Dams and Infant Mortality in Africa

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Abstract

This paper investigates the impact of dams on infant mortality using 32 waves of DHS data that have GPS locations of households. This allows us to estimate the impact of dams on households that reside both downstream and within their immediate vicinity. We use a sample of over 400,000 children in 17 countries in Africa. In contrast to earlier research on the impact of dams on agricultural productivity and poverty, we examine child-level outcomes and measure the impacts of dams on downstream households that are both close to and very far from the dam. For non-migrant households we find the following. First, children born in households that reside immediately downstream to a dam experience a significant reduction of 6.19-6.96% in infant mortality. This is because the benefits of irrigation services of the dam are large for downstream households geographically close to the dam. Second, for children born in households that reside further downstream, infant mortality significantly increases by 2.18-2.36%. This is because dams reduce water levels downriver, and households cannot access compensating irrigation services from dams, or benefit from the reduced volatility of water flow that dams provide. Children born in the vicinity of the dam experience increased infant mortality of at least 2.27%, with evidence linking the increase to increased malaria incidence and reduced agricultural productivity near the dam reservoir.

"It completely regulates flooding in the Omo, which has been a major problem."

-Ethiopia Prime Minister Zenawi, on Gibe III dam planned for the Omo River, 2009.

"We will suffer because there will be no more floods. I don't think the government likes the Omo tribes. They are going to destroy us."

-Mursi tribe elder, on Gibe III dam being built upstream, Ethiopia, 2009.

1 Introduction

The debate on the welfare effects of large dams has become increasingly vocal in recent years. Many developing countries have undertaken very large investments in dam construction to increase irrigation and hydroelectricity generation capacity, to the extent that dams have been placed on nearly half the world's rivers [7]. Dam construction has undoubtedly played an important role in economic development, with 30-40% of the irrigated area and 19% of the total electricity generation in the world being dependent on dam operation [17]. However the effects of dam construction have often been visibly harmful and extremely severe. Documented consequences include flooding beyond the reservoir, increased saline content in the soil, and detrimental changes in cropping patterns forced by altered river flow patterns. Declining water levels and changing currents due to upstream dams can also permanently alter the river ecosystem, as well as the livelihoods of communities who rely on this ecosystem and the natural flow of the river. Whether these various dam effects have a direct impact on infant survival is a question that is yet to be answered. Ideally the answer to this question should be a fundamental underpinning of the dam-building process. This paper investigates whether dam operations have indeed had an impact on infant mortality in Africa; the continent that is currently undergoing a surge in dam construction and where the policy implications of this analysis are highly relevant.

To the best of our knowledge this is the first paper that attempts to identify the impact of dams on infant mortality. The findings of our analysis are meant to improve on what is already known on the welfare effects of dams by investigating this question for a very large sample of children across several countries in Africa. If dam operations have any significant effects on infant mortality, then our sample alone would account for nearly half a million children who potentially experience these effects. We additionally separate the impacts of upstream dams close to households from the effect of upstream dams farther away up the river, which is another contribution to the existing literature. Disaggregating dam impacts based on distance is important, as the effect of dams on agriculture changes from within the extent of the dam irrigation network to outside this extent farther downriver. Additionally, this is the first paper we are aware of that uses estimations at the level of the individual children as the unit of analysis to assess the impact of dams on a welfare outcome.

Our empirical analysis faces some fairly weighty confounding factors. The first issue is that regions selected for dam construction are likely to be very different from those not chosen, as dams require moderate to steep river gradients to operate. There are also political and other regional factors besides geography that determine dam placement. Hence even though we have significant regional variation in intensity of dam construction, a simple comparison of infant mortality probability between these regions will lead to biased estimates of dam impacts. To address this we exploit the fact that there is variation in child exposure to dams at birth both across regions, and over time due to variation in the timing of dam construction and child birth. This allows us to use a difference-in-difference (DID) estimation using this variation across both regions and time in exposure to dams at birth to ascertain dam impacts on infant mortality. We also present results from an instrumental variables regression exploiting regional variation in river gradients, which reinforces the findings of the difference-in-difference procedure. To check that our results are not driven by differing regional trends between dammed and non-dammed basins, or by endogenous placement of dams to areas with higher or lower infant mortality, we show that there is no correlation between an infant's mortality risk between ages 0-12 months and the number of dams he is exposed to 5 years or more after he is born. We also implement placebo regressions using dams located very far away from children as the source of exposure rather than dams that are closer, and ensure that estimated impacts shrink as a result.

The second major issue is that of selective migration bias. The enmasse displacement of people due to dams as well as voluntary migration potentially leads to highly selected samples of mothers in each region, making it potentially difficult to separate dam effects from unobserved maternal characteristics that influence both the decision to migrate to particular regions and the probability of infant survival. To deal with this concern we identify women interviewed in our sample who have never migrated, and carry out our main analysis only for children born to these non-migrant mothers. This reduces sample selection bias from parental migration out of areas harmfully affected by dams into areas that are benefited. However non-migrant mothers also constitute a selected sample, which has implications for both the internal and the external validity of our results. Regarding internal validity, our results on dam impacts may be biased if non-migrant mothers are systematically different in their child-rearing practices across different forms of regional dam exposure due to sample selection. They could also have unobservable characteristics that determine migration status, the form of dam coverage they are exposed to, and also the mortality risk of their children. Our instrumental variables regression again provides encouraging evidence that our results are not being driven by these potential sources of bias. Also the lack of correlation we find between an infant's mortality risk and dams he is exposed to past infancy alleviates concerns that our results are driven by systematic differences between non-migrant households. With regard to external validity, the results may only be justifiably generalised to children of non-migrant mothers. But the results still carry significant policy relevance, as affected populations who face barriers to migration may be more adversely affected by dam construction than those who can relocate. The results also shed light on what the net effects are on those non-migrants who may have access to unobserved compensating factors that counteract the negative impacts of dams.

Since dam effects vary depending on where households are located along the river network relative to the dam, we define whether dams are upstream, downstream, or in the same vicinity as households by using river drainage basins. The entire African continent can be broken down into these river basins, and each basin is coded so that we can identify whether it is upstream or downstream along the river network from every other basin. We identify which river basins households and dams lie in, and then define whether dams are upstream, downstream, or in the same basin as households using the basin river linkages. We then exploit the regional variation in our sample to separately identify the effects of upstream, downstream, and within-basin dams on infant mortality.

The results for children of non-migrants indicate that each dam in the neighbouring upstream river basin reduces infant mortality by 6.19-6.96%, conditional on other forms of dam exposure at birth. In contrast, upstream dams farther up the river increase infant mortality by 2.18-2.36% on average. Duflo and Pande (2007) does not estimate the impact of upstream dams farther upriver beyond the neighbouring district. However doing this is important in Africa, where unlike in India there is widespread household reliance on floodplain recession agriculture and wetland ecosystems. Dams provide irrigation services within a designated command area immediately downstream by redirecting river flow, which increases access to water and reduces vulnerability to rainfall shocks. Beyond the command area however, dams significantly reduce the amount of water that flows downriver. While dams also reduce the variance in rainfall shocks downriver via regulated discharges in periods of water shortage, the height of the water level is much more important for the health of the floodplain ecosystem that households depend on. This is reflected by our results which find that infant mortality increases due to upstream dams farther upriver that reduce water levels but are too far away to provide compensating irrigation services. We verify the impact in floodplain regions by showing that upstream dams increase infant mortality by a much larger 7.57% in cropland areas where river runoff is greater than 250 milimetres per year.

Within-basin dams increase infant mortality risk by at least 2.27%, and the harmful effect increase steadily to well past 10% as the number of these dams children are exposed to increases. This is consistent with the results of both Duflo and Pande (2007) and Strobl and Strobl (2010), which find that dams increase vulnerability to rainfall shocks in the region where they are built due to negative impacts of the reservoir on the soil [19]. We provide further evidence of this by showing that infant mortality increases disproportionately more due to within-basin dams in basins with cropland. We also use geo-spatial data on seasonal malaria incidence to show that mortality most likely increases due to increased malaria in the vicinity of dams built in areas where the malaria transmission season is longer than 3 months a year.

The rest of the paper is organised as follows. Section 2 presents background information on dams and previous analyses concerning their effects in the African continent and other parts of the world. In Section 3 we describe the data used for our estimations, and outline our empirical strategy for identification of any possible dam effects on infant mortality. The results of these estimations are shown and summarised in Section 4, and results from various robustness checks are also presented. Finally in Section 5 we summarise and discuss the implications of our results.

2 Background

In this section we summarise the geographical and humanitarian effects generated by dams. We then place these effects in the context of Africa, and outline our use of river basins in constructing our null hypotheses about dam impacts on infant mortality.

2.1 Dams and Welfare

Dams have varying and complex impacts on their surrounding areas and the resident population depending on whether these areas are upstream, downstream, or in the immediate vicinity of them, and how far along the river away from the dam these areas are. Illustrating the importance of dams is not a difficult task. Approximately a third of the entire world's irrigated lands rely on dams as mentioned previously. Dams are also estimated to contribute about 12-16% of world food production. Other purposes for which dams are built include hydroelectricity production, flood control, and water supply. Hydropower generated by dams accounts for more than 50% of the national electricity supply in 63 countries [17]. While there are no studies on the welfare impacts of hydropower generated by dams, hydroelectric dams are usually coupled with irrigation infrastructure built as part of the structure. Their effect on agricultural productivity is therefore assumed to be the same as irrigation dams in Strobl and Strobl (2010), and we do the same for our analysis.

The distributional effects of dam construction, and its effects on agricultural productivity have been investigated previously [7, 19]. The evidence indicates that upstream dams significantly increase agricultural productivity, by providing dam irrigation services in the command area immediately downriver and by regulating water flow to counteract rainfall shocks downriver. Duflo and Pande (2007) also find a decline in poverty incidence among households living downstream from dams in India. However the impact of dams on agriculture is likely to differ depending on the nature of cultivation techniques employed, as well as households' dependence on their surround ecosystem. Farming in Africa is typically based in floodplain recession agriculture, which relies on the cyclical flooding of rivers every year to deposit fertile silts. Hence dam impacts on the African continent are likely to be qualitatively different than in India where floodplain recession agriculture is not widely practiced. When considering infant mortality, we must also take into account the potential impact of dams on the disease environment around the reservoir. We now discuss in further detail the impact of dam construction on agriculture and disease prevalence in the vicinity of the dam site, on areas nearby downriver, and finally farther downriver beyond the dam's irrigation network.

