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The Health Impact of Extreme Weather Events in Sub-Saharan Africa

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Abstract

Extreme weather events are known to have serious consequences for human health and are predicted to increase in frequency as a result of climate change. Africa is one of the regions that risks being most seriously affected. This paper quantifies the impact of extreme rainfall and temperature events on the incidence of diarrhea, malnutrition and mortality in young children in Sub-Saharan Africa. The panel data set is constructed from Demographic and Health Surveys for 108 regions from 19 Sub-Saharan African countries between 1992 and 2001 and climate data from the Africa Rainfall and Temperature Evaluation System from 1980 to 2001.

The results show that both excess rainfall and extreme temperatures significantly raise the incidence of diarrhea and weight-for-height malnutrition among children under the age of three, but have little impact on the long-term health indicators, including height-for-age malnutrition and the under-five mortality rate. The authors use the results to simulate the additional health cost as a proportion of gross domestic product caused by increased climate variability. The projected health cost of increased diarrhea attributable to climate change in 2020 is in the range of 0.2 to 0.5 percent of gross domestic product in Africa.

This paper—a product of the Environment Department, Sustainable Development Network—is part of a larger effort in the department to analyze the health impact of extreme weather events associated with climate change in sub-Saharan Africa. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at lwang1@worldbank.org.

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The health impact of extreme weather events in Sub-Saharan Africa

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1. Introduction

We are still at an early stage of understanding the current and potential future health effects of climate change. In 2002 the World Health Organization (WHO) estimated that climate changes that had taken place over the previous 30 years (see IPCC, 2001a; Zwiers, 2002) were causing 154,000 deaths annually (WHO, 2002). Health impacts are likely to intensify given the anticipated speed of anthropogenic climate change (the scientific bases for which are discussed in detail in IPCC (2001b; 2007b)). Nordhaus (2007) comments that the Intergovernmental Panel on Climate Change's (IPCC) best case (i.e. lowest) temperature increase estimate for the coming century in its Fourth Assessment Report is "much more rapid than any changes that have occurred for more than 10,000 years".

As well as the often cited forecast increases in mean temperatures, the frequency of extreme weather events, such as heat waves, excess rainfall, droughts, and storms are likely to increase (McMichael et al., 2004; Karl et al., 1995; Easterling et al., 2000; Katz and Brown, 1992; IPCC 2001b; IPCC 2007b; Mason et al.,1999). Katz and Brown (1992) suggest that changes in variability are more important in their consequences than changes in mean climate variables. Extreme rainfall and temperature have serious implications for health outcomes. Crop yields may be reduced (see for example Ravallion, 1987), insurance markets disrupted, transportation systems damaged and sewerage and water systems overloaded. These factors can severely compromise people's ongoing abilities to derive their livelihoods. Experience of repeated extreme events undermines the ability to cope and recover (Alderman, Hoddinott and Kinsey, 2006; Alderman, 1994) and if such events contribute to the burden of early childhood malnutrition, then this has long-term consequences for growth (Martorell, 1995; 1999), behavioral development (Lasky et al., 1981) and academic achievement (Glewwe, Jacoby and King, 2001).

There is little doubt that Sub-Saharan Africa is one of the regions most affected by climate change (IPCC, 2007a) and that the region will face an increasing burden of disease from ongoing climate change[2]. It is not only that changes in climate are likely to be experienced intensely in Sub-Saharan Africa, but also that the incidence of disease and rates of mortality are already significantly higher than in other regions. Black, Morris and Bryce (2003) estimate that 41 percent of global child deaths occur in Sub-Saharan Africa. In addition, Sub-Saharan Africa's rapid population growth implies an increasing share of global child deaths would emanate from the region. UN population projections predict in the period from 2000 to 2020 the population of Sub-Saharan Africa will increase by around 400 million under its medium variant population projection with 41 million of this increase in the under-age-five population (UN, 2006).

[2] Patz el al. (2005) define two regions of Africa, AFR D^2 and AFR E^2, where they estimate the effects of climate change are to increase mortality in 2000 by 66.83 and 109.4 deaths per million respectively.

In this paper we quantify how extreme rainfall events and temperature events have impacted children's health across 19 countries in Sub-Saharan Africa in the period between 1992 and 2001. We look at the incidence of diarrhea, malnutrition and infant mortality at sub-national regional levels. The use of three indicators is in recognition of the multidimensional nature of health. Additionally the use of multiple health indicators enables us to understand their differential sensitivity to weather shocks within the timeframe we study. We would expect weather shocks to have the most evident impact on the short-term health indicators of diarrhea and weight-for-height malnutrition[3], rather than on height-for-age malnutrition, which is an indicator of longer term nutritional status and infant mortality, which is rarely the result of one preceding event. We employ measures of malnutrition for the population under age three as it has been demonstrated that, for example, the drought impact on malnutrition manifests most strongly in the age group of 12 to 24 months (Hoddinott and Kinsey, 2001).

The focus on diarrhea is because of its critical importance to child health. The World Health Organization (WHO) estimates that in 2000 recent climate change was responsible for approximately 2.4 percent of global diarrhea. The high prevalence of the disease means that the global impact of this increased incidence is large.

Although we look separately at indicators of children's malnutrition, disease and mortality, these are closely connected. WHO estimates of under-age-five child mortality rates attribute 22 percent of deaths to diarrhea (Patz et al., 2005). Studies have found that a high cumulative burden of diarrhea, that is accounting for number of episodes and duration, leads to stunting (Checkley et al., 2003; Moore et al., 2001).A vicious cycle between diarrhea and stunting means that children with stunted growth are more likely to contract diarrheal disease (Bern et al., 1992).

In our study, extreme rainfall events are defined as those that cross a defined upper threshold from the seasonally adjusted 20-year monthly rainfall average in the wet season. We also take into account the frequency of monthly rainfall exceeding the threshold in a defined time period. Extreme temperature is gauged by the maximum and minimum monthly average of the highest maximum or lowest minimum temperature of six months of the year.

The links between extreme weather and health have long been recognized but have been hard to quantify accurately. Recent advances in the measurement of weather events and definition of climatic zones permit more detailed study of the effects of weather patterns at sub-national regional levels.

A significant contribution of our study is the compilation of a panel data set across sub-national regions in Sub-Saharan Africa that contains indicators of key health outcomes, socioeconomic conditions, access to health and environmental services and critical climate variables including monthly precipitation, maximum and minimum temperature.

