The Dammed Gender? Water, Dams, and Female Schooling in Sub-Saharan Africa

Li Han* Pak Hung Lam† Yabin Yin‡

Abstract

This paper investigates the gender-asymmetric impacts of dams on schooling in Sub-Saharan Africa. Validating and utilizing the fact that dams reduce groundwater storage in the nearby downstream area in an arid environment, we employ a generalized DID strategy to compare the changes in schooling of individuals residing close to and those relatively distant from dams after the construction of dams, for downstream and upstream separately. We find that exposure to dams before age 15 reduced female schooling by 1.2 years in the close-to-dam area, compared to those in the distant area. The decreased schooling is associated with more fertility. The effect is particularly pronounced for societies with entrenched patriarchal traditions. No similar effects were found for males or in the upstream. We show that a major mechanism is school disruptions due to increased time in water-fetching — a burden primarily borne by school-aged girls.

Keywords: Dams; Gender; Education; Water Access; Sub-Saharan Africa.

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*Division of Social Science, The Hong Kong University of Science and Technology; Email: lihan@ust.hk.

†Samuel Dubois Cook Center on Social Equity, Duke University; Email: pakhung.lam@duke.edu.

‡Division of Social Science, The Hong Kong University of Science and Technology; Email: yyinak@connect.ust.hk.

1 Introduction

Water scarcity is a growing global challenge to human development. According to UNICEF and WHO (2019), 30% of the world's population lacks access to safe water, and over 50% to safe sanitation and hygiene facilities. This crisis is particularly concentrated in developing regions, notably Sub-Saharan Africa and Asia. Meanwhile, these areas have seen widespread implementation of large-scale infrastructures in recent years, aimed at boosting economic development (e.g., Dinkelman 2011; Duflo and Pande 2007; Kebede 2024). However, these well-intentioned projects could yield unintended environmental consequences, even exacerbating the already serious water scarcity problem (see Jayachandran 2022 for a comprehensive review). Crucially, such social costs are markedly gender-asymmetrical, since women and girls bear the brunt of water scarcity in most of developing regions. As the main undertakers of water collection in households without on-premises water, they spend considerable time fetching water from distant public water points. According to Kremer et al. (2011), a Kenyan rural family does seven 20-minute trips per day. This gender-specific burden severely significantly constrains females' opportunities for self-improvement.

This paper focuses on the gender-asymmetrical impacts of large irrigation dams in Sub-Saharan Africa. While these dams are prominent infrastructures intended to promote agricultural intensification, they arguably cause adverse hydrological effects and disrupt water cycles, especially in the downstream (Armanuos et al. 2017; Bahir et al. 2019). Anecdotal evidence suggests that the presence of large dams has intensified water scarcity in the downstream and widened the gender gap among local communities in various aspects. However, few studies in economics have paid attention to this issue.

Our research represents the first empirical investigation into the impact of large irrigation dams on the gender gap in educational attainment, specifically years of schooling. Specifically, we seek to answer two primary questions: whether females' years of schooling were shortened after the presence of nearby dams, and to what extent the observed decline was due to worsened water scarcity issue and prolonged time spent on water collection by females.

We begin by estimating the effect of dams on surrounding groundwater storage. We focus on groundwater because it is the primary water source for people in Sub-Saharan Africa due to its cleanliness and safety. Dams reduce downstream groundwater storage through two main channels: (a) decreased recharge from surface water due to the truncation of natural river flow, and (b) over-pumping from aquifers driven by irrigation systems associated with dams (Armanuos et al. 2017). On the contrary, upstream regions are less affected. We define the downstream and upstream areas of a dam based on the average elevation of the sub-basins relative to the elevation of the dam. Empirically, we examine the monthly changes in groundwater storage of areas within 10km, 10-20km, 20-30km, and so on up to 80-90km from a dam, compared with areas 90-100 km away, after the completion of the dam, separately for downstream and upstream regions. We found that after a dam commissioned, monthly groundwater storage in the downstream vicinity significantly decreased. This effect persisted within 50km from the dams and disappeared from 50-60km. No such effect was found in upstream regions.

Next, we estimate the effect of dams on females' years of schooling. The individual data is drawn from the Demographic and Health Survey (DHS) phases II to VII (1990-2018), and the primary sample consists of individuals aged 15 to 35 and were local to the area. Since most individuals in Sub-Saharan Africa have finished their education before the age of 15, this sample selection allows us to separate cohort effect from age effect. We spatially match individual samples with the dam sample based on their geo-locations. Based on the above hydrological evidence, we adopt a generalized difference-in-differences (DID) model to compare younger (under age 15 at the time of dam completion) and older cohorts living within 50km of dams (*nearby* group) versus those living 50-100km away (*distant* group). We assume that the younger cohort, having exposure to dams during their school age, were more affected in terms of education, while the older cohort had likely finished schooling before the presence of dams. Above all, to identify causality, we conduct balance checks and event study model to demonstrate no significant pre-existing difference between treatment and control areas. Unlike previous studies that used river gradient suitability and policy inertia as instrumental variables for the number of upstream dams (Blanc and Strobl 2014; Duflo and Pande 2007; Mettetal 2019), this paper provides a novel identification to examine the effect of dams at a more disaggregated level.

We find that exposure to upstream dams before age 15 reduced female schooling by 1.2 years ($\sim$ 27.6% of the sample mean) in the nearby area, compared to those in the distant area. The magnitude is surprisingly large, partly because dams not only shortened female schooling by 0.7 years for those who were enrolled (intensive margins) but also significantly reduced female enrollment rates by 15.6% (extensive margins). In contrast, males in downstream regions and both genders upstream were not affected by dams, suggesting that the effects were particularly concentrated in downstream regions and for females. Moreover, the effect is more salient in regions with entrenched patriarchal traditions, highlighting the asymmetric consequences of dams could be linked to pre-existing gender perspectives. Beyond education, females exposed to dams before age 15 were more likely to marry down and have higher fertility rates, likely due to lower educational attainment.

The main findings remain robust across various checks. We categorize river branches as affected or unaffected based on their spatial relationship to the dam within the same river basin, finding that only females near an affected branch were adversely impacted. We treat individuals in upstream areas as an additional comparison group to construct a triple differences model, and the results remain consistent. We conduct a within-household analysis to alleviate the concern regarding the influence of household characteristics, comparing siblings with different dam exposures, and the results supports our main findings. We also demonstrate that the baseline findings are unlikely to be confounded by dam-induced displacement and school relocation, and are robust across alternative treatment group selections and different samples.

Did dams impede female education by increasing time spent on water collection chores? We find that households closer to an upstream dam spent 20% more time on water collection daily compared to those farther away. The increased time correlates with fewer years of schooling for girls, while no such correlation exists for boys. We further demonstrate that the prolonged time spent on water collection is due to worsened water scarcity downstream. Our study shows a direct link between reduced groundwater storage and longer water collection time, particularly in regions with low groundwater storage and during dry seasons. We do not find enough evidence, at least in our context, to support alternative mechanisms such as increased incidence rate of waterborne diseases or decreased household income.

On a positive note, better management of dams tend to moderate the adverse effects. The study reveals that individuals living in river basins that has been protected by international freshwater treaties were less affected by the dam. This finding sheds light on the importance of infrastructure management. Overall, water and energy management needs to take into consideration this gender-asymmetric cost.

This study contributes to three strands of literature. First, it contributes to the literature pertaining to the impact of dams. Previous studies have shown a positive impacts of irrigation dams in promoting agricultural production in the downstream region (Duflo and Pande 2007; Hansen et al. 2009; Jones et al. 2022; Sarsons 2015; Strobl and Strobl 2011). [1] However, less attention is given to dams' direct impacts on domestic water use. Mettetal (2019) found the irrigation system associated with dams caused more water pollution and led to higher infant mortality rate in South Africa. Ando and Lei (2023) shows that dams on Mekong River exacerbates water scarcity in the downstream during dry seasons due to poor management and international coordination. To our knowledge, this paper provides the first empirical estimates of how dams affect the gender equity among local communities, and by taking the gender-specific impacts of water availability into consideration, it provides valuable implications to policymakers.

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[1] Chen et al. (2022) is an exception, it found the construction of the Three Gorges Dam, the largest hydropower dam in the world, altered rainfall patterns in downstream regions. It decreased rainfall and reduced agricultural production in rural areas.

Secondly, this research directly speaks to the literature on water-related issues in developing countries. Water accessibility is one of the most crucial factors for individual well-being, especially in underdeveloped regions. There is a large literature indicating that access to clean water on premises significantly improves people's physical and mental health (Devoto et al. 2012; Frempong et al. 2021; Galiani et al. 2005), boosts children's school enrollment (Choudhuri and Desai 2021; Koolwal and van de Walle 2013), increases adults' labor participation (Meeks 2017), and reduces interpersonal conflicts and poverty (Blakeslee et al. 2020; Sekhri 2014; Unfried et al. 2022). However, willingness to pay for clean water (technology) is relatively low in developing countries (Berry et al. 2020; Kremer et al. 2011; Wagner et al. 2019), making groundwater the primary source. Groundwater could be depleted and polluted by development process itself, such as agricultural intensification and industrialization. This study contributes to the recent discussions on the relationship between water infrastructure and groundwater storage (Fishman et al. 2023; Pfeiffer and Lin 2014; Sayre and Taraz 2019), further underscoring the gender-asymmetric cost such infrastructures could bring in less developed societies.

Lastly, our paper also contributes to the broader literature on environmental justice. A vast array of studies show that the negative environmental consequences of industrialization and urbanization are disproportionately undertaken by disadvantaged people (see Banzhaf et al. (2019a; 2019b) for a comprehensive review). Due to limited bargaining power and lower willingness to pay for a clean environment, people of color are more likely to suffer from hazardous waste exposure and resource depletion, e.g., higher infant mortality (Chay and Greenstone 2003), poorer health outcomes (Currie et al. 2011; Schlenker and Walker 2016), and reduced educational performance (Aizer et al. 2018; Persico et al. 2020). While existing studies largely concentrate on racial disparities in developed countries, less attention is paid to that in developing countries. An exception is von de Goltz and Barnwal (2019), which found that women near heavy metal mines experience higher incidence rates of anemia than men. Our paper provides novel empirical evidence to the literature, documenting the environmental inequities between genders in developing regions.

The rest of our paper is structured as follows. Section 2 introduces the role of dams and background. Sections 3 and 4 display the data we used and the empirical design of the paper, respectively. Section 5 shows the results. Section 6 examines the mechanisms. Section 7 discusses the policy implications of international treaties. Section 8 concludes.

2 Institutional Background

2.1 Gendered Impacts of Water Scarcity

Water scarcity represents a critical challenge in Sub-Saharan Africa. According to UNICEF (2022), 65% of the population lacks access to on-premises piped water. Consequently, a significant portion of the population must collect water from distant public water collection points to meet their daily needs. This task predominantly falls on women and girls, in nearly 80% of households without access to water on premises, women and girls are the primary water providers (UNICEF 2024).

Groundwater from wells and boreholes are the primary source of drinking water, as it is generally cleaner and less polluted than surface water or rainfall. The standards for drinking water exceed those for irrigation water, necessitating deeper wells or boreholes to access cleaner aquifers. However, drilling deep wells or boreholes is costly, and the success rate depends on the underground lithology (Blakeslee et al. 2020). Many households cannot afford on-premises wells or boreholes, hence women and girls must fetch water from public water sources.