2.1.1 Dam Impacts in their Vicinity

In the vicinity of the dam there are numerous and conflicting impacts. Creating the dam reservoir requires flooding thousand of square kilometers, often with harsh consequences to people's homes and livelihoods. The reservoir drains a proportionate fraction of its surrounding land known as the catchment area of the dam. A common outcome of the reservoir in this catchment area is increased salinisation and waterlogging of the soil due to rising groundwater levels. This greatly reduces the productivity of the land near the reservoir; a result that has been shown in the literature [20, 16]. The reduced land productivity is a potential detriment to household income. There is also evidence in the medical literature of increased malaria incidence among children living near dam reservoirs in Africa [9, 14, 23]. There are however benefits from increased economic activity around the dam while it is being constructed. Large numbers of labourers are often employed in the construction of these dams, creating a short-lived but large spurt in incomes that may have more sustained impacts in the regional economy via increased demand for goods and services. This increased economic activity often leads to the creation of informal settlements around dam sites, with in-migration of people looking to provide goods and services to dam labourers. On the other hand there are documented harmful impacts on health due to the sudden influx of workers and migrants, such as increased incidence of HIV and AIDS as well as diseases related to poor sanitary conditions [17]. There are therefore potential impacts of dams on infant mortality within their vicinity through both household income as well as direct exposure to disease. The net effect of these various impacts is however ambiguous.

2.1.2 Dam Impacts on Areas Nearby Downriver

For households immediately downstream from dams the story is largely beneficial. The irrigation network provided by dams within the command area greatly reduces the effective variance in rainfall shocks experienced by households who are close enough to use it. The increased irrigation also compensates for the reduction in floodwaters by allowing diversification to other types of agriculture that are less dependent on rainfall. Hence the net effect on welfare for households who reside close enough downriver from the dam to access the command area is purely beneficial, as agricultural productivity is protected against rainfall fluctuations within this area. Increased migration to the command area as well as the presence of the dam site close by also increase economic activity and employment opportunities. There is likely to be inflation in land prices due to increased demand combined with increased value from irrigation benefits that increases the real value of land holdings. There are however potential problems if too much in-migration increases population pressure on existing resources and creates health and sanitation problems. This increased population pressure may increase infant mortality, which would otherwise decline in these areas due to increased household wealth and income.

2.1.3 Dam Impacts on Areas Farther Downriver

Dams reduce water levels downriver beyond their irrigation command areas, and can therefore significantly reduce the height of river floodwaters that deposit fertile silts that downstream households rely on for cultivation [2, 5, 15]. This is potentially very detrimental for floodplain agriculture in areas downriver beyond the irrigation command area of the dam, and there is evidence that households dependent on agriculture in these areas also suffer as a result. In North-West Nigeria for instance, the Balokori Dam reduced flood levels by 50%, leading irrigated area to decline by 53% and a quarter of households to abandon dry-season agriculture as a way of life. Similar detrimental impacts on floodplain agriculture have been seen in Niger, Chad, Sudan, Senegal, and Mali [3]. While regulated discharges of water from upstream dams can be used to smooth the impact of rainfall shocks downriver, it is unlikely to compensate for the decline in the height of floodwater these dams cause.

The impact of dams on floodplain farmers living downstream may not only be through changes in land productivity. In fact, a river flowing without seasonal fluctuations in water height may improve productivity of surrounding land for certain types of crops and vegetation even if this water height is reduced by upstream dams [19]. However floodplain farmers depend on the seasonal flooding of land not just to fertilise the soil with silts, but also to create diversity in soil wetness. This allows risk diversification between dry-land and wetland cultivation, in case seasonal conditions adversely affect either form of agriculture [4]. The disappearance of the floodplain may therefore make them more vulnerable to rainfall shocks if there is less diversity in soil types for farmers to exploit in smoothing weather shocks. Floodplain agriculture is also based in experience and specialised skill acquired over generations, as farmers make planting decisions based on past flooding patterns and adapt to varying flood levels by planting different crops [4]. The value of this specialised knowledge is likely to be lost if farmers are forced to adopt different cultivation techniques, and they also must bear the cost of adopting these new techniques. The result is a potential decrease in household incomes both for farmers themselves, and for others in the regional economy if household spending contracts and demand for goods and services shrinks. Lower household incomes could then potentially cause greater infant mortality due to malnutrition, reduced child health investments, or illness.

The reduced height of floodwaters downriver from the dam also causes the degradation of wetland ecosystems in floodplains that are fed by the river inundation cycle. African households traditionally have a symbiotic relationship with the wetlands, relying on them for fuel collection, fishing, and dry-season grazing of cattle [4, 18]. Hence dams can potentially cause additional harm to households living downriver via destruction of wetlands, over and above their effect on floodplain agriculture. In terms of general equilibrium impacts, the degradation of wetlands and inability to continue with floodplain recession agriculture will most likely induce out-migration, which in turn reduces economic activity in the region. The reduced demand for land along with the disappearance of valuable wetlands is also likely to drive down land prices, which reduces the real value of land holdings for households that remain. Some of these detrimental effects may be offset by reduced population pressure on local natural resources, but to what extent this occurs is uncertain.

2.1.4 Affected Areas as River Drainage Basins

The dam impacts described above are summarised in Figure 1a, where Dam A is an example dam on a river flowing East to West. If we could accurately pinpoint dam catchment and command areas, as well as household locations, our analysis would be made easier. Unfortunately such information on catchment and command areas is unavailable, and the households we use in our analysis can only be located within a ten kilometre radius. We therefore instead use data on river drainage basins, for which upstream and downstream linkages can be determined, and construct our null hypotheses on the different forms of dam exposure based on which of these river basins dams and households are located in. The data on river drainage basins comes from the HYDRO1K dataset released by the US Geological Survey. The drainage basins are defined at six different levels according to size, with level 1 being the largest and level 6 the smallest. The level 6 basins are nested within the level 5 basins, the level 5 basins within the level 4 basins, and so on up to level 1. At the smallest level of regional subdivision, there are 7,131 level 6 basins in the continent with an average area of about 4,200 km^2. Mean basin area increases dramatically to about 18,350 km^2 from level 6 to level 5, and further to about 148,160 km^2 at level 4. We exploit this variation in basin size between levels for our robustness checks.

Figure 1b uses quadrants as theoretical representations of these river basins to illustrate the possible dam impacts on infant mortality based on household locations, which are also depicted. In quadrant I, where Dam A is built, infant mortality is likely to decline among children born in the part of the command area that lies within the quadrant. On the other hand it will probably increase among children born within the catchment area. Dam catchment areas can be reasonably assumed to lie completely within the basin where dams are constructed, as is assumed in Strobl and Strobl (2010) who find that this is the case for most South African dams. Children born in quadrant I are potentially affected by increased economic activity around the dam or increased disease incidence, even if not by changes in agricultural productivity. Children born in quadrant II will experience lower infant mortality risk if their parental households are located in the command area of Dam A built in the neighbouring upstream quadrant I. Those born outside the command area in quadrant II are potentially harmfully affected by the decline in river water level. Again, there are possible gains from increased economic activity around them dam in the neighbouring upstream quadrant. In quadrant III, the upstream dam in quadrant I is too far upriver to compensate for declining water levels with command area irrigation. This is supported by the fact that the average extent of irrigation schemes in Africa since the 1980s has been about 18 km^2, whereas the mean size of our river basins in 4,200 km^2 [19]. Gains from regulated discharges of water from the dam could however outweigh the detriments of the reduced height of floodwaters. Those born in quadrant IV are unconnected to the dam by river flow, but may experience general equilibrium effects due to increased economic activity around the dam site in neighbouring quadrant I. However we do not attempt to identify any such impacts of dams on basins unconnected by river flow, and instead treat households in such basins as our control group. Our estimations will therefore capture dam impacts that are propagated via the river network.

We not only attempt to identify the impact of dams on infant mortality within households residing in the same basin, but also to separate the effects of upstream dams that are in neighbouring basins from those in basins farther upriver. We do this by controlling for the total number of upstream dams a child is exposed to at birth, and then also separately including the number of such dams that are in the neighbouring upstream basin as an additional regressor in our estimations. For instance, for children born in households in quadrant III of Figure 1b, we include both the total number of upstream dams in quadrants I and II as well as *only* the number of neighbouring upstream dams in quadrant II in our specifications.

2.2 Dams in Africa

Africa is often referred to as the "under-dammed continent". This is because only 5.5% of the continent's renewable water resources are used (compared to 20.4% in Asia) despite it being the driest and least electrified continent in the world. The potential for better exploitation of these water resources is greatest in Sub-Saharan Africa, where only 3.5% of total cultivated area is irrigated [8]. There was a spate of dam building across the continent in the latter half of the twentieth century to meet increasing demand for irrigation and industrial water supply. According to the International Commission on Large Dams (ICOLD), Africa accounted for more than 1,200 large dams at the beginning of the millennium, as well as a host of other reservoirs that are not recorded [12]. Lack of investment in water infrastructure has nevertheless still left much of the available water resources unused. As a result there is large variation in the number of dams present across different parts of the continent, which we exploit for our empirical analysis.

We use the geo-referenced database on African dams released by the Aquastat programme of the Food and Agriculture Organisation (FAO) in 2006 to identify the geographic locations of dams across the continent of Africa. The FAO used the World Register of Dams, national reports and experts, and the internet to compile the database, which includes both large dams as defined by ICOLD and all other dams for which locations were found. The database also contains the year in which dams were completed or began operation; information we exploit in our analysis to compare children born after the dams are completed to children born before in the same region. We filled in missing values for year of construction in the database to the best of our ability using updated ICOLD data [13] and internet searches. Of the 1,040 dams in the database for which geographical coordinates are available, we are able to obtain the year of completion or start of operations for 967. The regional variation in dam construction is visible in Figure 2, which depicts African dam locations from our data as well as the continent broken down into level 6 river basins. The earliest constructed dam in the dataset was built in 1691, and the last in 2008.[1] The frequency of dams built annually

[1]Six of these dams are still under construction or not operational. We use them in our analysis as dams present but not operational before children in connected river basins are born.

in Africa from the year 1900 according to our dataset is shown in Figure 3.