[3] A child is considered to be underweight when his or her weight for age is more than two standard deviations below the NCHS/WHO reference weight. A child is stunted when his or her height for age is more than two standard deviations below the NCHS/WHO reference.

The data set is constructed using panel data from the Demographic and Health Surveys for 108 regions from 19 Sub-Saharan African countries between 1992 and 2001 and climate data from the Africa Rainfall and Temperature Evaluation System (ARTES) from 1980 and 2001.

The sub-national regions are overlaid with the Köppen-Geiger (Kottek et al., 2006) climate map for Sub-Saharan Africa which we use to identify climate zones. The interpretation of the effects of extreme weather can then be made net of climatic zone effect and in conjunction with the particular climatic zone under study at a regional level.

The panel element of the data makes it possible to estimate better the independent impact of the explanatory variables controlling for unobservable confounding factors and regional-level fixed effects. The sub-national level information can substantially overcome the limitation of national level analyses that can obscure the strong patterns in biophysical or geographical correlates of mortality, malnutrition or disease across regions within a country. For example, sub-national data are particularly relevant in studying infant mortality rates, which vary considerably within countries, with some areas representing infant mortality hot spots (Storeygard et al., 2008). The evident clustering of diarrheal outbreaks also indicates the importance of sub-national level analysis (Luby et al., 2005).

The included socio-economic variables capture the local population's capacity to adapt and cope with weather shocks. There is well established literature on the socioeconomic determinants of child health which relates to access to health care, maternal education, access to safe water and sanitation. We are particularly interested in the potential use of our analysis to assess the extent to which public health interventions in these areas may mitigate the adverse effects of extreme weather events, that is, through the interaction between weather shocks and access to basic services.

Our findings assess how extreme weather events have already impacted on child health using historical data, but can also be used to simulate the future health burden from increased frequency of weather shocks as a result of climate change. We estimate the potential future health cost from an increased incidence of diarrhea caused by more frequent extreme weather events in Sub-Saharan Africa. However, the estimated relationship between health outcome indicators and extreme weather variables is particularly useful as it provides the statistical basis for more precise health projections in conjunction with localized or down-scaling climate models in Africa.

This paper is organized as follows. In the next section we present some of the existing evidence of how climate and its variations impact our chosen indicators of health. In Section 3 we describe the data. In Section 4 we describe our analytical strategy. In Section 5 we present the results of our analyses of the effects of extreme climate events on child health outcomes. In Section 6 we simulate the economic cost of a projected increase in weather variability in terms of cases of diarrhea and conclude with some policy recommendations for our results in Section 7.

2. Previous research on the effects of weather on health outcomes

A model of potential pathways through which climate change impacts health is constructed by McMichael et al. (2006). In this model extreme weather events are one of the manifestations of environmental change. The impacts of extreme weather events on health are seen through deaths and illness from thermal stress; microbial proliferation which can result in unsafe water and food poisoning; reduced crop, livestock and fishery yields which lead to impaired nutrition, health and survival and loss of livelihoods.

Although studies have already investigated the impacts of extreme weather events on a range of health outcomes, relatively few have quantified weather effects at high resolution. IPCC (2007) details several studies that have documented the incidence of diarrhea in the aftermath and during floods, for example India (Mondal et al., 2001), Bangladesh (Kunnii et al., 2002; Schwartz et al., 2006) and Mozambique (Cairncross and Alvarinho, 2006). Moreover O'Shea and Field (1992) illustrate the connections between the functioning of infrastructure and extreme weather events: floods may cause contamination of water sources as sewerage systems fail to function with heavy water loads, and storm run-offs can cause proliferation of pathogens. These papers concentrate on the links between water levels and disease, rather than directly on rainfall levels, although the two are, of course, related.

The direct links between excessive rainfall and the incidence of waterborne disease outbreaks are established by Curreiro et al. (2001) by analyzing a database of all reported waterborne disease outbreaks in the USA from 1948 to 1994. Results show that 51 percent of waterborne disease outbreaks were preceded by precipitation events above the 80^{th} percentile of monthly average for the particular weather station. The time period for the disease outbreak to occur varied: those due to surface water contamination showed the strongest association with extreme precipitation in the month of the outbreak whereas for groundwater contamination a lag of up to two months was allowed. Surface water is quickly contaminated during heavy rainfall events, but the period in which groundwater contamination can occur may be longer. The difficulties of establishing the lag within which rainfall can impact diarrheal incidence led Hashizume et al. (2007) to analyze the impact of rainfall above a threshold on the incidence of non-cholera diarrhea over a period of 16 weeks. The possible ecological pathways through which climatic changes, including higher precipitation, impact in relation to the specific pathogen vibrio cholera are discussed by Colwell (1996). Although there is strong evidence that extremely high precipitation leads to an increased incidence of diarrhea, it should also be noted that higher rainfall levels could potentially improve water quality through the dilution of pathogens (Hunter et al., 2002).

Extreme high or low rainfall events have also been found to impact nutritional status. Hoddinott and Kinsey (2001) find that in Zimbabwe children aged 12 to 24 months lose 1.5cm to 2.0cm of growth in the aftermath of a drought. In this study, they calculate the percentage of rainfall in a year as a percentage of the long-term average over a period in excess of 20 years and match children who were initially aged 12 to 24 months to drought conditions, as children in this age group are most likely to suffer growth suppression

from drought. These children are identified as drought cohort children and the analysis studies their growth. Del Ninno and Lundberg (2005) find that in the aftermath of a flood in Bangladesh, flood exposed children were smaller than those not exposed and that after the flood they did not catch up. Exposure to flood was measured at the household level by the level and duration of water in the actual dwelling. Foster (1995) finds that floods in Bangladesh were associated with lower child weight, and that households that were better able to smooth their consumption were more able to avoid adverse growth consequences for children under five. In summary the findings of these studies cover differential impacts of floods and drought on households depending on their income, education, landholding and their ability to smooth their consumption.

The links between rainfall variation and child survival in rural Burkina Faso are studied by Dos Santos and Henry (2008) using event history analysis. They divide the country into four agro-climatic regions. Of particular interest in this study is the construction of the rainfall variables, comprising a variable for long-term average yearly rainfall in the area, the yearly deviation from the long-term average in the locality and each month's deviation from the long-term average. The construction of our rainfall variables builds on this approach. In studying temperature and rainfall the approach in our paper is similar to a study conducted by Hashizume et al. (2007) in which they analyze the effects of both rainfall and temperature on non-cholera diarrhea in Dakha, Bangladesh.