Water collection is a considerably time- and energy-consuming task. A typical woman in the region spends 33 minutes daily on a round trip to water collection points, often with additional time spent queuing upon arrival (UNICEF 2016). The return trip presents an even greater challenge, as she must carry a water-filled bucket weighing approximately 40 pounds (18 kilograms). UNICEF (2016) reports that women in Africa collectively spend 200 million hours every day on water collection. This arduous daily burden, repeated day after day, significantly encroaches on women's time and energy, diverting them away from other self-improvement activities.

In many households, school-age girls often assist their mothers in water collection. The chores significantly limits their educational opportunities compared with their male siblings. Water collection not only exposes them to potential injuries during the journey but also imposes substantial time and energy costs. Even when girls remain physically unharmed, the cumulative effect of these daily burdens can lead to frequent late or even miss school. While a 30-minute water collection trip might seem manageable in isolation, its impact adds up over time. The daily accumulation of missed educational time can cause girls to fall behind academically, struggling to catch up. This persistent educational disadvantage may ultimately lead to drop out from schooling altogether.

2.2 Dam Construction and Downstream Water Availability

Irrigation dams play a crucial role in Sub-Saharan Africa's development, particularly in the agricultural sector. Despite agriculture being the primary production mode in Sub-Saharan Africa, much of the region significant agricultural challenges. Over 40% of the land is arid or semi-arid, and irrigated cropland is severely limited, accounting for only 3.5% of the total agricultural area (FAO, 2001; World Bank, 2017). Moreover, water availability for agriculture in the region is highly uncertain, and the situation is further exacerbated by climate change. In this context, irrigation dams serve as vital infrastructure, enabling more effective water resource management and providing stable irrigation water throughout the year.

To promote agricultural intensification, irrigation dams have been widely constructed across Sub-Saharan Africa. Since the 1950s, the rate of new dam construction has increased dramatically, as illustrated by the blue bar charts in Figure 1. While dam construction rates have decelerated since the 1990s, the average height of new dams has increased, as shown by the rising trend line in Figure 1. This shift potentially indicates a focus on larger-scale water management projects.

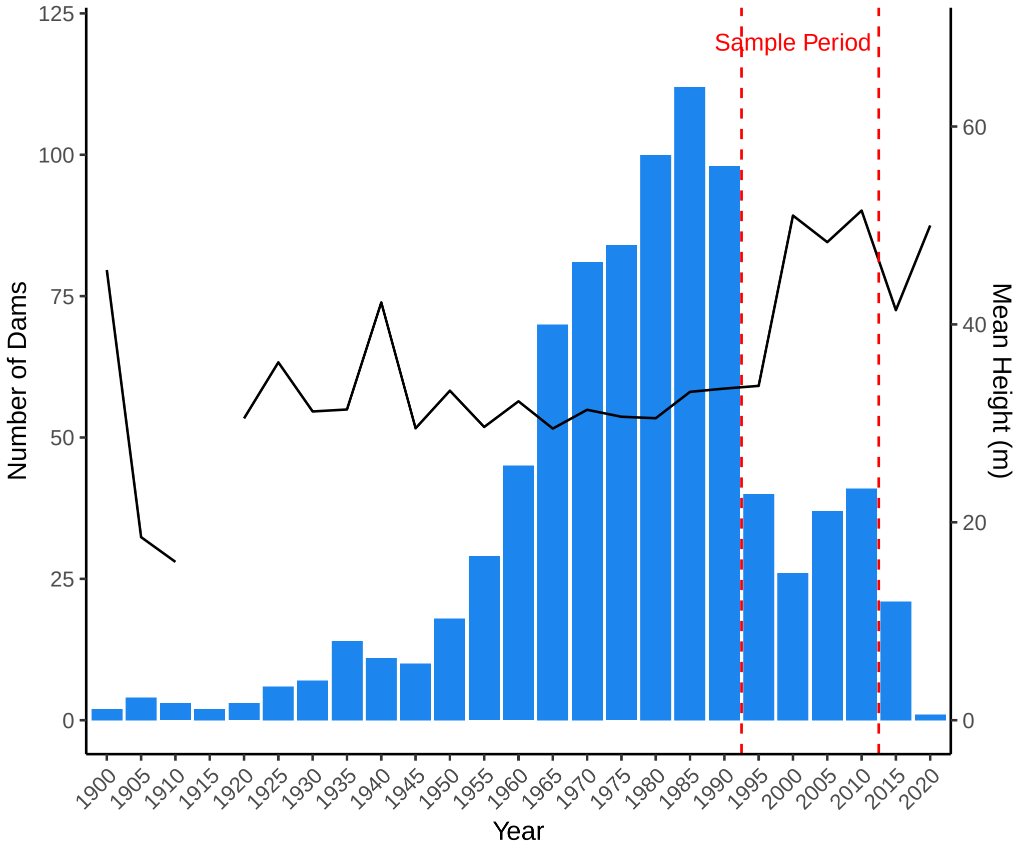


Figure 1: The trend of the irrigation dams' number and average height by time. Blue bars represent the number of newly constructed dams. The black line indicates the average height of these dams.

The primary function of dams is to regulate water flow by storing large volumes in reservoirs and releasing it as needed. During wet seasons, dams retain excess water, while in dry periods, they increase downstream flow. This regulation helps mitigate the risks of severe floods and droughts. However, despite these potential benefits, dams, particularly large ones, have faced persistent opposition. The most prominent criticism centers on their potential adverse impacts on river ecosystems, especially in downstream areas. Dams, without proper coordination, could significantly reduce downstream water availability by retaining excessive water in reservoirs and releasing insufficient amounts (Ando and Lei 2023). The Grand Ethiopian Renaissance Dam (GERD) in Ethiopia exemplifies this issue. The project has met strong resistance from downstream nations, namely Egypt and Sudan, who express concerns over impending water resource shortages caused by the dam's reservoir filling process and anticipated seasonal water scarcity once operational.

Dams pose a threat to downstream groundwater systems primarily through two mechanisms. First, dams regulate river flows, leading to an overall reduction in downstream water surface area (Lajoie et al. 2007). This diminished surface water availability can result in lower groundwater storage, especially in arid or semi-arid regions where groundwater is recharged by surface water. Studies indicate that dams generally lead to a net decrease in downstream groundwater storage (Armanuos et al. 2017; Bahir et al. 2019). Second, the implementation of irrigation systems alongside dams can exacerbate these issues. Local communities often resort to excessive groundwater extraction for agricultural purposes, intensifying the decline in groundwater levels and further disrupting the delicate water balance (Armanuos et al. 2017; Bahir et al. 2019; Di Baldassarre et al. 2018). In contrast, the impact on upstream groundwater storage is typically less pronounced due to the preservation of natural river flow.

The situation can worsen if dam management and coordination are suboptimal. Inaccurate weather forecasts may lead to misguided water retention or release strategies, particularly problematic during periods of drought or heavy rainfall. Additionally, the absence of collaborative water management strategies can result in disproportionate water retention in upstream reservoirs during dry seasons, exacerbating the challenges faced by downstream regions (Ando and Lei 2023).

3 Data and Measurements

To explore the impacts of dams, we utilize the Demographic Health Survey (DHS) conducted in Sub-Saharan African countries. We begin by finding out the dams which are located in the areas covered by this survey. Next we synthesize information from diverse sources on dam construction, land topology to delineate upstream vs. downstream areas. Based on the local hydrological effects of the dams, we delineate the treatment areas and control areas for the upstream and downstream areas separately. Lastly, we combine the ecological and geographical data on dams with geocoded household and village data drawn from DHS and present the summary statistics of key variables by groups.

3.1 Dams, River Basins, and Up/Downstreams

We focus on irrigation dams which were completed between 1990 and 2010 in SSA so as to match them with our household and individual level data drawn from DHS (matching details in section 3.3). For this purpose, we draw upon two comprehensive databases of dams: the Global Reservoir and Dam Database (GRanD ver1.3) and AQUASTAT. The GRanD database, administered by the United Nations, catalogues 7,320 large dams worldwide, each with reservoir capacities exceeding 0.1 km^3 , while AQUASTAT, maintained by the Food and Agriculture Organization (FAO), documents over 14,000 dams globally.

Those two databases keep records of a total of 48 dams built between 1990 and 2010 which are located in the geographical areas covered in the DHS of Sub-Saharan African countries. The geographical distribution of these dams is illustrated in Figure 2. Most of Sub-Saharan African countries have at least one dam completed during this 20-year span, while some have multiple. Panel A of Table B.1 in appendix summarizes the characteristics of these dams, with an average height of 40.4 meters, a mean reservoir capacity of 81.161 million m^3, and an average reservoir area of 15.904 km^2.

Next we map those identified dams to their respective river basins – a portion of land drained by a river and its tributaries — using the information contained in HydroBASINS database. A product provided by the HydroSHEDS project, which was initiated in 2006 by World Wildlife Fund US, this database provides extensive geographical details on the geo-delineation of river basins and sub-basins based on the natural drainage of the rivers and tributaries, area, and distance to most downstream sinks, and more. As shown in Panel A of Table 1, for the river basins mapped with our sample dams, each basin, on average, consists of approximately 420 sub-basins, with an average size of 120 km^2. We also utilise the waterway data drawn from HydroRIVERS database provided by the HydroSHEDS project to disentangle the relationship between relevant rivers and tributaries, which help us distinguish tributaries affected by the dams and those not.

To determine the downstream and upstream positions in relation to the dams, we utilize elevation data for both the dams and the sub-basins within their respective river basins. This data is obtained from the $90m \times 90m$ grid-level Digital Elevation Model (DEM) available in the Hydrologic Derivatives for Modeling and Analysis (HDMA) database, which enables us to compute the average elevation of each sub-basin. Sub-