Recent years have seen a resurgence in large-scale dam projects being commissioned across Africa. The major motivation behind the spurt of new dam construction is the continent-wide high demand for electricity. The amount of hydropower under construction in Africa increased by 53% from 2004 to 2006 [21]. Countries with a high hydropower generation capacity such as Ethiopia and the Democratic Republic of Congo have begun building dams of vast proportions to meet their own power needs, and also to export electricity to neighbouring countries.[2] Several of these projects have received substantial financial support from the World Bank and other development finance institutions. Many new large dams, such as the Gibe III in Ethiopia and the Merowe dam in Sudan, are also being financed by Chinese private firms and large banks [1, 11]. The growing number of projects and the level of financial support from international sources shows a great deal of confidence in dams as an investment in the future of Africa, but the impact on welfare these new projects will have forms an important part of the return to this investment.

3 Empirical Strategy

In this section we discuss the household data we use for our analysis, and how we implement our estimations. We then outline the specifications and econometric procedures we use on the data, and discuss the results in the next section.

[2] The Grand Inga dam on the Congo river will cost approximately $80 billion to build, and is estimated to be capable of providing power to 500 million households on its own (World Bank, 2009). It is planned to generate twice the amount of power currently generated by the largest hydropower generating dam in the world; the Three Gorges dam in China.

3.1 Household and Infant Mortality Data

Our data on children and households comes from the Demographic and Health Survey (DHS) that is carried out across several countries in Africa at different points in time. Clusters of households are randomly selected across each country to participate in the survey, and all women aged 15-49 years are interviewed in each household. A detailed fertility history is collected from each interviewee along with information on maternal and child health indicators, child mortality outcomes, household members, personal background, and wealth indicators. For several of these surveys, the latitude and longitude of the location of each cluster of selected households is recorded, and can be accurately pinpointed within a ten kilometre radius. We use every wave of the DHS survey carried out in an African country for which this geographic data is available. This gives a sample of women and children from 32 waves of DHS surveys in Burkina Faso, Cameroon, Cote d'Ivoire, the Democratic Republic of Congo, Egypt, Ethiopia, Ghana, Kenya, Morocco, Madagascar, Malawi, Nigeria, Namibia, Swaziland, Tanzania, Zambia, and Zimbabwe whose geographic locations we can identify for our analysis. The clusters of women interviewed in the Cameroon DHS survey in 2004 are shown in Figure 4, along with the locations of dams in the country and the division of the terrain into level 6 river basins. The size of the entire pooled sample from all the surveys is 231,169 women and 912,080 children. The fraction of children born each year that die aged 0-12 months in the final pooled sample for birth cohorts born from 1960 onwards is shown in Figure 5.[3] There is a clear downward trend in the infant mortality rate over time, although some of this is driven by differing survey years across countries.

In Table 1 we also report the number of children of non-migrants that are exposed to at least one dam at birth, broken down by category of dam exposure and time period of the

[3]70% of the 134,143 children who die aged five or below in our sample are 0-12 months old at the time of their death.

child's birth. Within-basin dams and farther downstream dams are by far the most prevalent forms of dam exposure at birth. There are however enough children born into each category of dam exposure, and enough variation within each category over birth cohorts, to carry out our analysis. The number of dams children are exposed to at birth within each category is reported in Table 2.

3.2 Estimation Procedures

There are two major issues intrinsic to dam construction and the resulting consequences that complicate the empirical investigation. The first is that river basins where dams are constructed are geographically different from those where they are not. As explained in Duflo and Pande (2007), dam operations require rivers flowing at different gradients depending on the purpose of the dam. According to the dam engineering literature, irrigation dams require a gentle river slope to create a long reservoir in proportion to the height of the dam and to allow the water to reach the irrigated area via gravity [10, 6]. If the river gradient is too steep the water flow will erode the canals that transport water to the command area. In contrast, hydroelectric dams require a steep river gradient so that fast-flowing water can power the electricity-generating turbines [22, 6]. Therefore river basins with river gradient conditions and geography suitable for dam construction will most likely differ from other basins in agricultural conditions, average elevation, temperature, and other factors that influence regional infant mortality rates. There are also undoubtedly region-specific political elements that influence the negotiations, contracts, and agreements that determine where dams are going to be constructed. These elements in all probability are closely linked to economic factors at a more disaggregated level within each country, which determine both regional dam placement and infant mortality rates. An OLS regression of infant mortality rate or child survival probability on the number of dams exposed to will therefore lead to biased estimates.

We implement a DID estimation to deal with the above concern. Specifically we examine different levels of exposure to dams at birth, which is determined by the river basin where the child was born, the years dams were constructed, and the child's year of birth. The geographical factors that influence dam construction are nearly constant over time, and the concentration of dams in a river basin is a good indication of how effective the other influences behind dam placement are in the region. We can therefore consider children born in the same river basin to be subject to the same elements that determine selection into the different kinds of exposure to dams, and use the variation in dam construction over time as well as child birth cohorts in our sample to examine the impact of this exposure on these children based on how many dams were operating upstream, downstream, or in the same river basin in the year of their birth. The children's years of birth in the sample range from 1953 to 2008, covering more than 50 years. This period coincides very closely with the years when dams were constructed most rapidly across Africa, which was approximately 1950 to 1995. There is therefore a lot of variation in the intensity of children's exposure to dams that we can exploit for our analysis. Of course the validity of this procedure rests on the assumption that trends in infant mortality between basins would not differ in the absence of dam construction. We ensure this assumption is not violated in our robustness checks by showing that there is no significant correlation between child mortality during ages 0-12 months and the number of dams built 60 months or more after these children are born. This check also alleviates concerns that dams are placed endogenously with respect to infant mortality rates across basins.

The second serious concern for our empirical estimations is that households often migrate in large numbers due to the effects of dams on the geography in their place of residence. This migration, whether forced or voluntary, can lead to biased estimates of dam impacts if households select themselves endogenously into regions that benefit from dams based on unobservable characteristics. To deal with this econometric concern, we carry out estimations only for children of non-migrant women as discussed in the introduction. However this sample also makes our estimations prone to different sources of selection bias. We therefore again argue that the lack of significant correlation between infant mortality and dams built long after children are past infancy shows that systematic differences between households across types of dam coverage are not driving the results. We identify non-migrant mothers using the information on the number of years each woman interviewed has lived in her current place of residence. If the answer to the question is "always", the woman is classified as a non-migrant. This process gives us a sample of 103,211 non-migrant women and 415,548 children born to non-migrant mothers.

Our outcome of interest is whether a child dies aged 0-12 months. The central econometric approach we use to find any impact of dams on this outcome is a linear probability model (LPM). The LPM is attractive due to its simplicity, but the linear specification may lead to probability estimates lying outside the unit interval. We perform checks to make sure that enough of the predicted probabilities from the model lie between 0 and 1.[4] We can also correct for the individual-specific heteroscedasticity built into the error structure of the LPM by using robust standard errors. To illustrate our DID procedure using the LPM specification, consider the following regression:

$$y_{ij} \;=\; \alpha \;+\; \beta_1 WDAMS_{ij}^{B} \;+\; \beta_2 UDAMS_{ij}^{B} \;+\; \gamma X_{ij} \;+\; \theta \;+ t_i \;+\; \epsilon_{ij} \tag{1}$$

where the dependent variable y_{ij} is a dummy variable taking the value 1 if child i born in river drainage basin j died when aged 12 months or younger. Regressors $WDAMS_{ij}^{B}$, and $UDAMS_{ij}^{B}$ represent respectively the total number of within-basin and upstream dams

[4]Approximately 96% of the estimates lie in the unit interval in our final OLS results.

built before the child's birth year t_i for basin j. X_{ij} is a vector of other regressors that affect child survival probability. θ is a basin fixed effect that we include in the specification to control for unobserved time-invariant regional factors that influence infant mortality. We experiment with the coverage of the basin fixed effect in our estimations, inserting both level 5 and level 6 basin fixed effects and comparing the results. t_i is a birth year fixed effect for child i to control for time trends in infant mortality probabilities. ϵ_{ij} is an idiosyncratic error term. If we believed that an OLS regression would yield unbiased results, then the estimated beta coefficients from this regression would capture the effects of upstream, downstream, and within-basin dams on infant mortality probability. However, as discussed earlier, neighbouring upstream and neighbouring downstream dams could have differential effects from upstream and downstream dams farther away. We could therefore expand (1) to the following,

$$\begin{aligned} y_{ij} \;=\; & \alpha \;+\; \beta_1 WDAMS^B_{ij} \;+\; \beta_2 UDAMS\_NBR^B_{ij} \;+\; \beta_3 UDAMS^B_{ij} \\ & +\; \gamma X_{ij} \;+\; \theta \;+ t_i \;+\; \epsilon_{ij} \end{aligned} \tag{2}$$

where we now include $UDAMS\_NBR^B_{ij}$, which represents the number of neighbouring upstream dams from basin j that were built before the birth year of child i. Including this dam count alongside the total number of upstream built by year t_i will allows us to separately identify any differential effects neighbouring upstream dams may have from dams that are further away upriver. These differential effects are measured by the difference $\beta_2 - \beta_3$. However, estimating (1) and (2) using OLS would lead to biased results due to omitted regional variables that determine the number of dams built in any river basin, and also household level unobservables that determine both migration status and infant mortality risk. To deal with regional omitted variables that determine"selection" into differing intensities of dam exposure, we further alter (2) to the following,

$$
\begin{aligned}
y_{ij} \;=\; \alpha \;+\; \beta_1 WDAMS^{B}_{ij} \;+\; \beta_2 UDAMS\_NBR^{B}_{ij} \;+\; \beta_3 UDAMS^{B}_{ij} \\
+\; \delta_1 WDAMS_j \;+\; \delta_2 UDAMS\_NBR_j \;+\; \delta_3 UDAMS_j \\
+\; \gamma X_{ij} \;+\; \theta \;+ t_i \;+\; \epsilon_{ij}
\end{aligned} \tag{3}
$$

so that the specification now includes the total number of dams *ever built* in basin j, in all the upstream basins along the river from basin j, and also separately the total dams ever built in the neighbouring upstream basins from basin j. We represent them the same way as we do the number of dams in built in these basins before the child's birth year t_i, but we remove the superscript 'B' and subscript 'i' to indicate that they are the total counts of dams ever built in these basins. These dam counts capture the effects of the various influences behind dam construction in the basins where they are built, therefore conditioning on the time-invariant factors behind "selection" into the different kinds of dam exposure all children born in basin j are subject to. The actual intensity of exposure for each child in the first 12 months of life however, is determined by the number of dams in each category of basin already operating at the time of the child's birth. These dam counts are the ones we began with in (1) and (2), but in (3) these regressors will identify their differential impact from total dams ever built on mortality probability for child i. The specification in (3) is therefore our baseline specification, and the beta coefficients on the superscripted dam-count variables are our treatment effects of interest. The basin linkages by river flow and the resulting dam counts are calculated at the level of the level 6 drainage basin, the smallest level of regional basin disaggregation.