The effects of the El Niño Southern Oscillation have provided guidance as to the potential impact of temperature and rainfall increases on health. In Peru, hospital admissions of children under age ten with diarrheal disease increased to 200 percent of the previous rate during the 1997 to 1998 El Niño episode in which mean ambient temperature in Lima increased by five degrees Celsius. The increase in hospital admissions during the El Niño event was much greater than the 8 percent increase per one degree rise in mean ambient temperature seen before the El Niño event (Checkley et al., 2000). This provides an example of how extreme weather changes can cause significant discontinuities with previously estimated effects.

The vulnerability of the poor to extreme weather events is documented both in developing and developed countries, although the scale of the problem is much greater in developing countries given the limited safety nets and capacity to deal with risks (UN-Habitat, 2003; Parry et al., 2007). The poorest are most exposed to increases in food prices brought about by deteriorating crop yields. Hoddinott and Kinsey (2001) found that in Zimbabwe drought only affected the growth of children residing in poor households. The effects of flood events and excess rainfall are differentiated according to the specific attributes of the population: those with poor sanitation infrastructure and living in areas with pre-existing high burdens of infectious disease are more likely to experience elevated rates of diarrheal diseases after flood events (IPCC, 2007), as are those living in crowded areas.

3. Data and methods

Our data set is constructed from the Demographic and Health Surveys (DHS) for Sub-Saharan Africa (DHS, 2008) and the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank, 2003). The DHS data sets are from nationally representative surveys of households with at least one woman of reproductive age, usually between 15 and 49 years of age. All eligible women in each selected household are included in the survey. The large sample sizes of the DHS surveys mean that they are particularly well suited to the aggregate level analyses that are undertaken in this paper. The details of the number of regions included in each country and the time points are provided in Table 1.

The ARTES database provides daily rainfall and temperature from 1977 to 2000, and monthly rainfall from 1948 to 2001. All weather variables are aggregated on sub-national administrative unit which corresponds, in most cases, to the sub-national indicators from the DHS.

3.1 Dependent variables

The diarrhea variable is the proportion of the child population under age three in the region affected by diarrhea in the survey period. At an individual level, incidence of diarrhea is defined in the DHS questionnaire as whether a child had a diarrheal episode in the two weeks prior to the survey. This short period of recall is necessary to ensure the validity of the measure of diarrhea. A drawback of the aggregate measure of the incidence of diarrhea is that respondents were asked the question throughout the survey year, and therefore the diarrheal incidence should be regarded as an average measure for the survey year.

The malnutrition variables are measures of children suffering from malnutrition as a proportion of the under age three population in the region. Two measures of malnutrition are employed, that of weight for height (wasting) and height for age (stunting). In line with established practice children are classified as malnourished if either their weight for height or height for age z-scores are two standard deviations below WHO/NCHS reference population median (WHO, 1995).[4]

The infant mortality variable is the under five mortality rate, which is estimated based on births in the ten years preceding the survey which makes it difficult to match it with corresponding climate variables. A priori, the weather variation variables are not expected to impact significantly in a direct way on the under-five mortality rate. The analysis of the determinants of the under-five mortality rate, however, is useful to provide additional information for model specification validation purposes.

[4] Z-score = (observed value-median value of reference population)/(standard deviation of reference population).

3.2 Explanatory variables

Weather variables

The maximum and minimum temperature variables are constructed using the monthly average of the highest maximum and lowest minimum temperature of the highest and lowest six months' average monthly temperature during the year.

The rainfall variable is defined using the twenty year monthly average rainfall in the six months of the wet season for each region. The wet season is defined as the six-month period of highest rainfall from January to December for each region. The reference category is zero months with 20 percent rainfall above the 20-year average. Excess rainfall for a particular month is defined as monthly rainfall that is 20 percent above that month's 20-year average rainfall. The first rainfall dummy variable takes the value 1 if there is one month's excess rainfall during the wet season. The second rainfall dummy variable takes the value 1 if there are two or more months of excess rainfall during the six months of the wet season. The use of two excess rainfall variables allows us to test for nonlinearity in the degree and duration of excess rainfall on the health factors in comparison with the reference category of no excess rainfall.

Long-term rainfall is captured by two-year average rainfall and five-year average rainfall.

Climate zone

The global map of climate is constructed using the Köppen-Geiger climate classification system based on a large global data set of long-term monthly precipitation and temperature station time series data (Kottek et al., 2006, Peel et al, 2007). These climate variables were calculated from a 0.5^0 x 0.5^0 latitude and longitude grid of monthly climate data.

To match this climate classification with our regional health data, we overlay the Köppen-Geiger climate map for Sub-Saharan Africa with the administrative map to assign all 115 regions under study with an appropriate climate type classification.

The localities across countries in Africa in our sample fall into ten out of the 30 possible climate classifications, as detailed in Table 2. The majority of regions in our sample fall into the climate classification categories of equatorial savannah with dry winter (Aw) (51 percent), followed by warm temperate climate with dry winter and hot summer climate type (Cwa) (15 percent) and steppe climate and hot steppe or desert (Bsh) (12 percent).

Socioeconomic variables

We include variables on the proportion of households with access to piped water, the proportion of households without access to a toilet, the proportion of the adult female population with no education and access to health care. The health access variable is an

index constructed through principle components analysis and comprises measures of access to antenatal care, access to a treatment facility, and vaccination coverage.

Other variables

In order to account for structural differences in the determinants of health across countries, we also include variables for per capita income at the country level, a dummy variable for the year and dummy variables for each country. Per capita income is measured in constant US$ per annum adjusted for purchasing power parity.

4. Analytical framework

4.1 Model specification

The reduced form model approach is used to test the statistical relationship between health outcomes and extreme climate conditions, controlling for socio-economic factors. We employ the data set as a panel to address the problems associated with omitted confounding factors that limit the interpretation of causality in many studies on the determinants of health outcomes.

The full model specification is as follows:

$$H_{it} = a + b\,X_{it} + c\,Z_{it} + d\,(\text{Climate Zone}) + w_t + v_i + u_{it}$$

Where, H_{it} are the three health outcome measures, X_{it} are the key socio-economic variables and access to health services, Z_{it} are the climate variables specified, w_t is the survey year that captures weather (other than the weather effects specified) or economic shocks common across all localities, v_i is the unobservable region-specific fixed effect which are constant over time for individual region, and u_{it} is residual following i.i.d. distribution and uncorrelated with X and Z.

4.2 Estimation methods

Information from all localities has been collected for two time periods[5], although the starting and ending period varying across localities, hence the data is an unbalanced panel. For example, the starting and ending survey periods for Cameroon are 1991 and 1998, for Benin 1996 and 2001 (see Table 1 for all countries).