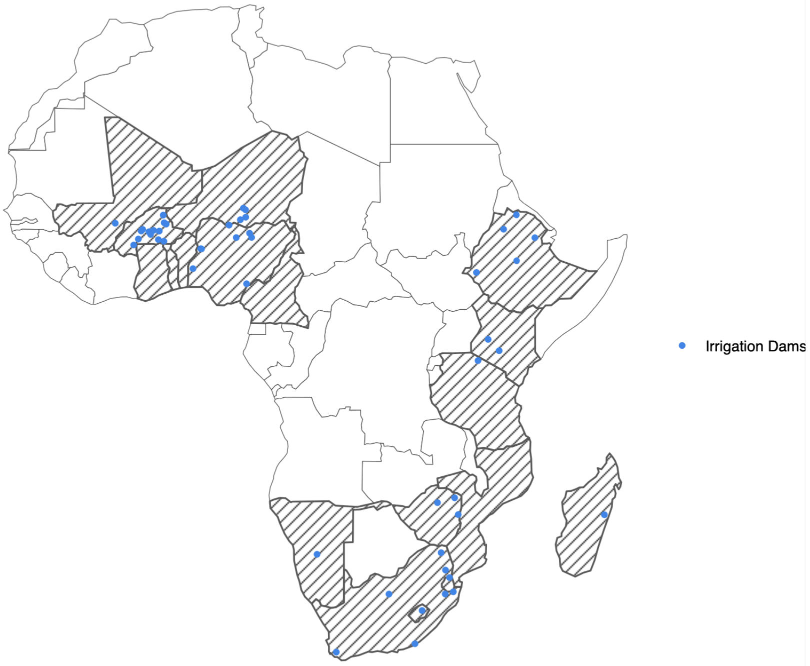


Figure 2: Dams' distribution in Africa

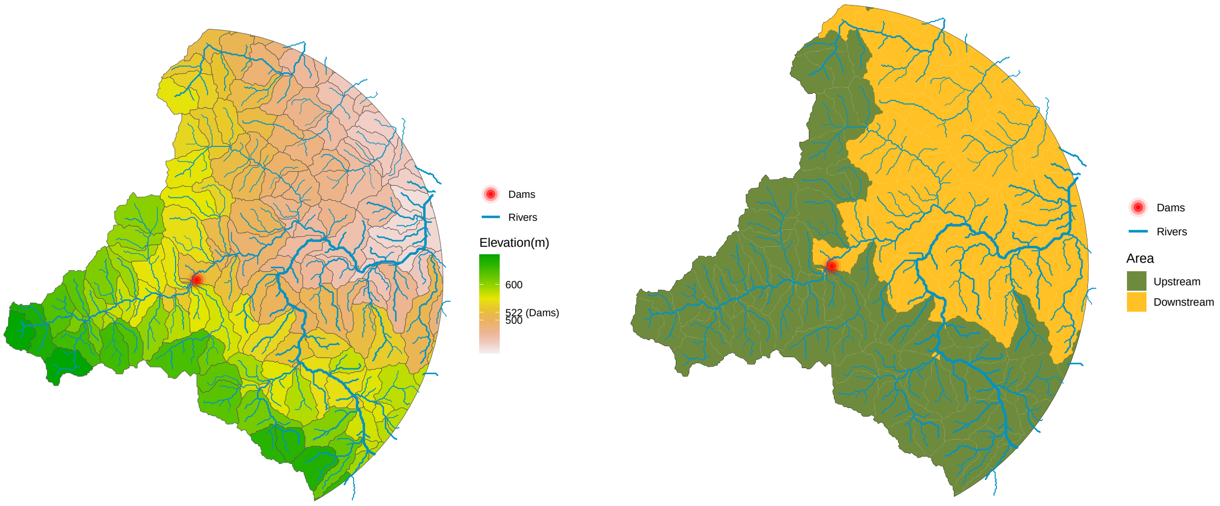
sequently, we compare the elevation of the dams with the average elevation of each sub-basin within the same river basin. Since natural flows typically move from higher elevations to lower elevations, sub-basins situated below the dams are classified as downstream, while those above are classified as upstream.

Figure 3 provides an illustration using the example of the Challawa Gorge Dam and its hosting Hededja river basin. In Panel (a), the elevation of each sub-basin is depicted using varying shades of green, with darker shades indicating higher elevations. The red dot marks the location of the Challawa Gorge Dam. Following our elevation-based classification, Panel (b) shows the delineation of upstream and downstream areas within this basin.

3.2 Surrounding Hydrology

As mentioned in Section 2.2, dams have been argued to diminish groundwater storage in the nearby downstream area. We first validate the hydrological effects of the dams on the downstream areas, which is used to motivate our empirical strategy.

To examine the effect of dams on the groundwater storage, we make use of the JPL TELLUS GRACE Level-3 Monthly Land Water-Equivalent-Thickness Surface Mass Anomaly (Release 6.0 version 04) provided by NASA's Jet Propulsion Laboratory (JPL). This dataset provides a monthly gridded record of on-land water-equivalent thickness (LWET) at a resolution of 0.5*0.5 degrees (approximately 55 km x 55 km) from April



(a) Hadedja river basin (b) Upstream and Downstream

Figure 3: Hadedja river basin and Challawa Gorge Dam in Nigeria as an example

2002 till now.[2] A measure for the amount of water stored in land, LWET is computed based on the change in the gravitational pull attributable to terrestrial water mass detected by highly sensitive satellite instruments. It is frequently used as a proxy for groundwater storage in hydrological studies (Syed et al. 2008; Zhang and Newhauser 2009).

We analyze the hydrological effects of dams in a series of concentric distance rings from the dams, namely, 0-10 km, 10-20 km, ..., to 80-90 km, with respect to the 90-100 km ring serving as the reference category. Therefore, we regress the LWET on the dummies for the respective rings and the post-construction time indicator $Post$, and their interaction terms at the $10km \times 10km$ cell level, controlling for monthly precipitation, the annual proportion of surface water area for each grid cell, as well as the ecological lithology types.[3] Standard errors are clustered at the grid cell level.

Figure 4 displays the estimated coefficients on the interaction terms, which represent the within-grid cell changes in the groundwater storage before and after the presence of the nearby dams. Panel (a) reveals a significant reduction in groundwater storage in the downstream vicinity following dam completion; this negative impact diminishes with increasing distance and becomes statistically insignificant beyond a 50-60 km radius. By contrast, no significant change is observed in the upstream area, as shown

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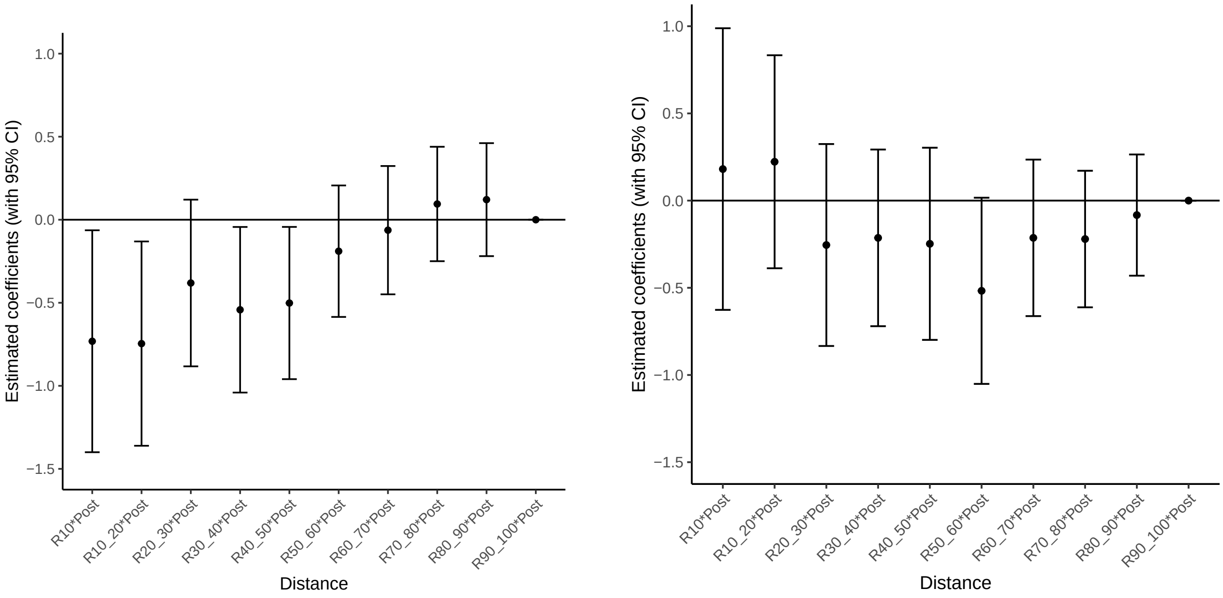
[2] The data is further re-scaled to a resolution of 0.1*0.1 degrees to align with other raster datasets. Figure B.1 in appendix illustrate the process.

[3] The annual surface water cover and monthly precipitation from the Global Land Cover Maps (Version 2.0.7), provided by CEDA Archive, and UDEL Historical Rainfall dataset (V 5.01), respectively. The Africa Surface Lithology dataset provides information on ecological lithology types, characterized by different permeability.

in panel (b). These hydrological findings lay the foundation for the baseline empirical design of our study.



(a) Downstream

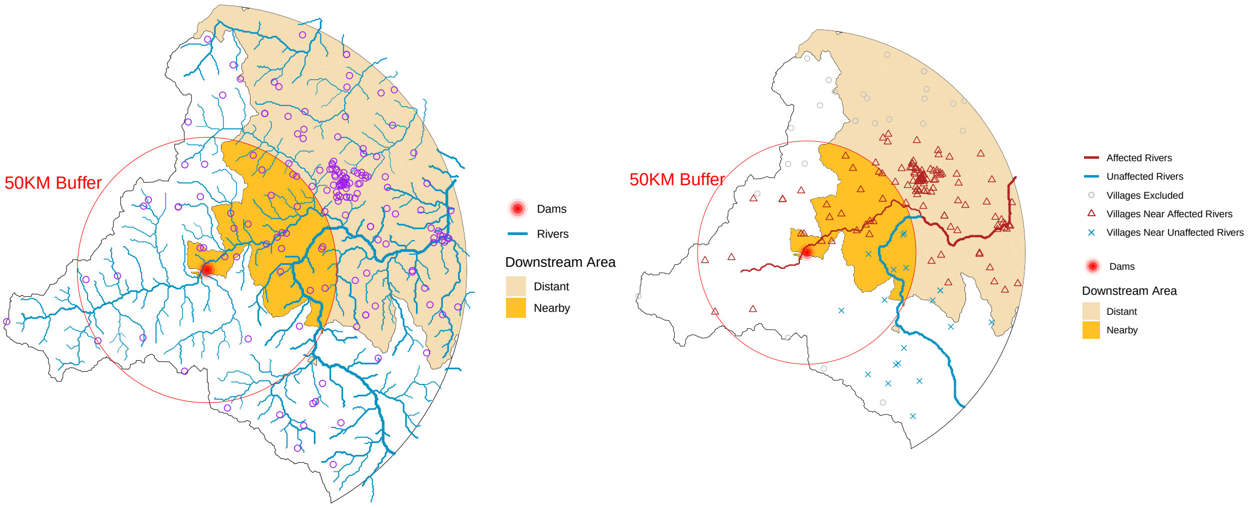
(b) Upstream

Figure 4: Dams' Effect on LWET By Distance

3.3 Sample Construction and Balance Checks

Based on the patterns shown in Figure 4, we focus on the area within a 100km-radius buffer of the sample dams, with the 0-50km buffer of each dam designated as the *Nearby* area and 50-100km as *Distant* areas. Taking the Challawa Gorge Dam as an example, Panel (a) of Figure 5 illustrate the delineation of the *Nearby* vs. *Distant* areas in the downstream.

We restrict our sample to localities that are within a 100 km buffer of and within the same river basin of a dam. It is possible that a village is in proximity to multiple dams, so our analytical unit operates at the village-dam level. Among villages matched with at least one dam in our sample, 69.8% are exclusively near one dam, 15.8% are in close proximity to two dams, and the remaining 14.4% is situated near 3 to 5 dams. In those villages a total of 28,565 households have been surveyed, with summary statistics presented in Panel C of Table 1. Each household on average consists of five to six members, with typically 1.268 adult females and 1.153 children under the age of five. Only 20.9% of surveyed households benefit from on-premise water facilities and only a mere 25.5% have access to clean and safe piped water. The majority of households, 56.6%, rely on well water (groundwater), and a significant number depend on potentially unsafe sources: 15.1% on surface water and 0.3% on rainwater for drinking purposes. The daily time used in water collection is, on average, 21.87 minutes



(a) Treatment and Control groups (b) Affected and Unaffected River Segments

Figure 5: Illustration of treatment and control groups. Using Hadedja river basin and Challawa Gorge Dam in Nigeria as an example.

but can extend to as much as over 700 minutes for certain households. These figures underscore a pronounced deficit in water accessibility across SSA and highlight the significant time cost shouldered by women in these communities.