As the specification in (3) implicitly reports the average impact of each dam as identical, we also look for non-linear results by breaking up the number of dams at birth by type of dam coverage into incremental categories. Specifically we use dummy variables for each different number of dams children are exposed to, as well as simple binary treatment indicators for the presence of dams at birth in each category of exposure. Treatment indicators assume dam effects appear immediately after the first dam is built, which is fairly realistic considering the mean area of each basin represents a quadrant with sides of only about 65 km. We include several other independent variables in the vector X_{ij} that influence infant survival probability, such as mother's education and age, birth order, the number of previously born living children and living sons in the household, the number of previously born children who have died, a child gender indicator, dummy variables indicating a child of a multiple birth, and several household wealth indicator variables such as the kind of toilet in the house, and whether the household owns durable assets such as a television, car, or motorcycle.[5]

We do not control for region-specific time trends in our specification, and it is therefore possible that differing economic shocks over time determine both dam counts and infant survival probabilities across basins. There are also still concerns arising from the fact that the error term contains unobservables that determine the household's decision to migrate, and are also potentially correlated with dam counts and infant mortality risk. There are also child-specific heterogenous unobserved factors that are part of the error term to consider. To deal with these concerns we also present results from an instrumental variables regression, using instruments very similar to those used in Duflo and Pande (2007) and Strobl and Strobl (2010).

As in the above studies, we exploit regional variation in river gradient that determines suitability for dam construction. Using data on African rivers from the FAO geographic database, we calculate river length of perennial rivers in each level 6 basin lying within four gradient categories, which are low slope (0-1.5%), medium slope (1.5-3%), steep slope (3-

[5]Each mother in our sample is treated as a single household.

6%), and very steep slope (6% or more). We then interact these perennial river lengths with the number of dams a child is exposed to in the same level-4 basin in the year of his birth, and use the interaction terms as instruments. The number of dams in the same level-4 basin as a child in his birth year is also correlated with the number of within-basin, upstream, and neighbouring upstream level-6 dams the child is exposed to at birth, as these level-6 basins are mostly contained within the much larger level-4 basin. Interacting the total level-4 dams with level-6 basin perennial river gradient lengths therefore predicts well how dams in a level-4 basin are allocated among the smaller level-6 basins it contains. At the same time, these level-4 dam-river gradient interaction terms are not very likely to be correlated with local economic shocks within level-6 basins or individual maternal unobservables that potentially determine exposure to level-6 dams and infant mortality rates. Both these assertions are borne out by the F-tests of instrument strength and Hansen's J-test of instrument exogeneity in the results. The specification for the first stage of the instrumental variables regression is given by,

$$\hat{D}_{ij} \;=\; \alpha \;+\; \sum_{k=1}^{4} \psi_k \, WDAMS_{ij4}^{B} \,*\, RG_j^k \;+\; \lambda \, X_{ij} \;+\; \theta \;+ t_i \;+\; \epsilon_{ij} \tag{4}$$

where $\hat{D}_{ij}$ represents the dam count at birth being instrumented in (3), namely $WDAMS_{ij}^{B}$, $UDAMS\_NBR_{ij}^{B}$ or $UDAMS_{ij}^{B}$. The variables RG_j^1, RG_j^2, RG_J^3, and RG_J^4 are the perennial river lengths in the four categories of slope within basin j by ascending steepness. $WDAMS_{ij4}^{B}$ is the number of dams in the same level-4 basin as child i in the year of his birth. The vector X_{ij} contains all the additional dam count and household regressors from (3), the un-interacted level-4 dam count at birth, and also level-6 basin perennial and ephemeral river lengths, basin area, basin elevations, and the percent of the basin falling within each slope category. The remaining fixed effects and error term being the same as previously.

The full estimation of both stages is carried out using a GMM procedure.

In addition to the instrumental variables regression, We carry out further estimations to eliminate concerns of omitted variable bias in our robustness checks. In all our specifications we include country fixed effects as well as river basin fixed effects. We also carry out estimations with heteroscedasticity-robust errors, which we cluster according to the size of the river basin fixed effects.

4 Results

Table 3 reports the first-stage results from regressing the dam counts at birth on our instruments. The coefficients indicate that low and steep river gradients increase the the number of level-4 dams that are eventually built in the same level 6 basin as child i, and therefore correspondingly decrease the number of these dams that are built in neighbouring or farther upstream level 6 basins from the child. Similarly, a very steep river gradient leads to a greater number of level-4 dams being allocated away from the level 6 basin to upstream basins, either neighbouring or farther away. The F-statistics on the instruments are very high, ranging from 83.38 to 1407.84, indicating that they are sufficiently strong for the second stage estimation.

The baseline results from estimating (3) as well as the instrumental variables results are reported in Table 4. Column (1) shows the coefficient estimates for the treatment dam counts from the specification with level 5 basin fixed effects. The estimates indicate that each neighbouring upstream dam at the time of a child's birth increases the child's probability of survival past age 12 months by 6.19%, which is significant at the 5% level.[6] On the other

[6] This is the difference between $\hat{\beta}_2$ and $\hat{\beta}_3$.

hand, each upstream dam operating in a basin farther upstream increases the probability of the child dying by age 12 months by 2.24%. This coefficient estimate is significant at the 1% level. Inserting level-6 fixed effects absorbs the impact of the total dams ever built in upstream and the same level 6 basin. However these fixed effects control more locally for regional time invariant factors that might influence dam coverage as well as infant mortality. The estimates from column (2) show increased magnitude of some impacts compared to column (1), with neighbouring upstream dams reducing infant mortality probability by 6.96% and upstream dams farther away increasing infant mortality probability by 2.36% on average. In both columns (1) and (2) however, we find no significant impact of within-basin dams. In column (3) we report the instrumental variables results. After instrumenting the impact of within-basin dams is found to be harmful and highly significant at the 1% level, with each such dam increasing infant mortality by 9.36%. This points to detrimental impacts, likely through waterborne disease and reduced agricultural productivity, that outweigh the gains from economic activity around the dam site. The harmful effect of upstream dams farther away is also magnified ten-fold after instrumenting and is significant at the 1% level, with each dam increasing infant mortality by 21.20%. The impacts of upstream dams on river flow are therefore very detrimental, as we would expect. However neighbouring upstream dams appear to reduce infant mortality enough to exactly offset the negative effects of upstream dams farther away, pointing to potential gains from increased agricultural productivity and perhaps nearby economic activity at the dam site as well. The Hansen J-statistic indicates that exogeneity of the instruments cannot be rejected, and the p-value is reassuringly high at 0.95.

In Table 5 we show results from estimating (3) with dummy variables for the presence of each type of dam at birth, regardless of the number. The results are qualitatively the same as in column (3) of Table 4, with coefficients of similar magnitude particularly for the impacts of neighbouring and farther upstream dams. The impact of dam presence in each category therefore appears to be non-linear, with a large once-and-for-all effect that dominates the effects of additional dams that are built subsequently.[7]

4.1 Ruling out Potential Bias

The results we have shown thus far are large, and at face value they point to the importance of dams in determining child welfare levels. However we still want to be sure that our results are actually reflecting the effects of dam operations, and not differential trends in infant mortality rates across basins or endogenous dam placement. To verify whether there is such bias in our results, we implement an additional econometric procedure.

Our main robustness check is to estimate whether there any impacts on infant mortality risk of dams built in each category of exposure 5 years or more after the child is born. There should be no significant effects of dams built well past the child's first year of life, unless our results are driven by systematic differences in maternal unobservables correlated with dam coverage, by differing time trends in infant mortality between dammed and non-dammed basins, or by endogenous placement of dams with respect to infant mortality. If household differences are systematically correlated with different types of dam coverage, they should be correlated with the number of dams present both before and after a child is born. We

[7] In Table A.1 in Appendix A we report results from inserting dummy variables for every additional dam that is present in each category at birth. The omitted comparison category is zero dams for each type of exposure. Upon inserting dummy variables for the number of within-basin dams children are exposed to, we find that these dams increase infant mortality steadily from 2.27% to more than 10% as the number of dams increases. We only show coefficients for the first 10 dams children are exposed to in the same basin. There are up to 41 such dams at maximum exposure, and the coefficients for each additional dam is positive and significant at the 5% level. The results are available from the author upon request. Estimating the impact of each neighbouring upstream dam and each upstream dam farther away using dummy variables yields qualitatively the same results as Table 5. Nearly every additional neighbouring upstream dam reduces infant mortality, and almost every additional upstream dam farther away increases infant mortality. The results from the same regression with level 6 fixed effects show the same qualitative findings, and are available from the author upon request.

should therefore find significant coefficients on dams built 5 years after the child is born, in the same direction as those we found for dams built before the child is born, if what we actually capturing in our results is systematic household differences due to selective non-migration. We should also find similar coefficients if we are capturing differential regional trends across basins that correlate with dam construction. Finally, if dams are endogenously placed with respect to infant mortality, our results are capturing reverse causality which should also be reflected in similar coefficients on dams built after the child's infancy. We insert the number of dams built when the child is aged 5 years or more in each category of exposure into specification (3), and report their estimated coefficients in Table 8. The notation for the dam counts is the same as for those representing dam counts at birth, except we change the superscript from B to A to indicate that these counts are for dams built after the child is born. In both columns (1) and (2) of Table 8, the coefficients on within-basin dams, neighbouring upstream dams, and upstream dams farther away are insignificant. This is encouraging for the validity of the impacts of these dams we find in our main results.[8]

4.2 Agriculture and Floodplains

We now attempt to isolate the effect of dams on infant mortality through their impact on agriculture, and additionally through their impact on floodplain cultivation. To do this we identify which river basins in our data are used for cropland cultivation using the FAO and NASA spatial dataset on global cropland occurrence published in 2007. While the data does not show changes in cropland area over time, we go by the assertion of Strobl and Strobl

[8]The other robustness check we carry out is to redefine the dam counts at the level of the level 4 river drainage basin. By changing the unit of land area in our analysis from the level 6 to the level 4 basin, we effectively ignore the river network linkages between the smaller, more closely connected areas and focus instead on linkages between much larger areas. We should therefore find either much smaller effects or zero effects of any dam counts by level 4 basin, indicating that we are capturing dam effects rather than bias from unobservables correlated with our dam counts. We re-estimate specification (3) using the new dam counts and report the results in Table A.2 in Appendix A. The results show statistically significant impacts of upstream dams farther away and neighbouring upstream dams, but the effects are ten to twenty times smaller that those of the corresponding level 6 dam counts in Table 4.