Both ordinary least squares (OLS) and panel data estimators are applied to test the impact of climate variability on health outcomes, allowing for climate zone differences and country level fixed effects.

In the panel data analysis, we test whether a random or fixed effects estimator is appropriate (Baltagi et al., 2003). In the fixed effects (FE) model, the locality specific effects are assumed to be fixed (i.e. v_i are assumed to have no distributions).

[5] Zambia is the only country with three time periods.

The null hypothesis that the conditional mean of the locality fixed effects is zero given the repressors is tested using the Hausman test. If the null hypothesis is rejected the FE model is chosen, otherwise the random effects (RE) model is chosen. One of the key advantages of the RE model in the context of this study is that it includes estimates of the climate zone variables that can be used for prediction of the health impact under different climate zone assumptions. The RE estimates are consistent under the assumption of no correlation between the locality specific effects and mean repressors, i.e. E (v_i | X bar) = 0.

We estimate the impact of climate variables on health indicators using both a full model specification that includes the country fixed effects, survey year, country GDP per capita and climatic zones and a parsimonious model which excludes these variables because of concerns about our sample size and high correlation among included explanatory variables and the country specific effects.

5. Summary statistics

5.1. Variable descriptive statistics

Table 3 provides some basic descriptive statistics for the data set under study. Across the regions of our study the average prevalence of diarrhea is 22.5 percent. The prevalence of height for age malnutrition is 34.5 percent and weight for height malnutrition is 9.0 percent. Thus in the regions under study the prevalence of long-term malnutrition is much higher than short-term malnutrition. There is also a wide range of values for prevalence of malnutrition. The prevalence of weight for height malnutrition ranges from 1.4 percent to 27.9 percent, and height for age malnutrition from 9.0 percent to 67.9 percent.

The mean across all regions of households with a piped water connection in our sample is 32.7 percent, without a toilet connection 30.7 percent and adult females with no education is 40.9 percent.

5.2 Weather patterns

Figure 1 shows the percentage of regions with two or more months of excess rainfall in each year between 1980 and 2000 for the overall sample and the three most common climate classification zones in the sample. More regions witnessed excess rainfall for two or more months in the wet season in the first decade as compared with the second decade. On average, the percent of regions with two or more months of heavy rain varied between 20 to 65 percent in the 1990s. Of the three climate zones, warm temperate climate with dry winter and hot summer (Cwa) zone showed the most variability in excess rain between 1980 and 2000.

Figure 2 shows the monthly average maximum and minimum temperatures for each year between 1980 and 2000 for the overall sample and the three most common climate classification zones in the sample. The year to year variation is much smaller at the

aggregate level as compared with spatial variation in maximum and minimum temperature across different climate zones. This is as expected since the climate zones are partly based on long-term temperature ranges. We are not sure of the reason for the dip in minimum temperature in the early 1980s, but one possible reason may be a lesser number of meteorological observation stations in the early years. However, this does not affect our analysis of the health outcome variables in the 1990s.

Casual observation of these figures indicates that at an aggregate level of the region, twenty years of precipitation and temperature data do not show any signs of climate change, but the time period is too short to drawn any conclusions.

6. Results and interpretations

6.1. The health impact of extreme weather variables

We find that most of the included socio-environmental variables become insignificant when country and climate zone dummy variables are included. In contrast, across both model specifications, the estimated impact of the key weather variables on health remains robust. This is as we would expect given the exogeneity of the weather events.

Moreover, the results confirm our expectations about the health impact of climate variables. Extreme weather events have a significant impact on the incidence of diarrheal disease and the incidence of weight for height malnutrition. The effects are much less evident on the long-term indicators such as the incidence of height for age malnutrition or the under-five mortality rate.

The estimated climate effects on the short-term health indicators, including incidence of diarrheal disease and weight-for-height malnutrition using the parsimonious model specification are presented in Table 4 and the full model is summarized in Table A. The height-for-age and under-five mortality results are also presented in Table A. The regression estimates from the OLS and RE method are of similar magnitude in both cases.

While the pathways through which climate variability and extreme weather conditions affect disease incidence and nutrition are complex and dependent on specific disease etiology and local socio-environmental conditions, our results provide strong evidence on the causal effect of climate conditions on health outcomes in the public health environments under study. Our disease incidence data are an average measure over the year, and it is likely that with more time-specific disease incidence data matched with the monthly rainfall and temperature we would find even stronger impacts.

The results show significant health impacts of extreme weather events in the case of both extreme temperature and excess rainfall in Sub-Saharan Africa. The effects are seen both on diarrheal incidence and weight for height malnutrition, our two short-term indicators of health. We would expect that there would be similar effects on both measures, given the close relationship between diarrhea and weight for height malnutrition.

In comparison with the reference group of normal rainfall, two or more than two months' excess rainfall during the wet season increases significantly the incidence of diarrhea (p= 5.0), while one month of excess rainfall does not significantly affect diarrheal incidence. In our random effects models on average, excess rainfall increases the incidence of diarrhea by about 2.1 percentage points in the model without country fixed effects and by 2.6 percentage points in a model with country fixed effects. This is a notable increase given the sample mean of diarrheal incidence is 22.5 percent. This finding is consistent with the existing evidence that shows that there is a strong association between heavy rainfall and outbreaks of diarrhea caused by waterborne disease (Curreiro et al., 2001).

The results also show that prolonged excess rainfall (two months or more) increases the proportion of weight-for-height malnutrition among children under three years of age by 1.7 percentage points (Table 4). But this effect does not persist in the full model (Table A). There is also tentative evidence on the link between heavy rainfall and height-for-age malnutrition: the coefficient is significant in the OLS specification but not in the random effects model (Table A). Thus the impact of sustained above average rainfall is to raise short-term malnutrition rates and possibly that of long-term malnutrition.

Another crucial finding of this study is the statistically significant impact of maximum and minimum temperature on the incidence of diarrhea and weight-for-height malnutrition. These results are robust and significant in our random effects specifications for both diarrhea and weight for height malnutrition, and also persist in the full model (Table A). The results in Table 4 show that an increase in monthly minimum temperature reduces diarrheal incidence within a region by 0.45 percentage points. A 1.0 degree Celsius increase in monthly maximum temperature increases the incidence of diarrhea by about 0.6 percentage points and increases the proportion of the population affected by weight for height malnutrition by 0.3 percentage points in the parsimonious specification. The estimated impact on weight for height malnutrition is important, representing in the region of a 3 percent increase in the incidence given that the average prevalence of weight for height malnutrition is 9 percent.