We mainly use the adult sample drawn from the DHS, i.e., those above 15 years old who have left school. We further restrict this sample to individuals who were under 35 as of the completion of a nearby dam and who were born in the current residence or migrated to the current residence before age 7. This restriction yields a sample of 8,784 females and 12,385 males. The summary statistics of the characteristics for those two samples in presented in Panel B of Table 1. The average age in our sample is 25 years. 31.5% of respondents experienced dam construction in their school age. The average years of schooling is only 4 years of schooling, indicating that the majority did not complete their primary education. Approximately 48.6% are either married or in cohabitation, while more than half of women were married before turning 18. The average age at first childbirth is as low as 18.306. Each woman in our sample on average has 2.4 children.

We further check the differences in the individual and household characteristics between the Nearby and the Distant group in the downstream and upstream respectively by regressing those characteristics on the indicator for the Nearby group (*Nearby*) for the cohorts who completed schooling before the completion of the nearby dams. Figure 6 shows the coefficient plots respectively for the downstream, suggesting no systematic difference in individual and household characteristics between nearby and distant areas. The complete balance check table can be found in Table B.2 in Appendix.

Table 1: Summary Statistics

Statistic	**Mean**	**St. Dev.**	**N**
Panel A: River Basin Characteristics			
# Sub-basins in a river basin	419.278	485.729	18
Sub-basin's distance to sink (km)	1,631.957	1,402.154	7,547
Area of sub-basin (km2)	119.727	78.812	7,547
Downstream Area of sub-basin (km2)	146.614	75.494	7,547
Upstream Area of sub-basin (km2)	11,389.090	105,417.400	7,547
Panel B: Adult Characteristics (Age 15-35)			
Female	0.415	0.493	21,169
Age	25.003	8.572	21,169
Age at dam completion	19.029	9.665	21,169
Exposed cohort	0.315	0.465	21,169
Years of schooling	4.008	4.638	21,169
Marital status:			
Single	0.486	0.500	21,167
Married/Cohabit	0.477	0.500	21,169
Divorced	0.029	0.167	21,169
Widowed	0.007	0.085	21,167
Female-Specific Characteristics			
Height at age percentiles	25.904	26.038	8,784
Age at first marriage	16.256	3.505	5,810
Underage marriage	0.573	0.495	7,357
Age at first birth	18.306	3.637	5,479
Total fertility	2.444	2.882	8,784
Husband Characteristics:			
Age	38.716	12.085	5,009
Years of schooling	3.013	4.757	5,429
Land ownership	0.678	0.600	696
Panel C: Household Characteristics			
# Members	5.486	3.133	28,565
# Women	1.268	0.819	28,565
# Children	1.153	1.141	28,565

Continued on the next page

Table 1 Summary Statistics (Cont')

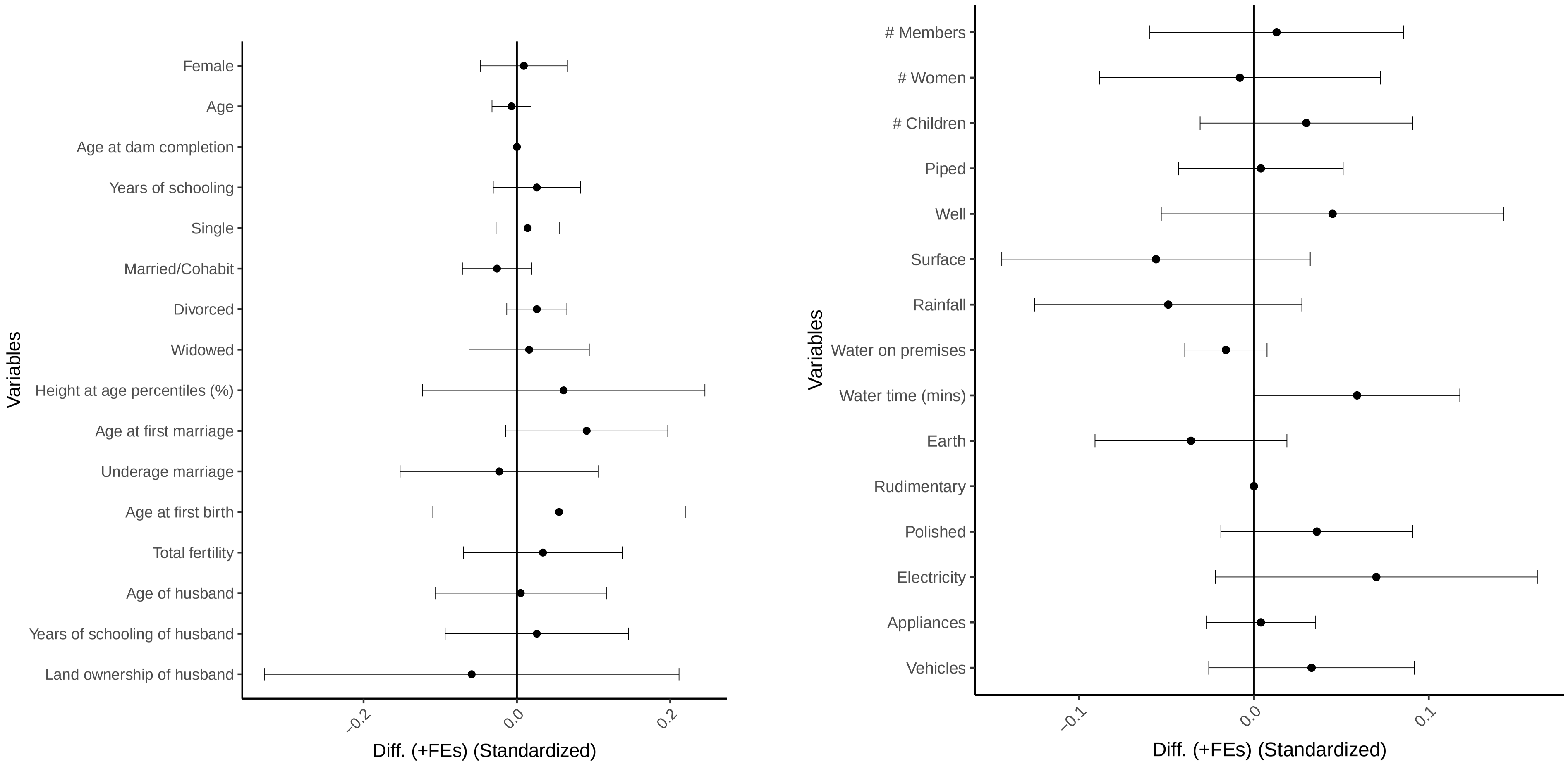
Statistic	**Mean**	**St. Dev.**	**N**
Water Sources:			
Piped	0.255	0.436	28,565
Well	0.566	0.496	28,565
Surface	0.151	0.358	28,565
Rainfall	0.003	0.054	28,565
Water on premises	0.209	0.407	28,565
Water time (mins)	21.870	34.699	28,565
Materials of floor:			
Earth	0.588	0.492	28,565
Rudimentary	0.006	0.080	28,565
Polished	0.405	0.491	28,565
Electricity	0.256	0.436	28,504
Appliances	0.623	0.485	28,241
Vehicles	0.404	0.491	28,388
Wealth	2.708	1.507	20,803

3.4 Other Data

In addition to main variables in the analysis, we utilize a wide range of auxilliary geographic, climatic, and socio-economic information. The variables are summarized in Appendix Table A.1. First, the Global Agro-Ecological Zones (GAEZ) v4 Theme 1 and the Harmonized World Soil Database v1.2, allow us to extract the information on cropland cover and topographic characteristics at the village level. The digitized World Map of the Köppen-Geiger Climate Classification allows us to construct the measures for the climate characteristics of the villages. We also draw upon the road network data from the Global Roads Open Access Data Set (gROADSv1) to compute the distance of each village to the nearest highways.

Besides the geographic information, we also utilise the data on gender norms and traditions to explore the heterogeneity of the dam effects. This data is provided by the Atlas of Pre-Colonial Societies (Atlas) — a digitized version of Murdock (1959). It provides rich ethnographic information and geographical distribution of pre-colonial tribes in Africa, including marriage, kinship, male dominance degree, and the typical production types.

Furthermore, we collect data on population, grain output, and school distribution. Population data is drawn from the Gridded Population of the World Version 3 and 4



(a) Individual Characteristics

(b) Household Characteristics

Figure 6: Balance Check between *Nearby* and *Distant* (Downstream)

(GPW v3 and v4) datasets sourced by NASA. It provides a high-resolution (300m*300m) gridded map on population counts globally in years 1990, 1995, 2000, 2005, 2010, 2015, and 2020. The data on grain production output is collected from the annual gridded map of Net Primary Production (NPP) from MODIS, dating from 2001 till now, with a resolution of 1km*1km. NPP measures the net carbon emission generated during the process of grain growing and is frequently used in economic papers to proxy for the grain output (e.g., Strobl and Strobl 2011). Finally, we get the data on school location from "My School Today" project hosted by OpenStreatMap. It is a user-contributed project that provides basic information about 52,166 schools in Africa, which allows us to examine the effect of dams on school relocation. [4]

Lastly, to investigate whether good management and regulation of the operation of dams can mitigate the negative effect, we gather data on international freshwater treaties from two sources: the International Freshwater Treaties Database, hosted by Oregon State University, and Bakker (2007).

4 Empirical Design

Based on the hydrological evidence shown in Section 3.2, we construct a Difference-in-Differences (DID) model. Specifically, we compare the changes in the educational outcomes of residents in the *Nearby* area (within 50 km buffer of a matched dam) and those in the *Distant* area (50-100 km from a dam). Our baseline estimation specification is as follows:

$$\begin{aligned} Y_{ijdk} =& \beta_1 Nearby_{jd} + \beta_2 Exposed\_cohort_{kd} + \beta_3 Nearby_{jd} \times Exposed\_cohort_{kd} + \\ & X_i \gamma + Geo_j \boldsymbol{\alpha} + \phi_s + \delta_d + \mu_{ck} + \epsilon_{ijdk} \end{aligned} \tag{1}$$

where Y_{ijdk} is the years of schooling of individual i in village j near dam d who was born in year k. $Nearby_{jd}$ takes the value of 1 if village j is within 50km buffer of dam d. $Exposed\_cohort_{kd}$ is a dummy variable indicating whether the individual was younger than 15 as of the completion of dam d. X_i denotes a vector of demographic characteristics, including age, religion, ethnicity. Geo_j denotes geographic characteristics of locality j. We further control for the sub-basin, dam, and country-cohort fixed effects, denoted as ϕ_s, δ_d, and μ_{ck} respectively. ϵ_{ijdk} is the error term. The standard errors are clustered at the village level.

The key parameter of interest is β_3, which denotes the within-subbasin change in the years of schooling for individuals of the exposed cohort relative to the earlier cohort in the close proximity to the dam (0-50km), as compared to that change for people in the

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[4] The data is updated on a daily basis.

more distant area (50-100km). We concentrate our analysis on adult females aged 15 to 35 in the downstream villages while separately estimate the effects for downstream males and both genders in the upstream. If females are most likely to be adversely affected by the exacerbated water scarcity due to dams, we would expect β_3 to be significantly negative for the downstream female group.

