with the specific goal of identifying the impact of temperature and precipitation we must incorporate a diverse set of factors related to an infant's biology, the socioeconomic characteristics of her mother and household, and factors related to food access. Therefore, to examine LBW we rely on three primary types of data – health, environmental/geographical and livelihood. The descriptions of the data and the measures calculated from each data source follow.

Health data and measures

DHS data provide detailed health and population information for most of the poorest countries around the world. These cross-sectional, spatially referenced data (DHS provides the latitude and longitude values of their sampling clusters which contain about 10-20 households) contain detailed information about maternal characteristics and provide retrospective information about the health of infants including their birth weights. This data provides the micro-level health and socio-economic information used in the analysis.

We use data on births recorded in the 5 years prior to the study. Each infant, with a recorded birth weight provided by the mother, is classified as LBW or no-LBW. Both the recorded birth weight and the categorical LBW measure will serve as the dependent variables. DHS data also provide information on length of time at current residence. We use this information to restrict the sample to only those households where the pregnancies occurred in the current area of residence. This restriction allows us to link past information to the relevant pregnancy[1].

We select a suite of explanatory variables from the DHS to control for variation in birth weight. We adjust for the child's sex as well as if the child is a twin (or triplet). Generally, male infants and multiples are smaller at birth than female infants and singletons. We also adjust for birth order and birth interval, with the assumption that children of higher birth order and those who were born within a short period of time following the preceding birth may be smaller than their counterparts (Seidman et al., 1998; Rutstein 2008b). There may be fewer food resources per person in a household with more children and the mother's time for personal care may be limited by the increase in childrearing responsibilities that come with more children and children spaced close in age.

Mother's characteristics are also included as control factors. Mother's height is included because it reflects the mother's experience with food insecurity – mothers who were stunted as children are more likely to give birth to LBW infants (Young, 2001). Maternal age is related to infant size as babies born to older women are more likely to weigh more than those born to younger women (Swamy et al., 2010; Seidman et al., 1998). Mothers' education is also included. More educated mothers may have greater access to health care, may have a greater understanding of nutritional requirements during pregnancy, and may also have greater social capital which may help to ensure a more healthy and less stressful pregnancy (see, for example, Caldwell, 1979 and 1994; Hobcraft, 1993).

With respect to household characteristics, floor material serves as a measure of household wealth (see Rutstein, 2008a for discussion of measuring wealth and different DHS variables). We assume that the poorest households, those with unfinished flooring, will be least able to mitigate against weather induced stresses. We include type of place of residence – urban or rural. We assume that urban households will likely have greater access to food markets and prenatal health care, which are both likely to impact the weight of a baby at birth. Finally, we incorporate birth year and birth season owing to the potential for political or

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[1] Unfortunately, DHS does not contain information on prior residence making it impossible to construct a full residential history or allow us to link women with information related to their prior place of residence.

environmental events that may have shifted health outcomes that we have not accounted for (Mason et al., 2011).

Environmental/Geographical data and measures

The livelihood zone data come from FEWS NET's efforts to characterize the dominant livelihood strategies in a number of developing countries. With the use of local weather patterns, market information and expert knowledge, FEWS NET has constructed zones that characterize the dominant strategy used to produce food in a general area. The livelihood zone data designates different areas based on the dominant subsistence pattern, for example 'Pastoralist', 'Agropastoralist', et cetera. As an example, livelihood zones for Kenya are shown in **Figure 2.** The livelihood zone information serves as a measure of a community's dependence on rainfall for food production which may be related to birth weight through the mother's food intake during pregnancy.

Methods

Other studies of low birth weight treat the outcome as either continuous or categorical. We examine both types of models in this study. Given the hierarchical nature of the data, specifically due to the assumption of non-independence among those who live within the same livelihood zone, we use multilevel[2] models (Gelman 2006; Gelman and Hill 2006) to examine birth weights. Births are nested within livelihood zone. In other words, livelihood zone is treated as a random effect in the models while the other variables listed in are treated as fixed effects. We use a bootstrapping approach to obtain confidence intervals for the estimated parameters. The bootstrap sampling process also incorporates the nested design of the data.