Our findings on the impact of temperature on diarrheal incidence are in line with two studies in the developing country context which focus on the statistical association between temperature and diarrheal incidence. Using data on daily number of hospital admissions of children under ten years of age with diarrhea in Lima, Peru, Checkley et al. (2000) showed diarrheal admissions increase 8 percent for every one degree Celsius increase in temperature (average across all seasons). Singh et al. (2001), using monthly data for Fiji, provided an estimate of about 3 percent increase in diarrheal notification for a one degree Celsius increase in temperature.

Our measure of diarrhea is not directly comparable with these estimates as the focus of these studies is hospital admissions whereas our measure relates to households' reporting of diarrhea. A further study that controls for access to water and sanitation and socioeconomic status in Dakha, Bangladesh, found that the percentage change in the

number of non-cholera diarrheal cases per week is 5.6 percent for a 1 degree Celsius increase in temperature (Hashizume et al., 2007).

6.2 Socioeconomic variables

This study also confirms findings in the existing literature that better access to health services, improving female education and access to sanitation facilities all bring significant health benefits. Greater access to health services significantly reduces the incidence of diarrhea by a large proportion, although the size of the coefficient is not directly comparable to the other coefficients as it is an index variable. We also attempt to identify the interaction effect between extreme weather events and adaptive capacity as measured by access to basic services, including health, water and sanitation facilities. The estimated coefficients of the interactive terms are statistically insignificant.

Table 4 shows that variables that have been found to affect diarrhea in other studies, such as access to piped water and connection to a toilet, are also found to be significant in the random effects model, but not in the full model presented in Table A in which we control for country fixed effects, country per capita GDP, climate zone and year. We interpret this as a problem of correlation between the variables for access to piped water and sanitation and the region fixed effects. The existing literature finds contradictory evidence of the impact of access to piped water (Esrey et al., 1991), but the incidence of diarrhea is generally considered to be affected by access to both piped water and sanitation.

Access to safe water is also found to be important for growth and nutrition. Esrey et al. (1992) found that children living in homes with contaminated drinking water were significantly shorter. Our results are consistent with this finding in that the impact of piped water on the prevalence of height for age malnutrition significantly reduces the prevalence of height for age malnutrition in our random effects specification with country, climatic zone, time and country per capita GDP as is seen in Table A.

The importance of maternal education for children's health and nutrition outcomes is well established and reviewed in surveys provided by Behrman and Deolalikar (1988) and Strauss and Thomas (1998). We find that maternal education is important in lowering the incidence of short-term and long-term malnutrition, and the effects are significant.

The large and significant effect of maternal education on the under five mortality rate is in line with a large body of other research, for example in Caldwell (1979), Hobcraft et al. (1984), Subbarao and Raney (1995), Cleland and Van Ginneken (1988) and Deaton and Paxson (2001). We also find that access to health care has a significant impact in safeguarding children's survival. These results on the determinants of the under-five mortality rate are in line with findings from a large body of research and provide validation for the other disease models that we study.

In the full specification models the region's average per capita income is controlled, which is found to be significant both for diarrhea and wasting (Table A). A one-unit

increase in per capita income (US$ in constant prices) is associated with a 0.05 percent decrease in the prevalence of diarrhea and weight-for-height malnutrition in a region. Collectively our climate zone dummy variables are not found to be significant but our country dummy variables are significant. We would expect the country dummy variables to represent significant differences in public health regimes and conditions net of per capita income differences.

7. Health impact simulation for 2020

In this section, we simulate the impact of an increased frequency of extreme temperature and rainfall weather events on health, focusing only on the incidence of diarrhea across regions of Sub-Saharan Africa by 2020.

The simulation is based on three working assumptions. First, the frequency of excess rainfall events and the average maximum and minimum temperatures would increase in Sub-Saharan Africa as a result of climate change. The probability of excess rainfall (two or more months) is assumed to increase from the current level of 43 percent to between a lower bound of 60 percent and an upper bound of 80 percent, and the maximum and minimum temperature both to rise by 1 degree centigrade by 2020.

The second assumption is that the level of public investment in social and environment sectors in the coming decade would be such as to maintain the current levels of population access to basic services. We essentially assume the rate of investment in access to basic services is the same as the population growth rate in Africa. That is, all other covariates in the model would be kept at the current level in the simulation.

World Bank data from the SIMA database show that between 1995 and 2006, the proportion of the population with improved water access increased from 40 to 51 percent, and access to improved sanitation from 30 to 50 percent, indicating the speed of improvement in safe water and sanitation access in Sub-Saharan Africa of between 2 percent and 6 percent per annum, respectively. Our assumption of the rate of investment in environmental infrastructure seems plausible in the light of the UN projected population growth rate of 2.4% between 2000 and 2020 in Sub-Saharan Africa.

The third assumption is that the population growth rate for the population aged under five in Sub-Saharan Africa between 2000 and 2020 will be in line with UN medium variant population projections (UN, 2006). As shown in Table 5, the UN projected population aged under five increases from 116 million in 2000 to 157 million in 2020 in Africa.

7.1 Projection of health burden and economic cost of diarrhea by 2020

The health impact of diarrhea is estimated using the incidence of diarrhea obtained from the econometric model presented in Section 3, and the UN population projections listed in Table 5. The results of this estimation are that diarrheal incidence would increase from

22.8 percent in 2000 to 23.5 percent and 24.6 percent by 2020, respectively, for the lower and upper bound climate change scenarios under the above assumptions.

The total number of diarrhea cases in children under age five would consequently increase by about 46 percent, from 26 million cases in 2000 to 38 million cases in 2020 in the upper bound scenario. The increase in diarrheal cases between 2000 and 2020 can be decomposed into two factors: the increase in diarrheal incidence as a result of the increased frequency of excess rainfall and rises in extreme temperature, and the increase in population under the age of five[6] Our calculation shows that population growth would account for 36 percentage points of this increase and the increased frequency of extreme events would contribute about 9 percentage points.

The potential health cost of diarrhea is illustrated through the calculation of the number of disability adjusted life years (DALYs). The calculation of DALYs attributable to diarrheal disease for children under the age of five is the sum of morbidity and mortality from diarrhea.