To examine whether the nearby and distant areas exhibited pre-existing trends in outcome variables, we further estimate the following event study model to explore which cohorts were affected by nearby dams:

$$\begin{aligned} Y_{ijdk} =& \beta_1 Nearby_{jd} + \sum \beta_2 Cohort_{kd} + \sum \beta_3 Nearby_{jd} \times Cohort_{kd} + \\ & X_i \gamma + Geo_j \boldsymbol{\alpha} + \phi_s + \delta_d + \mu_{ck} + \epsilon_{ijdk} \end{aligned} \tag{2}$$

where $\sum Cohort_{kd}$ consists of people aged from $k < 0$, 0 to 2, 3 to 5, ..., 32-33 when dams were completed, with the 33-35 age group as the reference age group. If the effects arise mainly due to the dams, we would expect to see more salient effects on the cohorts who were before or at school ages when a nearby dam was built.

5 Results

5.1 Baseline Results

We examine the dams' impact on females' and males' years of schooling by comparing the years of schooling between individuals of exposed cohorts (those under 15 at the time of dam completion) and earlier cohorts (those 15 or older at dam completion) who resided closer to dams (within 50 km), relative to those residing further away (50-100 km).

Table 2 reports the estimates from Equation (1) for adult females and males in Panel A and B, respectively. We separately present estimates for individuals residing downstream (columns 1-3) and upstream areas (columns 4-6) of dams. As section 2.2 indicates that dams predominantly impact downstream hydrology, we focus our discussion primarily on the downstream sample while considering the upstream results as a placebo test. For each sample, we systematically introduce controls. We begin with estimates with basic demographic characteristics, dam fixed effects, and cohort (birth year) fixed effects (columns 1 & 4); then proceed to include sub-basin fixed effects and country-cohort fixed effects (columns 2 & 5), and with a full set of geographical characteristics (columns 3 & 6).

The first three columns in Panel A indicate that dams significantly reduced females' schooling years in the downstream vicinity. The coefficient of interest, $Nearby * Exposed\_Cohort$, is significantly smaller than zero at the 1% level across all three regressions. After accounting for the full set of controls (column 3), the coefficient's magnitude is -1.218,

Table 2: The Effect of Dams on Adult's Years of Schooling

	Dependent Variable: Years of Schooling					
	Downstream			Upstream		
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: Females						
Nearby	0.438^{**}	0.394^{**}	0.959^{***}	0.245	-0.657	-0.727
	(0.214)	(0.184)	(0.325)	(0.298)	(0.479)	(0.671)
Exposed_Cohort	0.854^{***}	0.611^{**}	0.712^{**}	0.347	-0.168	-0.135
	(0.254)	(0.275)	(0.283)	(0.364)	(0.417)	(0.416)
Nearby*Exposed_Cohort	-1.183^{***}	-1.133^{***}	-1.218^{***}	0.403	-0.135	-0.142
	(0.312)	(0.337)	(0.346)	(0.468)	(0.465)	(0.480)
Mean	4.416	4.416	4.416	2.964	2.964	2.964
Obs	5770	5770	5770	3014	3014	3014
Adj.R^2	0.606	0.662	0.673	0.532	0.624	0.627
Panel B: Males						
Nearby	0.486^{**}	0.137	0.317^{**}	0.001	-0.044	0.220
	(0.194)	(0.101)	(0.156)	(0.152)	(0.087)	(0.173)
Exposed_Cohort	0.180	0.056	0.077	0.603^{***}	0.930^{***}	0.933^{***}
	(0.245)	(0.229)	(0.232)	(0.219)	(0.219)	(0.218)
Nearby*Exposed_Cohort	-0.442	-0.204	-0.207	0.020	-0.330	-0.352
	(0.278)	(0.301)	(0.303)	(0.282)	(0.255)	(0.259)
Mean	4.67	4.67	4.67	3.464	3.464	3.464
Obs	6241	6241	6241	6144	6144	6144
Adj.R^2	0.454	0.535	0.539	0.369	0.482	0.488
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	No	No	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	No	Yes	Yes	No	Yes	Yes
Cohort FEs	Yes	No	No	Yes	No	No
Country*Cohort FEs	No	Yes	Yes	No	Yes	Yes

Note: The table reports the effect of dams construction on the years of schooling of girls in Africa. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

representing a 27.5% reduction relative to the mean. This suggests that females in exposed cohorts experienced a decrease of approximately 1.2 years of schooling compared to earlier cohorts, relative to their peers residing further from the dams. Given that the average schooling for adult females in our sample is a mere 4.416 years, the reduction of 1.218 years is a substantial impacts.

For females in the upstream area, as shown in columns (4) to (6), exposure to dams during school-age years exhibits no statistically significant impact on educational attainment for those residing near dams compared to those further away. This finding aligns with the previously discussed hydrological impacts, which are predominantly observed in downstream areas.

Regarding adult males, Panel B demonstrates that, after accounting for the full set of controls, dams do not significantly impact the schooling of exposed cohorts either downstream or upstream (columns 3 & 6).

Overall, the contrasting outcomes for females and males suggest a gender-disparate impact of dam construction. Females experienced a substantial and significant reduction in their years of schooling, potentially attributable to their traditional roles, such as water collection, which may be complicated by dam infrastructure. Conversely, males did not exhibit a comparable decline in educational attainment. This divergence in outcomes suggests that the effects of dam construction on human capital formation are not gender-neutral, with females bearing a disproportionate burden.

Validity — To address concerns regarding potential pre-existing differences between the treatment group (0-50 km) and the control group (50-100 km), we conducted an event study analysis by estimating Equation (3). Figure 7 illustrates the estimated coefficients on the interaction terms between *Nearby* and age group dummies *Cohort* (<0, 0-2, 3-5, ..., 30-32) for adult females and males, along with 95% confidence intervals. The reference group in this analysis comprises individuals aged 33-35 when the dams were completed.

The left (right) panel shows the age-specific effects of dams on females (males) living in the downstream area, respectively. For downstream females, the effects fluctuated around zero for earlier cohorts (represented by black error bars), who had already finished school when the dams were constructed. It indicates that for those who should not be affected by the presence of dams in terms of schooling, there indeed was no significant difference with respect to the proximity to dams, which validates our DID identification. By contrast, the effects trended below zero for younger (exposed) cohorts (red error bars), who might not have finished their education yet when the dams were constructed. The absence of pre-existing differences in cohort trends between the treatment and control groups suggests that the adverse effect of dams is not endogenous to regional characteristics.

For males in the downstream area (right panel of Figure 7), the estimated coefficients for almost all cohorts fluctuated around zero and are statistically insignificant, indicating no significant effects of dams on male education. The exception is observed for boys living near dams who were aged 6 to 8 during dam completion; this group experienced significantly shorter years of schooling relative to their counterparts residing further away. Given that ages 6 to 8 are typically when children start primary school, this negative impact is likely attributable to delayed school enrollment caused by the presence of dams. In other words, the effect appears temporary for males while long-lasting for females. These findings align with our baseline results.

Interpreting the magnitude — To further elucidate the effect of dams on female schooling, we decompose the impact into extensive and intensive margins. Specifically, we investigate the effect of dams on the probability of female school enrollment

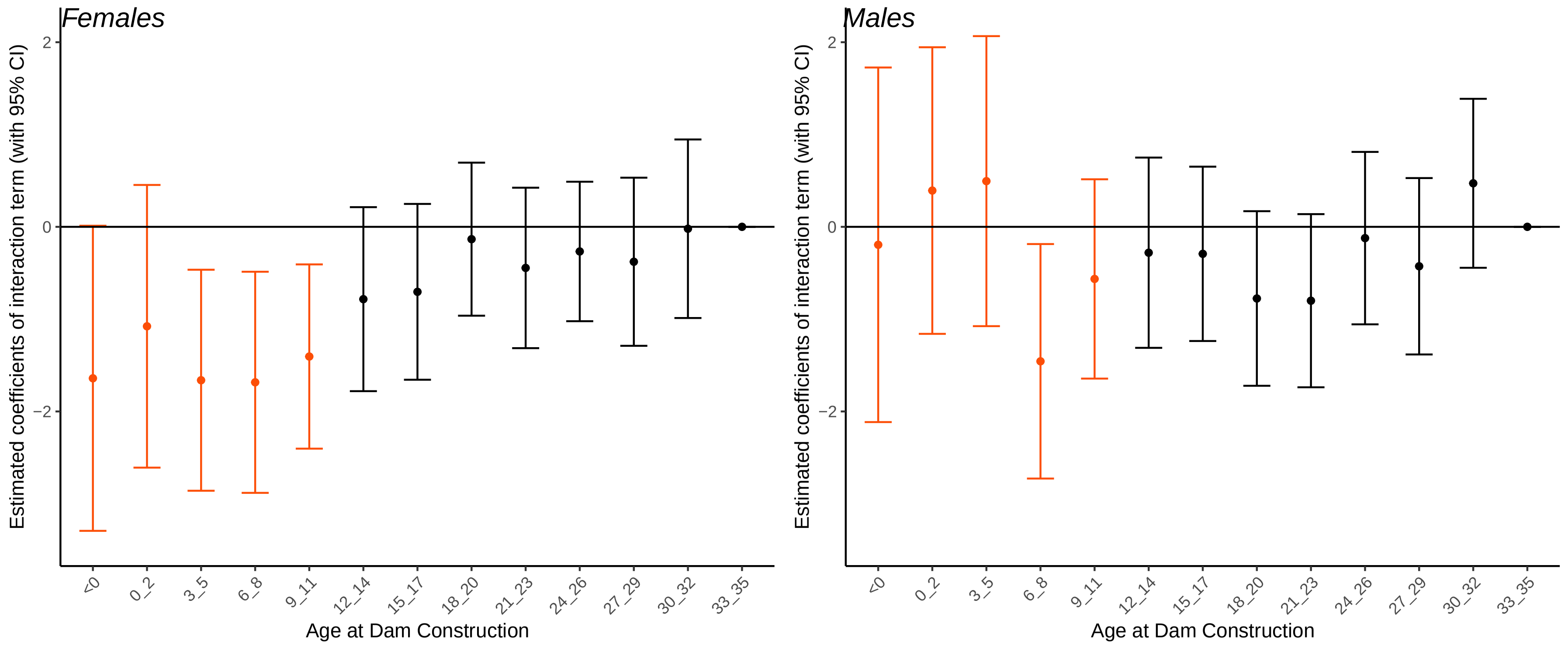


Figure 7: Event Study, Estimated Effect on Female's Years of Schooling by Age Groups

Table 3: Extensive and Intensive Margins

	Dependent Variable: Years of Schooling			
	Downstream		Upstream	
	Have Attended	Schooling | Attended	Have Attended	Schooling | Attended
Nearby	0.061**	1.113**	−0.107	1.678*
	(0.026)	(0.506)	(0.094)	(0.958)
Exposed_Cohort	0.056*	0.723	0.018	0.104
	(0.031)	(0.478)	(0.044)	(0.731)
Nearby*Exposed_Cohort	−0.156***	−0.775*	−0.056	−0.752
	(0.037)	(0.435)	(0.051)	(0.654)
Mean	0.528	8.367	0.395	7.496
Personal Controls	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes
Obs	5770	3045	3014	1192
Adj.R^2	0.619	0.447	0.576	0.387

Note: The table reports the effect of dams construction on the years of schooling of adult females in Africa. All standard errors are clustered at the sub-basin level. *p<0.1; **p<0.05; ***p<0.01

(extensive margin) and the years of schooling for those who were enrolled (intensive margin). Table 3 presents these results. From the first two columns, we find that the presence of downstream dams significantly reduced female enrollment rates by 15.6 percentage points (approximately 30% relative to the mean) and shortened the years of schooling for those who were enrolled by 0.775 years (approximately 9% relative to the mean). These results indicate that dams substantially influenced females' probability of starting education, while the effect on those already enrolled was moderate. In contrast, in the upstream area, we observe no significant effect of dams on either the extensive or intensive margins (columns 3 & 4).