(2010) who show that cropland areas in African countries have not changed during 1981-2000 and argue that these areas are unlikely to have altered significantly between birth cohorts. We then interact indicators for dam presence at birth with an indicator for whether the child was born in a river basin with cropland cultivation, to identify differential dam impacts in regions where agriculture is likely to form an important part of the local economy.

To further identify differential impacts in floodplain areas, we use spatial data on annual river runoff levels from the global river runoff dataset released by the Global Runoff Data Centre (GRDC) in collaboration with the University of New Hampshire in 2002. River runoff is defined as river water that travels across the land surface without being absorbed into the soil, the height and geographic extent of which is determined by the speed and volume of river water discharge as well as rainfall. The dataset provides annual mean river runoff data across Africa using river discharge data and climate water balance models since before 1975. We use this data to identify regions in Africa that are likely to be seasonally inundated and allow the practice of floodplain agriculture, as river runoff is the major mechanism through which both water and fertile silts are deposited in these areas.[9] We specifically identify regions with annual runoff of more than 250 milimetres per year, and search for differential dam impacts on infant mortality in these areas using three-way interaction terms of dam presence indicators, an indicator for birth in a river basin with cropland, and an indicator for birth in a region with high annual river runoff. The spatial cropland and river runoff datasets are depicted in Figure 6.[10]

[9] There is a potential concern that dams endogenously affect the levels of river runoff across the continent. The GRDC dataset is ideal in this regard, as it calculates *simulated* runoff based on river discharge measurements largely taken in the early part of the twentieth century before many of the dams were completed. The discharge measurements are combined with climate models and geographic data to create the completed dataset.

[10] The results are robust to different definitions of areas with high runoff. The 250 mm runoff level was chosen as it represents a reasonably high level of inundation in the context of Africa.

The results for children born in basins with cropland are presented in Panel A of Table 6. The presence of any within-basin dams at birth increases infant mortality by 1.15%, implying a detrimental impact of these dams on agriculture in their vicinity as in Duflo and Pande (2007) and Strobl and Strobl (2010). There are however no differential effects of neighbouring upstream or farther upstream dams in basins with cropland, compared to basins without. The results however change dramatically in Panel B upon further interacting the dam-cropland interaction terms with the indicator for birth in an area with high river runoff. We find no differential effects of within-basin dams across floodplain and non-floodplain regions with cropland, suggesting that the harmful effect of these dams is equally spread between floodplain cultivation and other types of agriculture. However there is a strong detrimental impact of both neighbouring upstream and farther upstream dams on infant mortality in floodplain regions with cropland, as compared to non-floodplain cropland areas. The presence of a neighbouring upstream dam at birth reduces infant mortality by 3.53%, while the presence of a dam farther upstream increases infant mortality by 7.57%. This is evidence that dams cause much harm to floodplain cultivation and wetland ecosystems downriver beyond their command area. The harmful effect of the presence upstream dams farther away is three times as large as the effect in Table 4, showing the additional harm to households caused by these dams in floodplain areas.

4.3 Malaria

We investigate the impact of dams on malaria using MARA/ARMA project data on the duration of the annual malaria transmission season across Africa. Dam reservoirs fill up during the rainy season, which is also when malarial transmission is at its highest. The breeding ground for mosquitoes provided by the reservoirs is therefore likely to increase malaria in their vicinity in areas where the annual duration of the transmission season, determined by both rainfall and temperature, is already lengthy. We should also not expect to find any effects of neighbouring upstream or farther upstream dams on malaria, as households are not close enough to the reservoirs of these dams to be affected. Hence establishing that malaria increases in the vicinity of dams but not downriver from them would go some distance in validating all our results. The spatial variation in length of annual transmission duration, along with the locations of our surveyed households, is shown in Figure 7.

We interact dummy variables for dam coverage at birth with indicators for whether children are born in areas where the length of the transmission season is 4-6 months, or 7-12 months of the year. The omitted category for comparison is 0-3 months duration. The results are shown in Table 7. Importantly, we find no differential effects of neighbouring upstream or farther upstream dams between regions of varying transmission intensity. This greatly reduces concerns that we our results are driven by regionally omitted variables, such as the effects of living in the tropics. The coefficient estimates for within-basin dams however show that they increase infant mortality in regions with intermediate malaria transmission duration by 1.18-1.23%, and by 3.15-3.33% in areas with the longest transmission period.

5 Discussion

Our results show large dam impacts on infant mortality among children born to non-migrants. We find from our OLS estimates that neighbouring upstream dams reduce infant mortality by 6.19-6.96%. Upstream dams further upriver on the other hand increase infant mortality by 2.18-2.36% among these children. These effects increase further after using instrumental variables techniques, with upstream dams far away increasing infant mortality by 21.20% and neighbouring upstream dams almost exactly offsetting this harmful impact with counteracting benefits. This is because households are able to benefit from the irrigation services and increased economic opportunities from the dam in the neighbouring upstream basin, but downriver beyond the command areas of these dams households suffer due to declining water levels that harm floodplain recession agriculture and the wetland ecosystem. This is further captured by the fact that the harmful impact of dams farther upstream triples to 7.57% for children born in floodplain regions with cropland. Within-basin dams appear to increase infant mortality by at least 2.27%, because agricultural productivity declines and disease incidence increase in basins where dams are built. The harmful effect increases steadily to more than 10% as the number of within-basin dams increases. The instrumental variables estimate of the harmful impact of these dams is 9.36% on average. The effect of within-basin dams through reduced agricultural productivity is evidenced by the 1.15% increase in infant mortality among children exposed to one or more these dams who are born in cropland areas, compared to those born in basins without cropland. The increase in infant mortality from increased malaria incidence due to within-basin dams is 1.18-1.23% in areas where the transmission season is 4-6 months per year and 3.13-3.33% where it is 7-12 months out of the year, compared to regions where it is 0-3 months annually.

Based on our instrumental variables estimates, neighbouring upstream dams are responsible for saving 33.86% of all 5,131 children that are exposed to these dams in our sample. On the other hand, within-basin and upstream dams farther upriver are together responsible for the deaths of 35.73% of the 11,503 children in our sample who die during infancy after being exposed to them. Placed in this context our estimated dam impacts are large, and have significant policy implications for dam construction in regions where migration may not be possible to offset any harmful impacts. These implications need to be taken into consideration given the surge in dam building taking place across Africa. Gains in neighbouring downstream regions may be offset by large detrimental impacts further downstream across international borders or even within the same country. A good example of this is the Gibe III dam being built on the Omo river in Ethiopia, which is planned to significantly increase hydroelectric capacity for both domestic consumption and export to neighbouring Kenya. However the impact on the river will possibly be to end its annual inundation cycle, which will harmfully affect Ethiopian tribes such as the Mursi living downstream from the dam, as well as reduce the height of Lake Turkana across the border in Kenya with potential consequences to the surrounding population. In the vicinity of dam reservoirs there needs to be an accompanying intervention such as the distribution of bednets to prevent an increase in malaria, and also an assessment of the impact on local agricultural production when assessing the costs of a dam project.

To attempt to quantify the potential future impacts of dams on African infant mortality, we calculate the net number of deaths that would take place among current infants born to non-migrants in our sample if additional dams were built in suitable river basins across the continent. To do this we first calculate a propensity score for the probability of each level-6 basin receiving a dam based on river gradients, river length, basin area, and country fixed effects. The propensity score for "treated" and "untreated" basins is shown in Figure 8, showing that our procedure predicts dam placement across basins fairly well.[11] Assuming that "untreated" basins with a propensity score of 0.25 or more receive a dam, our instrumental variables estimates show that this hypothetical increase in dam construction causes a net increase of 666 infant deaths among the 43,701 infants in our sample who are previously not exposed to any dams. This represents a potential increase in the infant mortality rate of up to 1.52% among these previously unexposed infants.

While we cannot be certain of the benefits new large dams being planned will bring, their impacts on river flow, agricultural productivity, and malaria have been documented

[11] The treated basins with low propensity score indicate that there is more to dam construction than simply geographical suitability.

previously. These impacts are ultimately absorbed by entire communities whose livelihoods are altered as a result, either for the better or for the worse. Infant mortality is a new dimension of welfare within which to measure dam impacts, and we feel our results reflect the importance of considering this dimension as part of the dam building process.

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References

[1] Dams in Africa: Tap that water. *The Economist*, May 6, 2010.

[2] W. Adams. The Downstream Impacts of Dam Construction: A Case Study From Nigeria. *Transactions of the Institute of British Geographers*, 10(3):292–302, 1985.

[3] W. Adams. The Social Impact of Large Dams: Equity and Distribution Issues, Thematic Review I.1. Technical report, World Commission on Dams, Capetown, 2000. Prepared as an input.

[4] W.M. Adams. Indigenous Use of Wetlands and Sustainable Development in West Africa. *Geographical Journal*, 159(2):209–218, 1993.

[5] E.B. Barbier and J.R. Thompson. The Value of Water: Floodplain Versus Large-Scale Irrigation Benefits in Northern Nigeria. *Ambio*, pages 434–440, 1998.

[6] Thomas V. Cech. *Principles of Water Resources: History, Development, Management, and Policy*. John Wiley and Sons, 2003.