Morbidity is estimated from the total diarrheal cases for any given year, assuming the average length per episode is four days, DALY disability severity weight of 0.11 and DALY age weight of 0.31 from WHO guidelines (Murray and Lopez, 1997). Mortality is calculated based on total diarrheal cases for any given year, estimated conditional mortality probability (3.7 %)[7] and discounted years of life lost per child from WHO guidelines. Using the predicted diarrheal incidence from our sample (see Table 5), the health burden of diarrhea among children under the age of five is about 33.5 million DALYs for 2000, which is very close to the WHO estimate of about 32.2 million DALYs for 2005 for Sub-Saharan Africa (WHO, 2008).

The economic costs of diarrhea are also presented in Table 5. The share of total health cost of diarrheal diseases in the under five age group is the ratio of DALYs multiplied by GDP per capita to total GDP for the corresponding years.[8] The ratio of health cost to GDP, as shown in footnote 8 is determined principally by three factors, the population age structure (ratio of population under age five to total population), the diarrheal incidence and the conditional under five mortality probability. The estimation results presented in Table 5 show that the economic costs of diarrheal disease relative to GDP

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[6] Δ diarrheal cases between 2000-2020
$= POP_{2020} * DI_{2020} - POP_{2000} * DI_{2000}$
$= POP_{2020} * \Delta DI + \Delta POP * DI_{2000}$
where DI refers to diarrheal incidence.

[7] The probability of under-5 death from diarrhea is estimated using the formula: Prob(death/diarrhea)=prob(death caused by diarrhea)/prob(diarrhea). The probability of diarrhea caused death is estimated using the WHO cause of death information for Sub-Saharan Africa in 2002. The estimated diarrheal incidence is from our own estimates using the DHS data for Sub-Saharan Africa.

[8] Health cost/GDP = (DALY * GDP per cap)/ Total GDP =
(Mortality DALY + Morbidity DALY) * GDP per cap)/ Total GDP = [(prob(death caused by diarrhea)*pop_4*DI*Φ+ pop_3*DI*Ψ]* GDP per cap)/ Total GDP, where DI is the diarrheal incidence = (Pop_4/Total pop)*{[(prob(death caused by diarrhea)*Φ+ DI*Ψ]}, where Φ and Ψ are fixed coefficients for disability weight, age weight and discounted years of life lost taken from WHO.

remain more or less constant at the level of about 5 percent between 2000 and 2020, reflecting the stability of the ratio of the population aged under five to the total population and moderate increase in the incidence of diarrheal disease of children under age five associated with the lower and upper bounds of extreme weather scenarios during the study period.

7.2 The health impact of climate change projection

The projected climate impact on diarrhea in 2020 is the excess health burden attributable to climate change, net of the population growth effect. This is estimated by comparing the projected number of diarrheal cases with and without climatic changes in 2020. Without climate change, the diarrheal incidence in 2020 is assumed to be the same as that in 2000 based on our sample estimate, i.e. 22.8 percent. The projections presented in Table 5 show that if the probability of extreme rainfall events were to increase to 60 percent or 80 percent, in combination with an increase in minimum and maximum temperature of 1 degree Celsius, there would be an increase in diarrheal cases among children aged under five, of between 1 million or 2.7 million cases in 2020 respectively.

The additional health cost of diarrheal disease attributable to this projected climate change in Sub-Saharan Africa is between 0.2 and 0.5 percent of GDP by 2020. This projection is confined to one disease and to the most vulnerable age group. However a range of other diseases have been found to be affected by climate change, including malaria[9], and dengue fever (Hales et al, 2002) in Africa. The full health cost of climate change could be much larger, possibly reaching at least 1% GDP, if taking account of all these health indicators

8. Conclusion

This study provides new evidence that extreme precipitation and temperatures have significant impacts on the incidence of diarrhea and malnutrition among children under the age of three in Africa. The effect of extreme weather events remains strong even after controlling for socioeconomic factors, climate zone and country fixed effects. The employment of panel data improves the measurement of the impact of socioeconomic factors by controlling for unobserved heterogeneity. From a policy perspective, the incorporation of weather and socioeconomic factors in one model addresses the issue that the many factors that influence human health cannot be considered in isolation (Scheraga et al., 2003). While adaptive capacity, in terms of income, female education, access to

[9] There are several studies on the impact of climate change on malaria. These include the study by Martens and et al (1999) that provides global estimates of the additional number of people at risk based on future climate scenarios and MIASMA malaria model; Bouma and Kaay (1996) who studied the association between the EI Nino Southern Oscillation and the malaria epidemics on the Indian subcontinent and Sri Lanka; the study by Zhou and et al (2004) on the association between climate variability and the number of monthly malaria outpatients in seven highland sites in East Africa; and Tanser et al (2003) who used the climate models to project the potential effect of climate change on transmission patterns of malaria and projected a potential increase of 16-28% in person-months of exposure across all three IPCC scenarios (low greenhouse gas emissions, medium-high and high emissions) in Africa.

health and environmental services, is important, when extreme weather events occur they have a strong adverse effect on children's health in Africa

In terms of socioeconomic factors, we find that an increase in the proportion of the population with access to piped water, sanitation and health care reduces the incidence of diarrhea, and higher rates of female education and access to health services reduce the incidence of weight-for-height malnutrition. The size of these effects in relation to the size of the weather effects suggests that it would be impractical in the short term to counterbalance the effects of extreme weather events through enacting measures solely to improve performance on these indicators. There are of course other good reasons for improving performance on these socioeconomic indicators, not least because they affect the populations all the time, and are an important part of the public health environment. In fact, public investment to improve access to basic environmental and health services and female education should remain a development priority in the face of projected population growth in Africa – which is the fastest growing in comparison with other developing regions – in the coming decades

Specific policy measures that can be taken to adapt to extreme weather events relate to prediction, monitoring and the implementation of early warning systems (Ebi and Schmier, 2005). Technical abilities to predict climate events have improved dramatically and now enable public health policy makers to use climate prediction as a central tool in developing early warning systems. This ability will become more important as climate variability increases. Our results suggest that the prediction capability is particularly important in the case of extreme temperature events in order to forewarn at risk populations. Two or more months' excessive rainfall during the wet reason significantly raise the incidence of diarrhea and weight-for-height malnutrition, whereas one month's excessive rainfall does not. There is scope to refine the exact time period available, but a window of opportunity exists to expand emergency access to healthcare and safe water. Early warning systems can be put in place to alert the at risk population of the potential dangers and highlight the need for preventive actions such as boiling water.

Our simulations based on assumptions on increased weather variability suggest that the health cost of more frequent extreme weather events on diarrhea alone would be large, in the region of 0.2 to 0.5 percent of GDP, net of the effect imposed by population change. This cost would be multiplied by population growth, which will create a large increase in the absolute numbers of children affected by episodes of diarrhea.