What role did gender norms play? — The asymmetrical effect of dams on educational outcomes for males and females may be indicative of gender-specific costs that align with traditional gender roles. To investigate the role of gender norms in shaping the effect of dams on the two genders, we examine the heterogeneity across regions characterized by varying levels of patriarchal traditions. Utilizing the digitized Atlas data, we measure the strength of a society's patriarchal tradition using four proxies: (a) the prevalence of male dominance in subsistence production, (b) the presence of patrilineal descent systems, and (c) the practice of patrilineal heir systems. By categorizing our baseline sample based on the intensity of local patriarchal traditions as defined by the aforementioned proxies, we re-estimate Equation (1) for these distinct sub-samples. The results detailed in Table 4 reveal a clear and consistent pattern that in regions with entrenched patriarchal traditions, the presence of dams is associated with a more pronounced decrease in the years of schooling of females (columns 1, 3 & 5), while in regions with less pronounced patriarchal norms, the negative effect of dams is attenuated or even disappeared (columns 2, 3 & 6).

Table 4: The Differential Effect of Dams on Female's Years of Schooling by Social Norms (Downstream)

	Dependent Variable: Years of Schooling					
	Male Dominance Degree		Patrilineal Descent		Patrilineal Heir	
	High	Low	High	Low	High	Low
Nearby	1.895^{**}	0.843^{***}	0.320	-0.403	1.762	0.263
	(0.947)	(0.293)	(0.359)	(1.108)	(6.621)	(0.413)
Exposed_Cohort	1.562^{***}	-0.008	1.151^{*}	-0.311	-0.035	-0.095
	(0.436)	(0.365)	(0.643)	(0.797)	(0.180)	(0.707)
Nearby*Exposed_Cohort	-2.178^{***}	-0.636	-1.127^{**}	-0.325	-3.154^{*}	-0.467
	(0.560)	(0.430)	(0.473)	(0.812)	(1.864)	(0.462)
Mean	5.592	3.049	3.57	3.582	3.909	3.843
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3101	2669	1360	679	461	1308
Adj.R^2	0.682	0.646	0.694	0.559	0.617	0.663

Note: The table reports the differential effect of dams construction on the years of schooling of girls by social norms in Africa. All standard errors are clustered at the sub-basin level. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Long-lasting effect on females' marriage and fertility choice — Building on literature that links lower educational levels in women with various long-term detriments — such as increased incidence of underage marriage, higher fertility rates, and lower quality of marital unions — we proceed to examine the extended consequences that dams have on women's future lives.

We re-estimate Equation (1) for adult females, while replacing the dependent variable with a series of outcomes related to marriage and fertility choices. Panel A of Table 5 displays the findings. We first investigate the underage marriage rates. The result in column (1) and (2) reveals an increase in the likelihood of dams-affected females marrying before the age of 18, and a decrease in the age of first marriage, respectively, though the effect is not statistically significant.

We then shift focus to fertility choices. While the age at first childbirth does not seem to be significantly decreased for females who had been affected by the dams (column 3), there is a substantial and significant increase of 0.781 children in total fertility (column 4), indicating a heavier childbearing burden on females whose schooling has been disrupted by the dams.

Next, we examine the quality of marital unions for affected women, specifically focusing on the characteristics of their spouses. The findings presented in the last three columns of Table 5 reveal some effects on spousal attributes. While the husbands of affected females do not differ significantly in terms of age or education level (columns 5 6), they are less likely to possess land (column 7). This reduced likelihood of land ownership among spouses is indicative of a potential "marrying down" phenomenon for affected females.

We further contemplate whether education acts as a mediator in these long-term consequences. The results reported in Panel B of Table 5 reflect a slight mitigation of these effects when conditioning on the years of schooling, suggesting that education partially mediates the long-term impacts of dams on marriage and fertility outcomes.

Table 5: The Effect of Dams on Females' Marriage and Fertility (Downstream)

	Child Marriage	1st Marriage Age	1st Fertility Age	Total Fertility	Age of Husband	Schooling of Husband	Land Own of Husband
Panel A: Not Conditional On Schooling							
Nearby	0.007	0.456	0.449	−0.190	−0.616	1.099^{**}	0.022
	(0.033)	(0.278)	(0.320)	(0.122)	(0.683)	(0.503)	(0.020)
Exposed_Cohort	−0.017	0.507^{*}	0.532^{*}	-0.375^{**}	0.391	0.227	0.011
	(0.035)	(0.303)	(0.311)	(0.145)	(0.946)	(0.426)	(0.015)
Nearby*Exposed_Cohort	0.019	−0.298	−0.022	0.781^{***}	0.033	−0.654	-0.026^{***}
	(0.035)	(0.283)	(0.326)	(0.211)	(1.045)	(0.434)	(0.010)
Mean	0.544	16.321	18.419	2.306	38.753	3.289	0.055
Obs	4837	3645	3424	5770	3029	3378	5770
Adj.R^2	0.498	0.361	0.235	0.733	0.607	0.510	0.569
Panel B: Conditional On Schooling							
Nearby	0.029	0.252	0.347	−0.103	−0.503	0.556	0.022
	(0.035)	(0.262)	(0.304)	(0.122)	(0.662)	(0.373)	(0.020)
Exposed_Cohort	−0.005	0.385	0.447	-0.310^{**}	0.446	−0.101	0.011
	(0.033)	(0.293)	(0.306)	(0.140)	(0.949)	(0.389)	(0.015)
Nearby*Exposed_Cohort	0.005	−0.196	0.026	0.670^{***}	−0.028	−0.338	-0.027^{***}
	(0.032)	(0.264)	(0.321)	(0.203)	(1.048)	(0.411)	(0.010)
Mean	0.544	16.321	18.419	2.306	38.753	3.289	0.055
Obs	4837	3645	3424	5770	3029	3378	5770
Adj.R^2	0.515	0.389	0.254	0.741	0.608	0.596	0.569
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The table reports the effect of dams construction on the years of famale's marriage and fertility in Africa. All standard errors are clustered at the village level. *p$<$0.1; **p$<$0.05; ***p$<$0.01

In summary, a dam's construction during a woman's formative educational years has a marked and enduring influence, curtailing not only her educational attainment but also her future marriage and fertility choices.

5.2 Identification Issues and Robustness Checks

We conduct a list of robustness checks in this subsection to address concerns regarding following issues.

5.2.1 Affected vs. Unaffected River Segments

Our baseline analysis is limited to individuals within the same river basins as the dams to capture the dams' hydrological effects on local communities. Given the complexity of river networks and their numerous tributaries, not all river segments within a basin are uniformly affected by a dam. This variation within river basins provides a potent quasi-experiment context, allowing us to isolate and scrutinize the dams' impact more precisely by comparing segments directly affected by dams with those that are not.

In this subsection, we leverage the natural variation provided by the presence of multiple tributary rivers in a basin, as illustrated in Panel (b) of Figure 5. Suppose there are two tributary river segments flowing in the same basin. When a dam, represented by a red dot, truncates one tributary, we identify this as the 'affected river' (red line). In contrast, an 'unaffected river' (blue line) refers to a tributary that flows untruncated until merging with an affected segment.

We selectively focus on basins with at least one affected and one unaffected tributary, constraining to individuals living within a 30km buffer of these rivers. This delineation is depicted in Figure 5 Panel (b), where villages near affected and unaffected river segments are denoted by red triangles and blue crosses, respectively. This sample limitation, while reducing our sample size, markedly enhances the precision of our findings by utilizing the complexity of river networks to our advantage.

Table 6: The Effect of Dams on Years of Schooling by River Segments

	Dependent Variable: Years of Schooling							
	Downstream				Upstream			
	Females		Males		Females		Males	
By River Segments:	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected	Affected	Unaffected
Exposed_Cohort	−0.056	0.450	−1.670*	−0.432	1.229	−1.353*	2.585	−0.736
	(0.881)	(0.665)	(0.947)	(0.821)	(1.920)	(0.803)	(4.933)	(1.008)
Nearby*Exposed_Cohort	−1.434**	−0.751	1.286	−0.109	−1.603	0.698	−3.525	1.240
	(0.721)	(0.878)	(1.003)	(0.786)	(1.573)	(0.729)	(2.106)	(0.775)
Mean	3.67	3.533	5.251	4.838	2.802	3.126	4.828	4.136
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	1282	1370	1100	1279	288	1632	239	1352
Adj.R^2	0.649	0.643	0.441	0.466	0.784	0.669	0.513	0.581

Note: The table reports the effect of dams construction on the years of schooling in Africa. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

We separately estimate Equation (1) for individuals living in proximity to affected and unaffected river segments. Table 6 presents the results. The first two columns report the dams' impact on the years of schooling of females downstream. A comparison between these two columns reveals that the presence of dams only significantly shortened the schooling years for females residing near affected river segments (column 1), but had no significant effect on those near unaffected river segments (column 2). Notably, the magnitude of coefficient $Nearby * Exposed\_Cohort$ for females near affected segments closely mirrors the baseline finding (-1.434 vs. -1.218), despite the current sample being less than half the size of the baseline sample.

By contrast, our analysis found no significant impact of dams on the education of males downstream (columns 3-4), nor on either gender located upstream (columns 5-8). These findings are consistent with those of the baseline analysis, reinforcing the notion that the dams' influence on education is gender-specific and predominantly in the downstream.

In summary, the above results underscore that the adverse effects of dams on educational outcomes are significant exclusively for females located downstream and near affected river segments. Conversely, females in downstream areas but near unaffected river segments did not experience a significant impact. These findings corroborate the initial design of our baseline study, clearly attributing the observed reduction in the schooling years for females to the alterations in downstream river flow caused by dam construction.

5.2.2 Other Robustness Checks

Triple Difference in Differences (DDD) — We exploit the fact that dams arguably have larger hydrological effects on the downstream area to conduct a DDD approach, with people in the upstream area as a control group. Building upon the baseline DID design, we introduce a triple interaction term in our regression, incorporating the proximity dummy, $Nearby$, the time indicator, $Exposed\_Cohort$, and a new binary indicator for downstream location, $Downstream$. This term, along with all the second-order interactions, enables us to merge the downstream and upstream analyses into a single regression, comparing the differential impact of dams on education for those residing closer to and further away from the dams in the downstream area with the difference between their counterparts in the upstream area.

As shown in Table B.3, dams had a significantly negative effect on the years of schooling for females in the exposed cohort living in the downstream area and closer to the dams, compared with their counterparts living in other areas (column 1). The effect size is in close alignment with our baseline DID results (-1.485 vs. -1.218 from Table 2), confirming the robustness of our initial findings. Notably, the second-order interactions, $Nearby * Exposed\_Cohort$ and $Downstream * Exposed\_Cohort$ are not significant, suggesting that the observed negative effect is not driven by the increase in schooling for those upstream nor those downstream at a distance from the dams. Regarding adult males, no significant negative effect was observed (column 2).