[7] Esther Duflo and Rohini Pande. Dams. *The Quarterly Journal of Economics*, 122(2):601–646, 05 2007.

[8] Food and Agriculture Organisation of the United Nations (FAO). Dams and Agriculture in Africa. May 2007. Prepared by the Aquastat Programme. http://www.fao.org/nr/water/aquastat/damsafrica/Aquastat_Dams_Africa_070524.pdf.

[9] T.A. Ghebreyesus, M. Haile, K.H. Witten, A. Getachew, A.M. Yohannes, M. Yohannes, H.D. Teklehaimanot, S.W. Lindsay, and P. Byass. Incidence of Malaria Among Children Living Near Dams in Northern Ethiopia: Community Based Incidence Survey. *Bmj*, 319(7211):663, 1999.

[10] Alfred R. Golze (ed). *Handbook of Dam Engineering*. Van Nostrand Reinhold Company, 1977.

[11] Hydroworld.com. Ethiopia, China sign agreement for Gibe III hydro project construction. May 17, 2010. http://www.hydroworld.com/index/display/article-display/0251345340/articles/hrhrw/News-2/2010/05/ethiopia_-china_sign.html.

[12] International Commission of Large Dams. *World Register of Dams*. Paris, 1998.

[13] International Commission of Large Dams. *World Register of Dams*. Paris, 2003.

[14] J. Lautze, M. McCartney, P. Kirshen, D. Olana, G. Jayasinghe, and A. Spielman. Effect of a Large Dam on Malaria Risk: The Koka Reservoir in Ethiopia. *Tropical Medicine & International Health*, 12(8):982–989, 2007.

[15] J.K. Maingi and S.E. Marsh. Quantifying Hydrologic Impacts Following Dam Construction Along the Tana River, Kenya. *Journal of Arid Environments*, 50(1):53–79, 2002.

[16] P. McCully. *Silenced Rivers: the Ecology and Politics of Large Dams.* Zed Books London, 2001.

[17] World Commission on Dams. Dams and Development: A New Framework for Decision-Making. 2000. Published by Earthscan London.

[18] L.M. Rebelo, MP McCartney, and CM Finlayson. Wetlands of Sub-Saharan Africa: Distribution and Contribution of Agriculture to Livelihoods. *Wetlands Ecology and Management*, pages 1–16, 2009.

[19] E. Strobl and R.O. Strobl. The Distributional Impact of Large Dams: Evidence From Cropland Productivity in Africa. *Journal of Development Economics*, 2010.

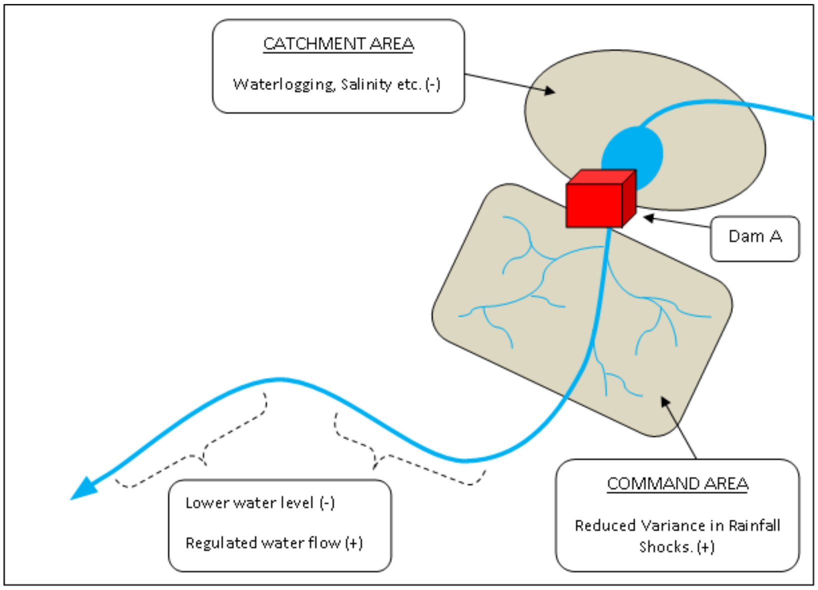
[20] IUCN-The World Conservation Union and the World Bank Group. *Large Dams: Learning from the Past, Looking to the Future. Workshop Proceedings.* World Bank Publications, 1997.

[21] Sarah J. Wachter. Giant dam projects aim to transform African power supplies. *New York Times*, June 19, 2007.

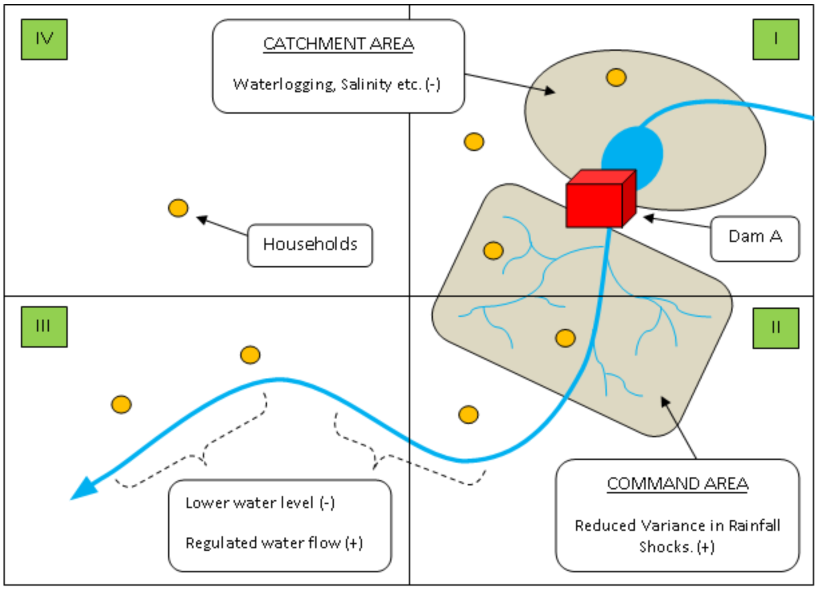
[22] C.C. Warnick. *Hydropower Engineering.* Prentice-Hall Incorporated, Englewood Cliffs, NJ, USA, 1984.

[23] D. Yewhalaw, W. Legesse, W. Van Bortel, S. Gebre-Selassie, H. Kloos, L. Duchateau, and N. Speybroeck. Malaria and Water Resource Development: The Case of Gilgel-Gibe Hydroelectric Dam in Ethiopia. *Malaria journal*, 8(1):21, 2009.

Figure 1: Dams Impacts by Region



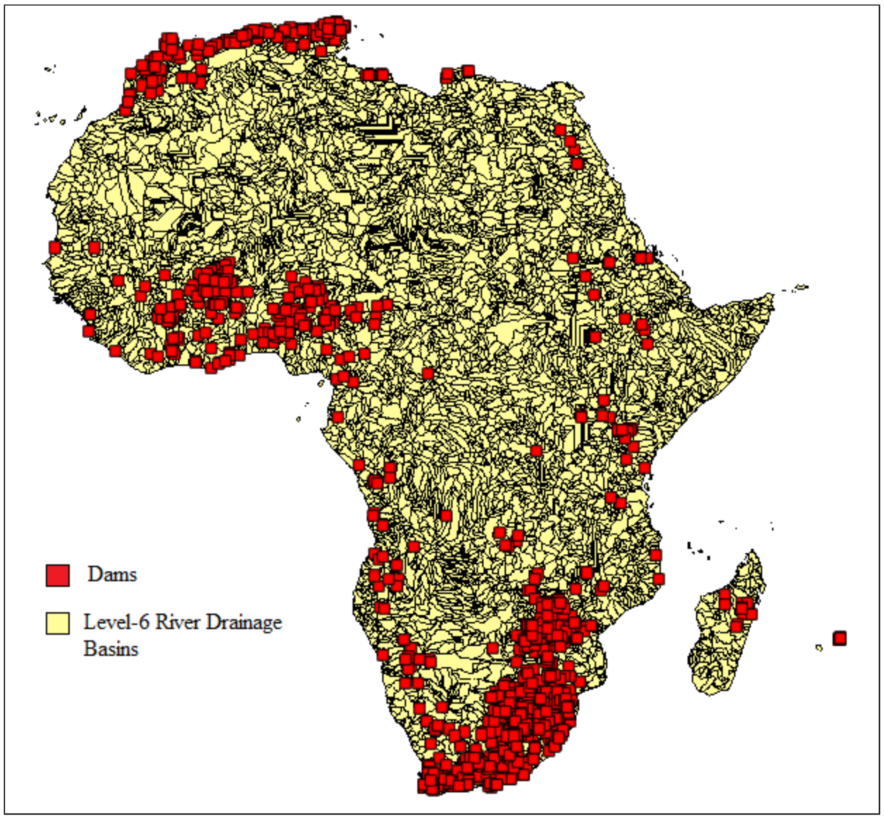
(a) Dam Catchment and Command Areas



(b) Households and Quadrants

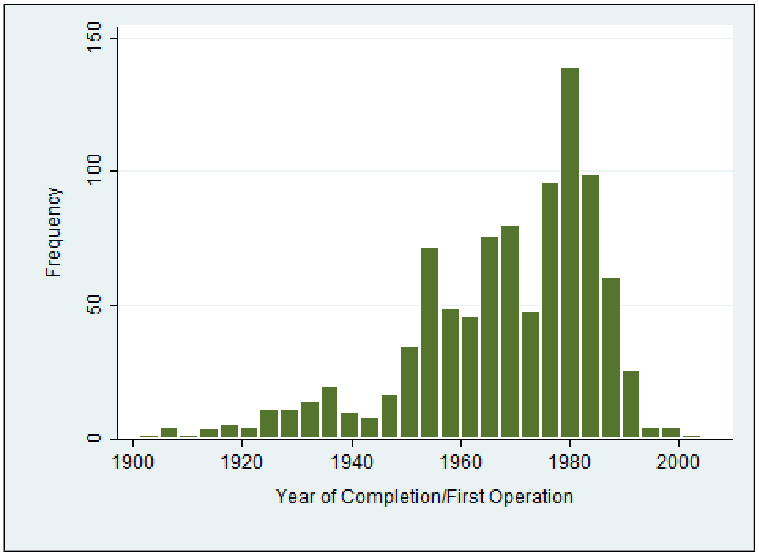
Notes: The figure is based on a diagram in Strobl and Strobl (2010). Plus signs indicate benefits from dams, and negative signs indicate detriments. Quadrants are theoretical representations of river basins, which are our geographical unit of analysis.