A key equity issue is how the costs of increased climate variability should be borne given that they are disproportionately experienced by the poorest people in some of the poorest countries of the world. Moreover the potential victims have made little contribution to anthropogenic climate change. Our results provide strong support for an increase in the provision of development finance to Africa as part of the international climate change negotiations

The results in this paper, which are based on analysis of a large number of regions across ten climate zones, can be used as an analogue in future work on Sub-Saharan Africa. As a

first step, the findings from this study can be used to project health consequences at the country level by incorporating the estimated health effect of extreme weather events into the currently developed downscaling climate model for individual countries in Africa.

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Tables

Table 1: Countries, regions, and years in the study sample

Country	No regions	Survey period	
		starting	ending
Benin	6	1996	2001
Cameroon	4	1991	1998
Ethiopia	1	2000	2000
Ghana	10	1993	1998
Guinea	1	1999	1999
Ivory Coast	1	1994	1998
Kenya	7	1993	1998
Madagascar	6	1992	1997
Malawi	3	1992	2000
Mali	6	1995	2001
Mozambique	5	1997	1997
Niger	5	1992	1998
Rwanda	11	2000	2000
South Africa	7	1998	1998
Tanzania	20	1992	1996
Togo	1	1998	1998
Uganda	4	1995	2000
Zambia*	9	1992	2001
Zimbabwe	8	1994	1999
Total	115		

Table 2: Köppen and Geiger classification of climate zones in Sub-Saharan Africa

Type	Description	Criterion
A	**Equatorial climates**	**Tmin ≥ +18 ◦C**
Af	Equatorial rainforest, fully humid	Pmin ≥ 60 mm
Am	Equatorial monsoon	Pann ≥ 25(100−Pmin)
As	Equatorial savannah with dry summer	Pmin < 60 mm in summer
Aw	Equatorial savannah with dry winter	Pmin < 60 mm in winter
B	**Arid climates**	**Pann < 10 Pth**
BS	Steppe climate	Pann > 5 Pth
BW	Desert climate	Pann ≤ 5 Pth
C	**Warm temperate climates**	**−3 ◦C < Tmin < +18 ◦C**
Cs	Warm temperate climate with dry summer	Psmin < Pwmin, Pwmax > 3 Psmin and Psmin < 40 mm
Cw	Warm temperate climate with dry winter	Pwmin < Psmin and Psmax > 10 Pwmin
Cf	Warm temperate climate, fully humid neither Cs nor Cw	
a,b,h	**Temperature (Third Letter)**	
a	Hot Summer	Tmax ≥ +22 ◦C
b	Warm Summer	not (a) and at least 4 Tmon ≥ +10 ◦C
h	Hot steppe / desert	Tann ≥ +18 ◦C

Source: Kottek et. al., 2006

Note: Tmin – minimum temperature; Pmin/Pann – minimum/annual precipitation; Psmin/ Pwmin – precipitation summer/winter minimum.

Table 3: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Diarrhea (%)	206	22.5	7.5	6.8	45.7
Height for age <2sd (%)	209	34.5	10.6	9.0	67.9
Height for age z-score	209	-1.4	0.4	-2.5	-0.4
Weight for height <2sd (%)	209	9.0	5.2	1.4	27.9
Weight for height z-score	209	-0.4	0.3	-1.3	0.7
U5MR (per 1000 births)	160	172.5	71.3	13.2	390.9
% hh with piped water access	208	32.7	24.1	0.6	98.6
% hh no toilet facilities	208	30.7	28.2	0.2	92.7
% hh with no electricity	208	83.2	19.8	7.6	100.0
% children with no antennal care	216	12.7	17.6	0.0	83.1
% children treated in clinics with diarrhea	216	39.3	19.6	2.5	94.7
% children receive all vaccinations	216	59.5	20.7	9.1	94.2
% adult female with no education	218	40.9	21.7	4.5	93.8
per capita income ($, country-level)	199	312.4	138.2	128.0	671.0
five-year average annual rainfall (mm)	218	893.8	317.1	154.6	2308.2
Monthly average maximum temperature (C^0)	218	34.4	3.3	28.6	42.4
Monthly average minimum temperature(C^0)	218	12.7	4.8	-1.9	21.8

Table 4: Main Results

VARIABLES	diarrheal incidence		%(WFH <2sd)	
	OLS	RE	OLS	RE
Percent with pipedwater	-0.039	-0.045*	0.017	0.017
	0.03	*0.03*	*0.01*	*0.02*
Percent without access to toilet	0.052***	0.044*	-0.008	-0.008
	0.02	*0.02*	*0.01*	*0.01*
Percent female with no education	0.019	0.043	0.074***	0.074***
	0.04	*0.04*	*0.02*	*0.02*
Access to health service (index)	-1.604***	-1.665**	-1.555***	-1.555***
	0.61	*0.73*	*0.36*	*0.39*
Average maximum temperature	0.616***	0.590**	0.256*	0.256**
	0.22	*0.23*	*0.13*	*0.13*
Average minimum temperature	-0.430***	-0.454***	0.157*	0.157*
	0.120	*0.148*	*0.085*	*0.08*
2-year average rainfall	0.000	0.001	-0.002	-0.002
	0.002	*0.002*	*0.001*	*0.001*
1 month excess rainfall dummy	-0.900	-0.945	0.797	0.797
	1.29	*1.09*	*0.75*	*0.68*
2 or more months' excess rainfall dummy	2.882**	2.145**	1.668**	1.668**
	1.13	*1.04*	*0.68*	*0.67*
Constant	4.877	4.702	-4.545	-4.545
	7.51	*8.12*	*4.73*	*4.48*
Observations	196	196	199	199
R-squared	0.363	.	0.537	.
Number of locations		107		100
Robust standard errors in italic				
*** p<0.01, ** p<0.05, * p<0.1				

Note: (1) Access to health service (index variable) is constructed through principle components analysis using a range of available variables in the DHS database, including access to antenatal care, access to treatment facility, and vaccination coverage. The magnitude of this variable is not directly comparable with other explanatory variables include in the regression. (2) The reference group for the excessive rainfall dummy variables is normal rainfall during the wet reason (i.e. zero month of excessive rainfall). The monthly excessive rainfall is defined as a rainfall that is 20% heavier than the 20 year average of the corresponding month.