Also, we use propensity score methods to compare multiple births to the same woman. Specifically we use this approach to examine the cases where a woman has one low birth weight experience and (at least) one healthy birth weight baby. In this way we can isolate the temperature and rainfall differences according to each pregnancy.

Anticipated Results

[2] These types of models are referred to by several different names – random effects models, regressions with varying intercepts, hierarchical models, etc. (see Gelman and Hill (2006) for an in-depth discussion of these methods).

We have already analyzed data from the Kenya DHS as a proof of concept. The results are presented in Table 2 below. Here we see the significant relationship in the anticipated direction of both rainfall and temperature. High temperatures are related to low birth weight and low rainfall is related to low birth weight. We look forward to expanding this analysis to the broader selection of countries over more time periods to more fully examine the relationship the Kenya case suggests exists.

Tables and Figures

Figure 1: Map of countries examined in this research

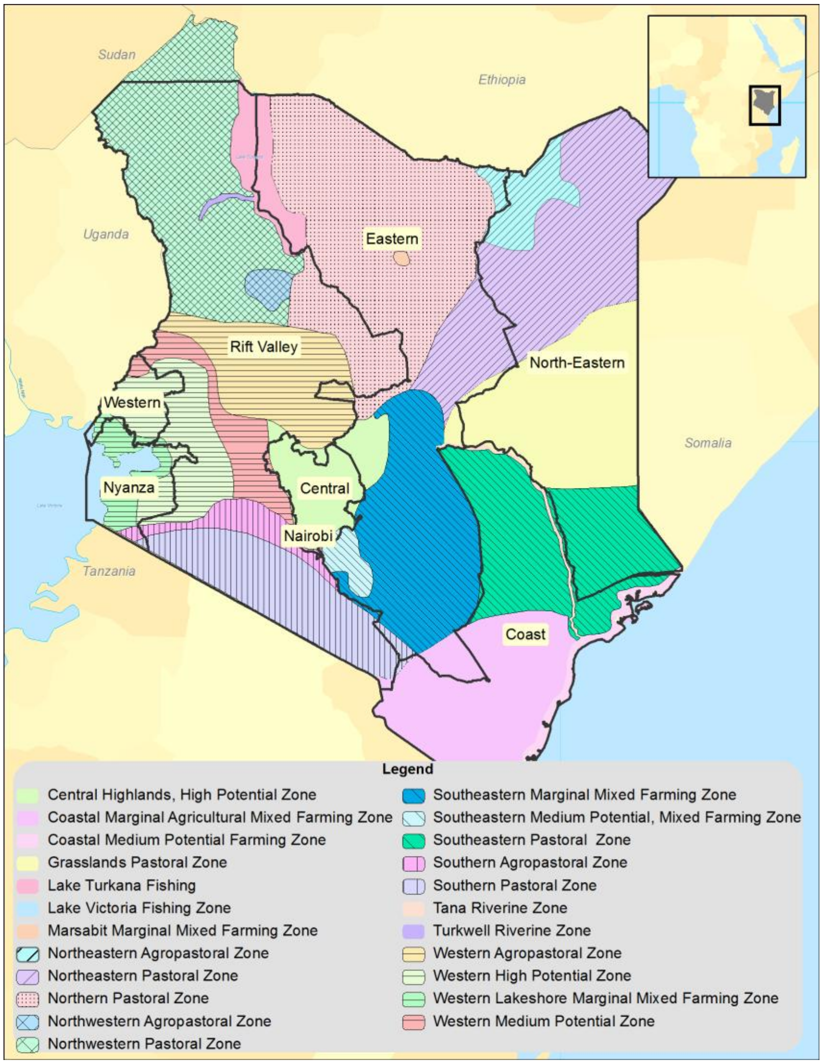

Figure 2: This figure shows livelihood zones in Kenya. Livelihood Zone data is provided by the USAID and show the dominant subsistence patterns within a given region