Figure 2: Dams and River Drainage Basins in Africa



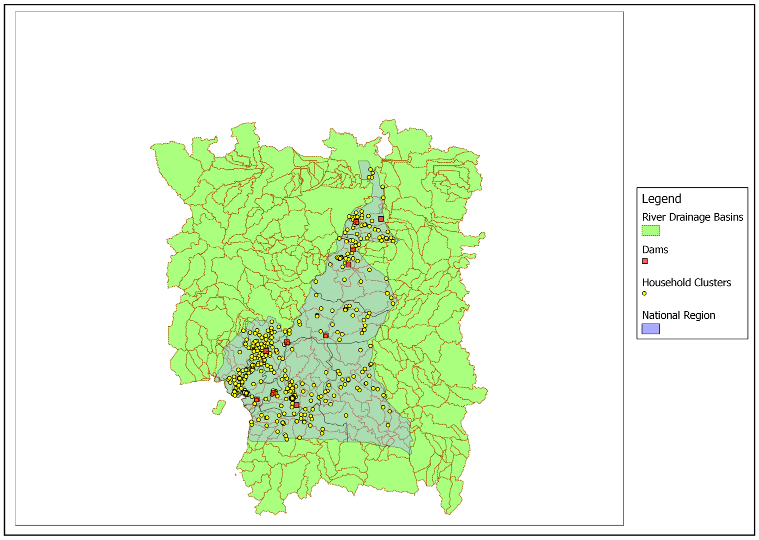
Notes: The river drainage basins depicted are from the HYDRO1K dataset provided by the US Geological Survey. The locations of the dams are taken from the geo-referenced database on African dams created by the Aquastat programme at the FAO.

Figure 3: Dams Completed Annually in Africa (1900-2008)



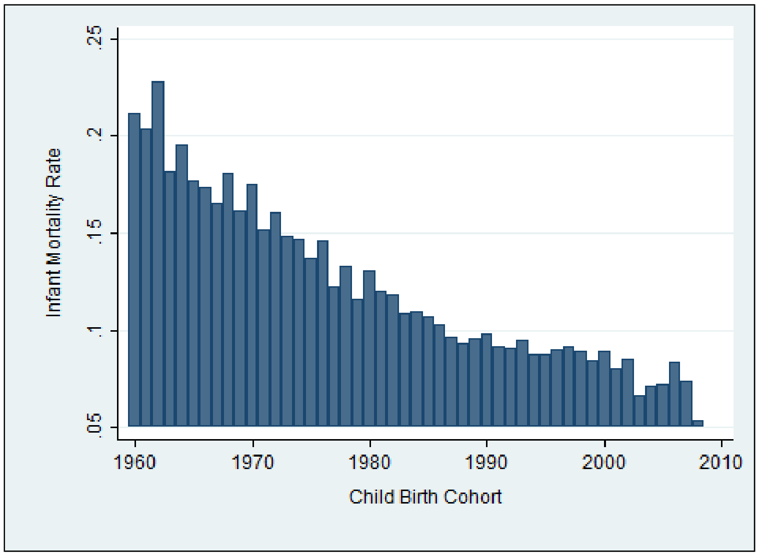
Notes: The year of completion/start of operation for each dam is taken from the FAO geo-referenced database on African dams, ICOLD data, or our own internet research.

Figure 4: Cameroon DHS 2004 - Households, Dams, and River Basins



Notes: The household clusters are sampled for the Measure DHS Survey in Cameroon in 2004. The cluster locations are accurate within a ten kilometre radius.

Figure 5: Annual Infant Mortality Rate



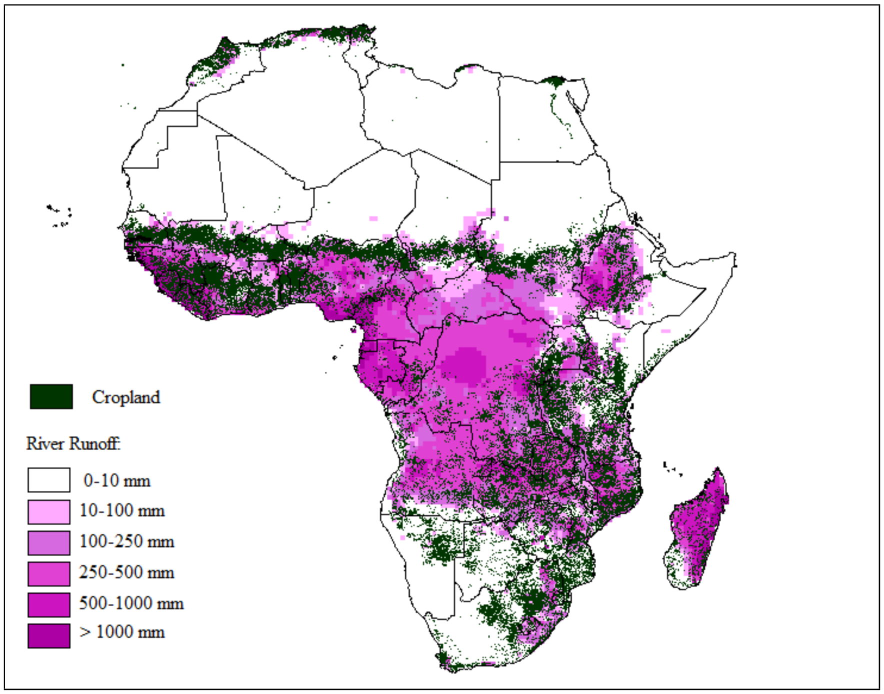
Notes: Infant mortality rates are calculated from the pooled final dataset used in our estimations, using several DHS survey waves from 17 countries in Africa as reported in Table A.3.

Table 1: Dam Coverage by Time Period of Birth

	1960-69	1970-79	1980-89	1990-99	2000-08	Total
Children Born in Period	8,015	54,250	143,193	166,855	67,076	439,389
Infant Deaths in Period	1,484	7,994	15,986	15,095	4,999	45,558
One Within-Basin Dam	909	8,651	27,785	31,856	10,740	79,942
One Neighbouring Upstream Dam	16	483	1,734	2,306	792	5,331
One Farther Upstream Dam	13	163	737	975	411	2,299
One Farther Downstream Dam	349	2,712	7,260	8,653	2,542	21,516
One Neighbouring Downstream Dam	40	402	1,212	2,110	686	4,450

Notes: Figures are for children born to non-migrant mothers. The sample of children is from 32 waves of DHS surveys across 17 African countries. Data on dams is from the geo-referenced database on African dams. The total refers to the number of children with at least one dam in the corresponding category of dam exposure at the time of their birth.

Figure 6: Cropland and River Runoff in Africa



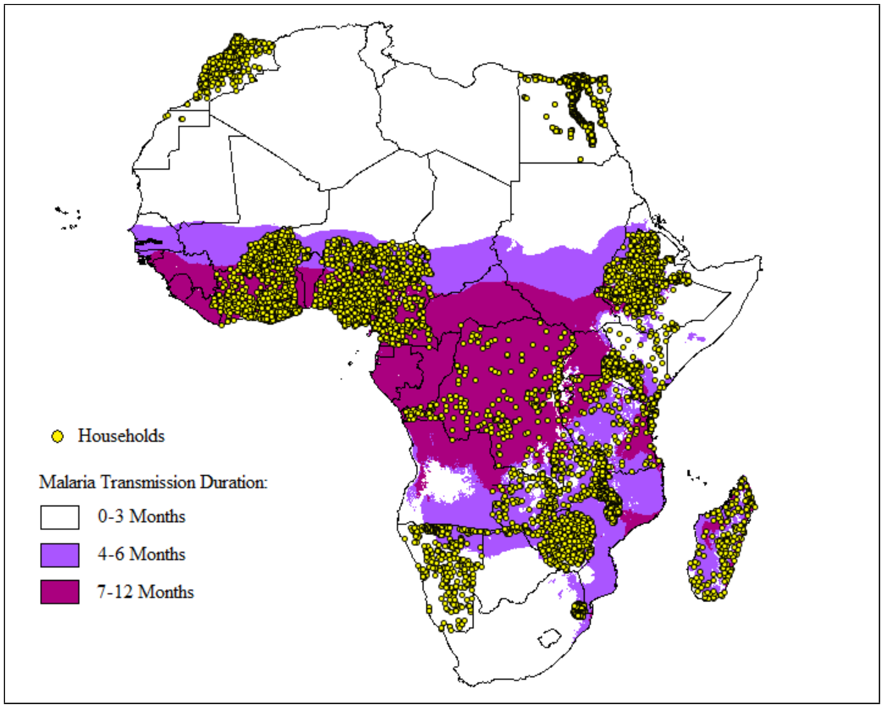
Notes: Cropland data is from the FAO spatial database on cropland occurrence created in conjunction with NASA in 2006. The river runoff dataset is from the Global Runoff Data Centre (GRDC) in collaboration with University of New Hampshire.

Table 2: Dam Counts By Exposure Category

	Dams Present at Birth		
	Mean	Min	Max
Within-Basin	1.07	0	67
Neighbouring Upstream	0.02	0	4
Farther Upstream	0.02	0	6
Neighbouring Downstream	0.04	0	69
Farther Downstream	0.21	0	11

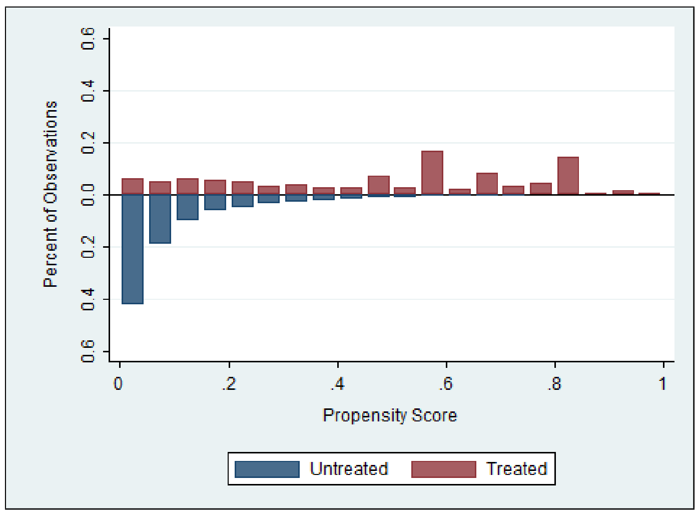
Notes: Figures are for children born to non-migrant mothers used in the analysis after removing outliers. Data on dams is from the geo-referenced database on African dams.