Table 5: Projected health impact in 2020

	2000	2020		Impact due to climate change in 2020	
		lower bound	***upper bound***	***lower bound***	***upper bound***
Diarrheal cases (1000)	26,451	36,813	38,536	1,037	2,761
DALY (1000)	33,459	46,566	48,745	1,312	3,492
Health cost/GDP (%)	4.97	4.31	4.51	0.20	0.52
Diarrheal incidence (%)	22.84	23.5	24.6		
Population aged 0-4(1000)	115822	156652	156652		

Note: (1) population for 2020 is from UN population projections(medium variant)

(2) DALY per child death is assumed to be 34 from WHO

(3) Total DALY cost is calculated using constant 2000 $ from the World Bank data

(4) The lower (upper) bound corresponds to the probability of extreme precipitation of 60% (80%) and a rise in maximum and minimum temperature of 10 C in the simulation

Table A: supplementary results

VARIABLES	diarrhea	%(WFH<2sd)	% (HFA<2sd)		U5MR	
	RE	RE	OLS	RE	OLS	RE
Percent access to pipedwater	0.048	0.018	-0.073**	-0.070*	0.098	0.011
	0.029	*0.017*	*0.032*	*0.040*	*0.166*	*0.197*
Percent without a toilet	0.030	-0.003	-0.115***	-0.097**	0.407**	0.410*
	0.033	*0.019*	*0.036*	*0.045*	*0.197*	*0.219*
Percent female with no education	0.087	0.061*	0.353***	0.297***	1.108***	0.999***
	0.057	*0.034*	*0.069*	*0.072*	*0.303*	*0.356*
Access to health care (index)	3.841***	-1.137*	0.940	1.163	31.73***	26.06***
	1.008	*0.602*	*1.324*	*1.164*	*6.015*	*5.665*
Average maximum temperature	0.787**	0.420**	-0.013	-0.150		
	0.316	*0.197*	*0.411*	*0.360*		
Average minimum temperature	-0.602**	0.044	-0.496	-0.524*		
	0.237	*0.144*	*0.305*	*0.314*		
2 year average rainfall	0.002	0.003**	0.006*	0.003		
	0.003	*0.002*	*0.003*	*0.003*		
1 month excess rainfall dummy	0.311	0.109	2.066*	1.387		
	1.080	*0.682*	*1.228*	*1.142*		
2 or more months' excess rainfall dummy	2.568**	0.875	3.506**	1.923		
	1.125	*0.730*	*1.383*	*1.239*		
Per capita income	-0.052*	-0.051***	0.045	0.029	-0.140	-0.116
	0.028	*0.019*	*0.031*	*0.029*	*0.136*	*0.104*
Year	-0.241	0.015	0.236	0.314**	-1.087	-1.267**
	0.157	*0.100*	*0.181*	*0.151*	*0.840*	*0.559*
5-year average maximum temperature					-2.739	-1.755
					2.451	*2.559*
5-year average minimum temperature					-3.474*	-3.138
					1.941	*2.170*
5-year average rainfall					0.032**	0.017
					0.016	*0.018*
Constant	485	-28	-469	-607.5**	2431	2775**
	315	*201*	*362*	*304*	*1658*	*1133*
climate zone (prob>chi2)	0.36	0.81	0.00	0.22	0.01	0.19
country effect (Prob>Ci2)	0.00	0.00	0.00	0.00	0.00	0.00
Hausman test	0.92	0.68		0.02		0.27
Observations	188	198	198	198	142	142
Number of location	99	99		99		71
R-squared	.	.	0.71	.	0.88	.

Robust standard errors in italic
*** p<0.01, ** p<0.05, * p<0.1

Figure 1. Variation in heavy rain in the sample climate regions from 1980 to 2000

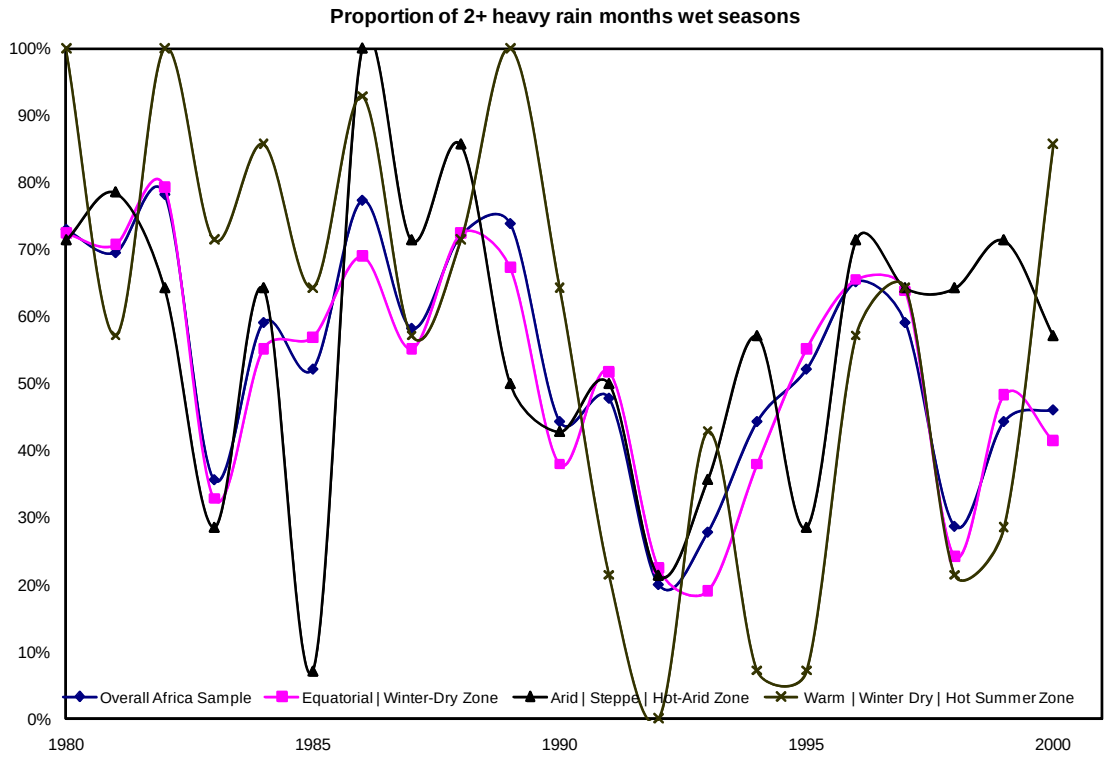


Figure 2. Monthly average maximum and minimum temperature from 1980 to 2000