	Survey Year																			
Country	*1986*	*1990*	*1992*	*1994*	*1995*	*1997*	*1998*	*1999*	*2000*	*2001*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*Total*
Burkina Faso			5143				4812				9097							14424		33476
Burundi																		8596		8596
Central African Republic				5551																5551
Ethiopia									14072				13721					16702		44495
Guinea								5090					6282							11372
Kenya											8561					9057				17618
Lesotho												8592					9391			17983
Liberia	5026													6824						11850
Madagascar						7171										17857				25028
Malawi									14213			13664						24825		52702
Mali					8716					12331				12998						34045
Mozambique																			13919	13919
Niger			5242				5928													11170
Nigeria		8999									7225					34070				50294
Rwanda													10272					12540		22812
Senegal			3528			4772							7412					7902		23614
Sierra Leone																7284				7284
Tanzania								3615									9623			13238
Uganda									7885					8870					9033	25788
Zambia															7164					7164
Zimbabwe								6369					9285					9756		25410
Total	5026	8999	13913	5551	8716	11943	10740	15074	36170	12331	24883	22256	46972	28692	7164	68268	19014	94745	22952	463409

Table 1: This table lists the countries we examine and the survey years for which we have data. The numbers indicate how many households are surveyed in each study.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
(Intercept)	7.9800***	8.4423***	8.1812***	8.1562***	8.1906***	8.2579***
	(0.0305)	(0.0617)	(0.0851)	(0.0869)	(0.0939)	(0.1147)
Rainfall	0.0024***		0.0017***	0.0016***	0.0016***	0.0014**
	(0.0004)		(0.0004)	(0.0004)	(0.0004)	(0.0005)
Temperature		−0.0137***	−0.0067*	−0.0060*	−0.0065*	−0.0077*
		(0.0026)	(0.0029)	(0.0029)	(0.0028)	(0.0035)
Population_Density				−0.0016	−0.0008	−0.0000
				(0.0025)	(0.0024)	(0.0032)
Child_is_Twin(yes)				−0.2086***	−0.2168***	−0.2365***
				(0.0377)	(0.0370)	(0.0445)
Child_Sex(male)				0.0393***	0.0399***	0.0435***
				(0.0094)	(0.0093)	(0.0111)
Water_Source(well)				0.0047	0.0071	0.0137
				(0.0146)	(0.0145)	(0.0161)
Water_Source(other)				−0.0329	−0.0297	−0.0066
				(0.0305)	(0.0302)	(0.0313)
Water_Source(piped)				−0.0171	−0.0116	−0.0124
				(0.0133)	(0.0130)	(0.0169)
House_Floor_Material(finished)				0.0065	0.0136	0.0088
				(0.0117)	(0.0125)	(0.0153)
Mother_Education(primary)					−0.0006	−0.0040
					(0.0135)	(0.0163)
Mother_Education(secondary and beyond)					−0.0118	−0.0104
					(0.0162)	(0.0199)
Marital_Status(married but does not live with husband)					0.0197	0.0353†
					(0.0174)	(0.0202)
Marital_Status(married and lives with husband)					0.0112	0.0287†
					(0.0132)	(0.0152)
Mother_Births_Past_5_Years					0.0096	0.0139
					(0.0087)	(0.0107)
Mothers_Age_at_First_Birth					−0.0029†	−0.0046*
					(0.0015)	(0.0020)
N	2075	2075	2075	2075	2075	1474
R^2	0.0420	0.0365	0.0455	0.0881	0.0934	0.1000
adj. R^2	0.0392	0.0337	0.0423	0.0819	0.0846	0.0876
Resid. sd	0.2068	0.2074	0.2064	0.2021	0.2018	0.2059

Robust standard errors in parentheses
† significant at $p < .10$; $^*p < .05$; $^{**}p < .01$; $^{***}p < .001$

Table 2: This table shows results from several regression models. The dependent variable in each model is the natural log of the child's recorded birth weight. Each model includes fixed effects for livelihood zone. The reported standard errors are clustered on the sampling clusters. The final column shows a model run on only rural households.

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