In summary, the DDD analysis corroborates the baseline results: the adverse effect of dams was more salient on females rather than males. These results validate the robustness of our main findings.

Within-household Analysis — To address concerns that household characteristics may confound the baseline results, we conduct a within-household analysis using the children's sample from the DHS. Specifically, we examine individuals aged 6 to 17 who are identified as daughters or sons of the household head. We restrict the sample to those with at least one same-sex sibling in the dataset. We then perform a regression similar to Equation (1), incorporating indicators for proximity ($Nearby$) and age at dam completion ($Age \leq 12$), as well as their interaction. This approach assumes that younger siblings (age ≤ 12) in households are more affected by nearby dams than their elder siblings (age > 12). Crucially, we include household fixed effects to control for any unobservable household-specific characteristics.

We conduct separate analyses for girls and boys. The results, presented in Table B.4 in Appendix B, reveal that younger girls (age ≤ 12 at dam completion) residing near dams experienced significantly shorter schooling duration—by 0.687 years—compared to their elder sisters, relative to those residing farther away. In contrast, we find no significant impacts for girls living upstream or for boys in either downstream or upstream areas. These findings align precisely with our baseline results, mitigating concerns about the influence of household characteristics in the baseline analysis.

Compositional change caused by displacement or school relocation? — Dam construction often involves large-scale displacement. Specifically, people living near dams may be required to relocate, or after dam commissioning, individuals might migrate to dam-affected regions to take agricultural advantages. Estimations of net population count changes caused by dams, utilizing high-resolution (1km*1km) satellite data on global population from 1990 to 2020 at five-year intervals, reveal a decline in net population count in regions proximate to dams compared to more distant areas, in both downstream and upstream regions (see results from columns 1-2 of Table B.5).

A potential concern is whether such displacement induces compositional changes in surrounding areas, for instance, if dam-induced migrants were more economically advantaged and thus had higher educational attainment. However, this concern is mitigated in our study, as our baseline analysis restricts the sample to native people or those who migrated with parents at a very young age. This restriction ensures we compare the effect of dams within a population of non-migrants, largely eliminating potential confounding effects.

To further address this concern, we conduct several robustness checks. First, we examine the migration patterns of individuals surveyed by the DHS within our sampled regions. We construct an individual-by-year dataset, incorporating yearly migration status to assess whether dams induced different migration patterns in areas close to or distant from dams. We regress an indicator for whether the individual migrated to the interview site in a given year on the proximity to dams (*Nearby*), a time indicator for post-dam completion (*Post*), and their interaction. The findings, presented in columns (3) to (4) of Table B.5, show no significant difference in migration likelihood between individuals residing closer to and farther from dams after dam completion, in both upstream and downstream regions. While we cannot trace out-migrants, we may capture them as in-migrants if they moved to the upstream area or 50-100 km area from the dams. Despite this limitation, we find no systematic difference in migration between treatment and control groups.

Next, we investigate potential systematic differences in educational attainment between post-dam migrants and other individuals. We construct an indicator for post-dam migrants and find no significant divergence in years of schooling between natives and migrants after dam construction in both downstream and upstream regions (columns 5 & 6 of Table B.5). Overall, while our analysis confirms that dams caused population displacement, the evidence suggests that such displacement did not introduce significant compositional changes to our sample.

A related concern is the potential impact of dam construction on school availability and accessibility. Schools may be relocated during dam construction, potentially making it more challenging for nearby residents to attend. To investigate this, we utilize data from the My School Today project, part of the SDGs Today initiative, which provides user-contributed information on school locations. Ideally, we would examine changes in school distribution over time. However, due to limitations in data on school founding dates, our analysis focuses on the current spatial distribution of schools relative to dam locations.

Our analysis is conducted at the 10km*10km grid cell level, with the number of schools in each cell serving as the dependent variable. The results, presented in the last two columns of Table B.5, indicate no significant difference in the number of schools between areas closer to and further from the dams (the coefficient on *Nearby* is statistically insignificant). This pattern of spatial indifference is consistent across both downstream and upstream regions.

These findings suggest that, at least in terms of current distribution, dam construction has not led to substantial disparities in school availability between areas proximate to and distant from dams. However, it's important to note that this analysis captures only the current snapshot of school distribution and cannot account for historical changes or relocations that may have occurred during or immediately after dam construction. Despite this limitation, the lack of significant spatial variation in school numbers provides some reassurance that differential access to schools is unlikely to be a major confounding factor in our main analysis of educational outcomes.

Robustness to Alternative Buffer Selections — While our initial choice of a 50 km buffer around dams for defining the treatment group is well-justified, we acknowledge potential concerns regarding this specification. To address these concerns and test the robustness of our findings, we conduct sensitivity analyses using alternative buffer distances. Specifically, we re-analyze Equation (1) using treatment groups defined by 30 km, 40 km, and 60 km buffers around the dams. The results of these analyses are presented in Table B.6.

Our findings demonstrate that the choice of alternative buffer distances yields results consistent with our baseline analysis. This consistency across different spatial thresholds reinforces the robustness of our initial findings and suggests that the observed effects of dams on educational outcomes are not sensitive to a particular buffer choice.

Alternative samples — In addition, we conduct further checks to ensure that our baseline results are not influenced by confounding factors. First, we remove observations residing very close to the dams (within 1km, 2km, 3km, 4km, and 5km buffer), as these individuals may be affected by the dams in a different way, such as being provided with labor opportunities during the construction of the dams. As shown in columns (1) to (5) of Table B.7, we found that our main results remain robust to the removal of these observations.

Another concern arises from the assumption that the hydrological effects of dams may not be uniform across the entire river basin. Specifically, individuals residing at a distance from primary watercourses or major tributaries were considered not to be affected. To address this, we reference the intricate network of river branches that permeate the whole river basins, as illustrated in Panel (d) of Figure 5. This extensive branching suggests a potential hydrological influence reaching individuals who are not in immediate proximity to the stem rivers. Besides, we refine our sample to include only individuals residing within a 30 km buffer zone of a stem river or a major tributary and re-estimate Equation (1). The result shown in column 6 indicates that this more geographically targeted sample produces results consistent with our primary findings.

Finally, some dams are geographically close, so their effect may confound each other. We address this issue by dividing dams by their completion sequences and re-estimate Equation (1). Columns (7) and (8) reveal that the first dams had a more prominent effect on females' schooling, while the later-built dams showed an insignificant impact.

The finding alleviates the concerns regarding the effect of multiple dams.

In summary, our baseline results are robust to the above robustness checks. They are not sensitive to alternative measurements of the explanatory and outcome variables, the models, and the samples, and they are not biased by the potential confounders such as migration, school relocation, construction, and multiple dams effect.

6 Mechanisms

Previous results have shown that dams have a significant negative effect on females' years of schooling, while males are not affected. We have also found that the effect of dams can be influenced by gender norms — the negative effects are more prominent in more patriarchal societies. In this section, we aim to investigate the mechanisms through which dams affect females' years of schooling in Sub-Saharan Africa. Section 6.1 examines how females' schooling was disrupted by the presence of dams. In section 6.2, we propose a possible mechanism that the presence of dams leads to a reduction in groundwater storage downstream, consequently increasing females' time use in collecting water. We also explore alternative mechanisms, including health and income effects in section 6.3. However, in our context, the evidence is not enough to support these alternative mechanisms.

6.1 When does schooling end?

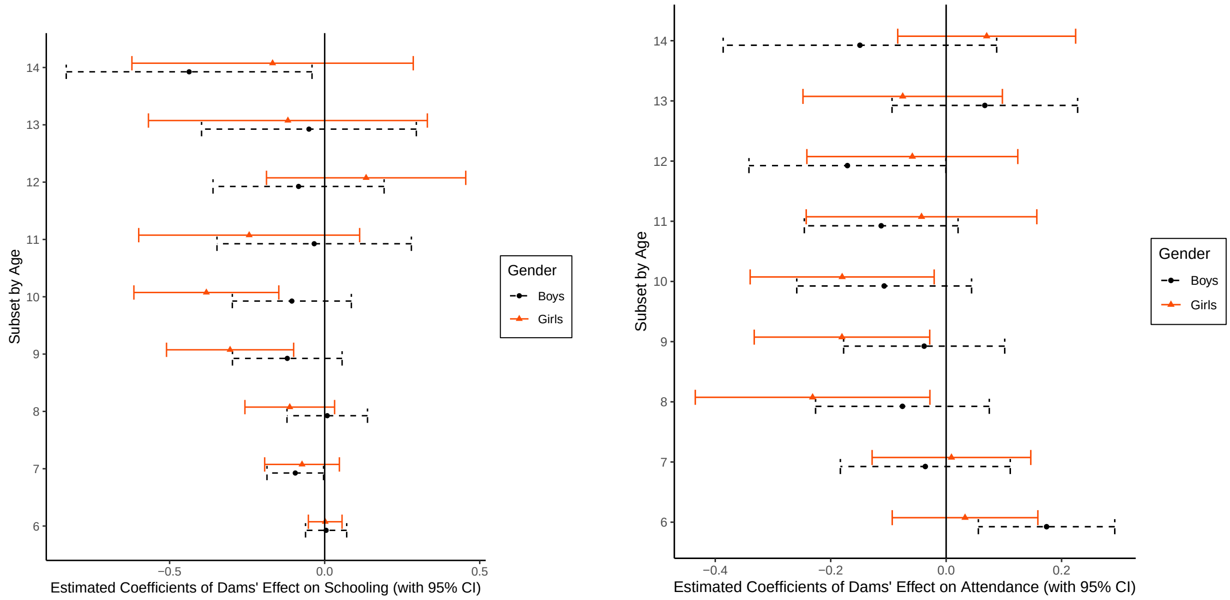
How did the dams shorten females' schooling? We first pinpoint the educational stage at which interruptions occur. Since the DHS does not provide detailed information on educational histories for adults, the study turns to investigate the immediate effect of dams on children aged between 6 and 14 at the time of interview (hereafter, children sample). Summary statistics of children sample is in Panel B of Table B.1. Similar to the baseline design, we exploit the variation in the child's proximity to dams to conduct a DID identification, with a distance of 0-50km to dams as the treatment group and 50-100km as the control group. Children in the treatment group will be treated if the dam has been completed. The specification is as follows:

$$\begin{aligned} Y_{ijdt} = &\beta_1 Nearby_{jd} + \beta_2 Post_{td} + \beta_3 Nearby_{jd} \times Post_{td} + \\ &X_i\gamma + HH_i\boldsymbol{\omega} + Geo_j\boldsymbol{\alpha} + \phi_s + \delta_d + \mu_{tc} + \epsilon_{ijdt} \end{aligned} \tag{3}$$

where i, j, d, t represent child i at locality j near dam d at interview year t. Y_{ijdt} represents either the years of schooling or school attendance for child i. $Post_{td}$ is a dummy variable indicating the presence of the dams, and it takes 1 if the interview year t is after the time of dam d completion and 0 otherwise. We control for personal characteristics X_i, household characteristics HH_i, and geographic characteristics Geo_j. Other variables and fixed effects are the same as that in Equation 1. ϵ_{ijdc} is the standard error clustered at the village level.