Figure 7: Households and Malaria Transmission in Africa



Notes: Households are from the 32 DHS surveys we use in for our analysis. Malaria transmission season data is from the MARA/ARMA project.

Figure 8: Propensity Score - Dam in Level-6 Basin



Notes: The propensity scores are calculated based on the geographic index of dam suitability, river lengths in drainage basins, and basin areas within each African country. The river drainage basins used as observations are from the HYDRO1K dataset provided by the US Geological Survey.

Table 3: Level-6 Dams at Birth - First Stage Results

	(1)	(2)	(3)
	$WDAMS^B$	$UDAMS\_NBR^B$	$UDAMS^B$
$WDAMS^B_{ij4} * RG^1_j$	0.0100***	-0.0183***	-0.0618***
	(0.0026)	(0.0008)	(0.0013)
$WDAMS^B_{ij4} * RG^2_j$	-36.9272	-0.9853	28.0969
	(25.6097)	(1.5054)	(23.6029)
$WDAMS^B_{ij4} * RG^3_j$	3.1870***	-1.0213***	-3.5402***
	(0.1994)	(0.0473)	(0.0844)
$WDAMS^B_{ij4} * RG^4_j$	-0.0193***	0.0063***	0.0217***
	(0.0014)	(0.0003)	(0.0004)
Observations	251,438	251,438	251,438
Level-6 Fixed Effects	Yes	Yes	Yes
Basins	1,098	1,098	1,098
F-statistic	83.38	159.22	1407.84

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include perennial and ephemeral river lengths in the level-6 basin, level-6 basin elevations, percent of the level-6 basin in each slope category, mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** Significant at 1% ; ** Significant at 5% ; * Significant at 10%.

Table 4: Infant Mortality and Level-6 Dams

	Child Died Aged 0-12 Months		
	(1)	(2)	(3)
	OLS	OLS	IV-GMM
$WDAMS^B$	0.0006	0.0007	0.0935***
	(0.0006)	(0.0008)	(0.0090)
$UDAMS\_NBR^B$	-0.0395**	-0.0460**	-0.3200
	(0.0174)	(0.0222)	(0.2080)
$UDAMS^B$	0.0224***	0.0236***	0.2120***
	(0.0069)	(0.0074)	(0.0644)
Observations	263,918	263,918	251,438
Level-5 Fixed Effects	Yes	No	No
Level-6 Fixed Effects	No	Yes	Yes
Basins	1,060	1,151	1,098
Hansen J-statistic = 0.004 (p-value = 0.949)			

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** Significant at 1% ; ** Significant at 5% ; * Significant at 10%.

Table 5: Infant Mortality and Level-6 Dam Indicators

	Child Died Aged 0-12 Months	
	(1)	(2)
$WDAMS^B$ *Present*	0.0239***	0.0257***
	(0.0089)	(0.0092)
$UDAMS\_NBR^B$ *Present*	-0.1900**	-0.2080**
	(0.0873)	(0.0964)
$UDAMS^B$ *Present*	0.1670*	0.1580*
	(0.0856)	(0.0921)
Observations	263,918	263,918
Level-5 Fixed Effects	Yes	No
Level-6 Fixed Effects	No	Yes
Basins	1,060	1,151

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** Significant at 1% ; ** Significant at 5% ; * Significant at 10%.

Table 6: Infant Mortality, Level-6 Dams, and Cropland

	Child Died Aged 0-12 Months
Panel A	(1)
$WDAMS^B$ *Present* * *Cropland*	0.1150***
	(0.0406)
$UDAMS\_NBR^B$ *Present* * *Cropland*	-0.1090
	(0.1200)
$UDAMS^B$ *Present* * *Cropland*	0.0621
	(0.1320)
Panel B	(1)
$WDAMS^B$ *Present* * *Cropland* **High Runoff*	-0.0148
	(0.0227)
$UDAMS\_NBR^B$ *Present* * *Cropland* **High Runoff*	0.0404***
	(0.0135)
$UDAMS^B$ *Present* * *Cropland* **High Runoff*	0.0757***
	(0.0248)
Observations	263,918
Level-6 Fixed Effects	Yes
Basins	1,151

Notes: Robust clustered standard errors are reported in parentheses. Basins with cropland identified using the FAO and NASA dataset on cropland occurrence. Areas with high runoff are defined as those with runoff of 250 mm or more per year according to the GRDC/UNH dataset on global river runoff. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** Significant at 1% ; ** Significant at 5% ; * Significant at 10%.

Table 7: Infant Mortality, Level-6 Dams, and Malaria

	Child Died Aged 0-12 Months	
	(1)	(2)
$WDAMS^{B}$ *Present* * $Malaria\ 4-6\ mths$	0.0118**	0.0123*
	(0.0059)	(0.0064)
$WDAMS^{B}$ *Present* * $Malaria\ 7-12\ mths$	0.0333***	0.0315***
	(0.0114)	(0.0114)
$UDAMS\_NBR^{B}$ *Present* * $Malaria\ 4-6\ mths$	0.0248	0.0183
	(0.0237)	(0.0598)
$UDAMS\_NBR^{B}$ *Present* * $Malaria\ 7-12\ mths$	-0.0525	-0.1320
	(0.0692)	(0.1140)
$UDAMS^{B}$ *Present* * $Malaria\ 4-6\ mths$	0.0016	0.0046
	(0.0099)	(0.0065)
$UDAMS^{B}$ *Present* * $Malaria\ 7-12\ mths$	0.0593	0.0382
	(0.0561)	(0.0731)
Observations	263,918	263,918
Level-5 Fixed Effects	Yes	No
Level-6 Fixed Effects	No	Yes
Basins	1,060	1,151

Notes: Robust clustered standard errors are reported in parentheses. Omitted malaria transmission duration category is 0-3 months per year. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** Significant at 1% ; ** Significant at 5% ; * Significant at 10%.

Table 8: Infant Mortality and Level-6 Dams After Birth

	Child Died Aged 0-12 Months	
	Level-5 FE	Level-6 FE
	(1)	(2)
$WDAMS^A$	-0.0044	-0.0048
	(0.0039)	(0.0039)
$UDAMS\_NBR^A$	0.0157	-0.0059
	(0.0748)	(0.0559)
$UDAMS^A$	0.0387	0.0098
	(0.0284)	(0.0499)
Observations	263,871	263,871
Level-5 Fixed Effects	Yes	No
Level-6 Fixed Effects	No	Yes
Basins	1,060	1,150

Notes: Robust clustered standard errors are reported in parentheses. Dam counts are numbers of dams built in each category more than 5 years after the child is born. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** Significant at 1% ; * Significant at 5%

A Additional Tables

Table A.1: Infant Mortality and Dams

$WDAMS^B$		$UDAMS\_NBR^B$		$UDAMS^B$	
Count	Coeff.	Count	Coeff.	Count	Coeff.
1	0.0227*	1	-0.1654**	1	0.0773**
2	0.0420**	2	-0.2138**	2	0.1287**
3	0.0398*	3	-0.2088	3	0.0800
4	0.0568**	4	-0.3913**	4	0.1640**
5	0.0779**			5	0.1409**
6	0.0728*			6	0.1620**
7	0.0431			7	0.1514
8	0.0981**				
9	0.0938**				
10	0.101**				

Estimations are with level-5 basin fixed effects. Omitted category is zero dams for each type of exposure. Coefficients for indicators for 11-41 within-basin dams not shown, but all are positive and significant at the 5% level. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. *** 1% Significance ; ** 5% Significance ; * 10% Significance.

Table A.2: Infant Mortality and Level-4 Dams

	Child Died Aged 0-12 Months
	(1)
$WDAMS^B$	0.0004
	(0.0006)
$UDAMS\_NBR^B$	-0.0025*
	(0.0011)
$UDAMS^B$	0.0023*
	(0.0009)
Observations	263,871
Level-6 Fixed Effects	Yes
Level-6 Basins	1,151

Notes: Robust clustered standard errors are reported in parentheses. Additional regressors include mother's educational attainment, mother's current age, mother's height, a child gender indicator, child of multiple birth indicators, birth order and sibling composition variables, birth year fixed effects, and wealth indicator variables. ** 1% Significance ; * 5% Significance.

Table A.3: DHS Survey Years and Frequency by Country

		Mothers		Children	
Country	DHS Year	Migrant	Non-Migrant	Migrant	Non-Migrant
Burkina Faso	1993, 1998-99, 2003	11,524	7,245	50,761	32,164
D.R. Congo	2007	2,871	3,983	12,435	15,902
Cote d'Ivoire	1994, 1998-99	4,076	1,652	16,821	6,754
Cameroon	1991, 2004	7,003	2,947	28,391	11,418
Egypt	1995, 2000, 2003, 2005	16,411	33,470	60,563	131,361
Ethiopia	2000, 2005	8,471	10,678	35,338	47,470
Ghana	1993, 1998, 2003	7,387	3,486	28,402	12,783
Kenya	1998, 2003	6,262	2,285	24,018	9,468
Morroco	2003-04	5,333	3,201	20,123	12,049
Madagascar	1997	2,567	2,574	11,006	10,363
Malawi	2000, 2004	10,598	8,665	39,148	36,012
Nigeria	2003, 2008	18,252	10,166	78,755	47,518
Namibia	2000, 2006-07	5,599	5,239	17,237	15,684
Swaziland	2006-07	2,505	804	8,857	2,067
Tanzania	1999	1,528	1,237	6,359	4,984
Zambia	2007	3,661	1,565	14,265	6,509
Zimbabwe	1999, 2005-06	6,289	4,014	20,105	13,042
Total		120,337	103,211	472,584	415,548

Notes: All frequencies are reported from the DHS surveys where number of years in current residence was available.