We separately estimate Equation 3 for each gender in each age group in the downstream and primarily focus on the coefficient β_3, which represents the change in the years of schooling or the likelihood of attending school before and after the presence of the dam for children living closer, relative to that change for their peers living further away. The estimated coefficient β_3 is reported with 95% confidence intervals by age and gender in Figure 8. Panel (a) presents the results on the years of schooling, revealing a contrasting gender divide: while boys' schooling (black dashed line) is not affected by the dams until very late (only at the age of 14), girls' years of schooling is significantly reduced at the ages of nine and ten (red solid line). In terms of school attendance shown in panel (b), we find a similar pattern: boys' school attendance remains unaffected, but girls are less likely to attend school after the presence of the dams, particularly between the ages of eight and ten.

These findings are particularly significant given the context of Sub-Saharan Africa, where delayed school entry is common: girls often begin primary school around ages seven to eight. Our results suggest that dams disrupt females' education at a critical early stage. The significantly lower attendance rate at age eight indicates that a substantial proportion of girls never enroll in primary school due to dam construction. This aligns with our previous findings on extensive margins, which shows that dams reduced female enrollment rates by approximately 15% (Table 3).



(a) Years of Schooling

(b) Attendance

Figure 8: The Effect of Dams on Children's Schooling by Age and Gender

The impact on girls' education is further contextualized by the average educational attainment for adult females in Sub-Saharan Africa, which is approximately 4 years of formal schooling. This suggests that many females typically exit the education system around age 11. Our findings indicate that dam construction acts as a significant push factor, precipitating girls' exit from education at ages when they might otherwise continue their studies. This effect is absent among boys until much later stages, implying that the negative externalities of dams on education are distinctly gendered.

6.2 Why do women quit? Reduced groundwater and prolonged water time

We proceed to investigate why women tend to leave school earlier with the presence of dams and why this effect is gender-specific. A potential mechanism is the increased burden of water collection caused by reduced groundwater storage near dams, as evidenced in Figure 4 and the first two columns in Table 8. Given that groundwater is the primary water source in Sub-Saharan Africa, and water collection is predominantly a task for women and girls, significant reductions in groundwater storage likely force females to spend more time on water collection at the expense of education.

First, we examine the association between groundwater storage reduction and time spent on water collection. Regressing time spent on water collection on standardized LWET, we find that a one standard deviation decrease in LWET corresponds to a 4.82-minute increase in household time spent on water collection (column 1, Table 7). Further investigation reveals heterogeneity between regions with low and normal groundwater storage, and between dry and wet seasons. In regions with overall low groundwater storage (column 2) and during the dry season (column 4), reduction in groundwater storage translates to a more significant increase in water collection time. Conversely, in regions with sufficient groundwater storage (column 3) and during the wet season (column 5), the correlation between groundwater storage and water collection time is not statistically significant. These results provide direct evidence that dam-induced groundwater storage reduction in downstream areas significantly increases time spent on water collection.

Next, we examine the relationship between water collection time and educational attainment. Specifically, we regress children's years of schooling on the logarithm of daily time households spend on water collection. This regression also controls for an array of personal and household characteristics, subbasin-cohort, and village fixed effects. As shown in column (6) of Table 7, a 1% increase in water collection time corresponds to a decrease of 0.031 years (approximately 11 days) in girls' schooling. Furthermore, a 1% increase in water collection time leads to a 0.7% decrease in the probability of girls ever attending school (column 7), and a 0.051-year decrease in years of schooling for those who have attended school (column 8). This relationship is not observed for boys (column 9), suggesting a gendered differential impact of dams through hydrological changes (columns 9-11).

To test whether dams exacerbate the time cost of water collection for females, we regress the logarithm of daily water collection time on a proximity indicator (*Nearby*), a post-dam time indicator (*Post*), and their interaction using the household sample. The regression includes household and geographical characteristics, along with a full set of fixed effects. Though the DHS only provides information on household time use, ethnographic research and time use surveys in Sub-Saharan Africa indicate that over 80% of water collection is undertaken by females, justifying our approach.

Columns (3) and (4) in Table 8 present results for downstream and upstream areas respectively. Downstream households near dams experience a 19.5% increase in water collection time after dam commissions, relative to households further away. No significant effect is observed in upstream areas.

It should be very prudent in interpreting the magnitude. Due to the right-skewed distribution of time spent on water collection, we apply "log-like" transformations on the variable, i.e., log(Y+1). This approach, while common, presents methodological challenges when dealing with variables containing a large number of zero values, as highlighted by Chen and Roth (2023). To address this issue, we adopt the approach recommended by Chen and Roth (2023), which involves estimating separate effects for extensive and intensive margins. In our analysis, the extensive margin captures the change in the proportion of households that must collect water externally rather than having access to water facilities on their premises. This measure reflects the shift in water accessibility at a fundamental level. Conversely, the intensive margin quantifies the change in time spent on water collection for households that consistently needed to collect water even before dam construction. This approach allows us to distinguish between the impact of dams on water access itself and the efficiency of water collection for those already engaged in this activity.

Results in columns (5) to (6) show that dams do not significantly increase the proportion of households collecting water from public sources. However, for those consistently collecting water, dams significantly prolong collection time by approximately 26% for downstream residents (column 7). This translates to an additional 8 to 15 minutes daily, based on average collection times of 30 minutes (with 15% of households spending over 60 minutes). No significant time increase was observed in the upstream region (column 8).

How to interpret the magnitude? While the daily increase may seem moderate, its cumulative effect is substantial and aligns well with our baseline results. Our analysis reveals that a 1% increase in water collection time leads to a 0.7% decrease in girls' enrollment rates (Table 7, column 7) and a 0.053-year decrease in schooling for girls who attend school. Consequently, the observed 19.5% average increase in water col-

Table 7: The Correlation among Groundwater Storage, Water Accessibility, and Schooling

	Time Spent on Water Fetching (mins)					Schooling					
		Groundwater Storage		Seasons		Girls			Boys		
	All	Low	Normal	Dry Season	Wet Season	Years of schooling	I(Attend)	Years of schooling | Attend	Years of schooling	I(Attend)	Years of schooling | Attend
LWET_std	-4.934^{*}	-5.307^{**}	17.727	-29.615^{**}	-7.849						
	(2.854)	(2.689)	(11.058)	(12.109)	(5.497)						
Log(1+Water Time)						-0.031^{*}	-0.007	-0.051^{**}	-0.018	-0.002	-0.017
						(0.016)	(0.004)	(0.022)	(0.015)	(0.004)	(0.023)
Mean	21.87	23.052	18.843	21.834	18.583	1.758	0.467	3.765	1.889	0.513	3.685
Household Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Water Controls	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Village FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year*Month FEs	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No
Subbasin*Cohort FEs	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Obs	12904	9696	3208	6205	6699	55276	55276	24184	59660	59660	28623
Adj.R^2	0.374	0.393	0.333	0.414	0.372	0.660	0.549	0.706	0.615	0.517	0.650

Note: The table reports the effect of dams construction on the local LWET and households' time spent on water collection in Africa. All standard errors are clustered at the sub-basin level for the first four columns, and at the 10km*10km cell level for the last two columns. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 8: The Effect of Dams on Groundwater Storage and Water Accessibility

	Dependent Variables:							
	LWET		Log(1+Time Spent on Water Fetching)		I(Water Time > 0)		Log(Time Spent on Water Fetching) | I(Water Time > 0)	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Nearby	0.292^{***}	0.071	-0.081	-0.043	-0.017^{**}	-0.004^{*}	-0.052	-0.069
	(0.058)	(0.077)	(0.059)	(0.073)	(0.007)	(0.002)	(0.065)	(0.090)
Post	0.076	0.699^{***}	-0.115	-0.014	-0.000	0.009	-0.080	-0.023
	(0.062)	(0.086)	(0.086)	(0.122)	(0.008)	(0.010)	(0.092)	(0.139)
Nearby*Post	-0.606^{***}	-0.131	0.178^{*}	0.106	0.012	-0.001	0.231^{**}	0.126
	(0.121)	(0.142)	(0.097)	(0.103)	(0.011)	(0.002)	(0.106)	(0.141)
Mean	2.249	2.084	2.348	2.204	0.793	0.777	2.882	2.746
Water Controls	Yes	Yes	No	No	No	No	No	No
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FEs	Yes	Yes	No	No	No	No	No	No
Year*Month FEs	Yes	Yes	No	No	No	No	No	No
Household Controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year FEs	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Obs	272968	187740	16539	11467	16539	11467	13051	8872
Adj.R^2	0.342	0.338	0.748	0.774	0.971	0.988	0.257	0.304

Note: The table reports the effect of dams construction on the local LWET and households' time spent on water collection in Africa. All standard errors are clustered at the sub-basin level for the first four columns, and at the 10km*10km cell level for the last two columns. *p<0.1; **p<0.05; ***p<0.01

lection time due to dam construction translates to a 13% reduction in girls' likelihood of attending school and approximately 1 year less schooling for girls who do attend. These magnitudes are consistent with our baseline findings presented in Table 3.

Daily increase in time spent on water collection may delay or prevent younger girls from enrolling in school due to increased family burdens. Moreover, the physical demands of carrying heavy water buckets may impact girls' ability to focus in class, even if they attend. The ripple effect of everyday lateness or missed school can significantly influence girls' academic performance, potentially leading to early dropout.

Overall, this analysis provides strong evidence for a causal chain linking dam construction to reduced groundwater availability, increased water collection burdens for females, and consequently, decreased educational attainment for girls. The gender-specific nature of these impacts underscores the need for targeted interventions to mitigate the unintended consequences of infrastructure development on vulnerable populations.

6.3 Alternative Mechanisms

In this subsection, we explore the alternative mechanisms that could lead to the imbalanced impact of dams on females in Sub-Saharan Africa.

Health Effect? — We investigate whether dams-induced water pollution influenced health outcomes in the downstream area. Due to the limited number of water monitoring stations in the region, direct water quality data was not available. Instead, we directly look into how individual's health outcomes were affected by dams.

The results shown in Table B.8 in Appendix indicate that following dam construction, downstream girls (aged 0-5) living within a 50km buffer of the dams showed a decreased likelihood of diarrhea (column (1)). Their probability of contracting non-water related diseases, fever, and cough remained unchanged (columns (2) - (4)). As for boys in the downstream, we observed no significant increase in the likelihood of diarrhea, fever, or cough (columns (5) - (7)), and a decreased probability of anemia (column (8)). We also explore dam's impact on long-term health and nutrition outcome by investigating adult females' height for age percentiles, and find the presence of dams significantly increased adult females' height (column (9)). This positive effect may be attributed to improved agricultural production facilitated by dam construction, leading to better nutrition over time.

To sum up, our empirical results do not support the hypothesis that dams caused increased water pollution leading to impaired health outcomes. Instead, the findings suggest potential health benefits, particularly in terms of reduced diarrhea incidence among young girls and improved long-term growth outcomes for women.

Income Effect? — Next, we investigate whether the income effect could be a mechanism that explains the negative effect of dams. In other words, we ask if the presence of dams adversely impacts downstream agriculture or household income, which possibly leads to a reduction in the education of females.

We first examine the change in agricultural production output. Since we do not have such disaggregated data on grain output, we instead introduce an indicator, Net Primary Production (NPP), to measure the output. NPP measures the total sum of carbon dioxide that the grain/vegetable will generate during their growing process and is frequently used to proxy for agricultural production output (e.g., Strobl and Strobl 2011).

Column (1) Table B.9 displays the results on NPP for downstream (Panel A) and upstream (Panel B) areas, respectively. We observe a significantly positive effect of dams on the NPP in the downstream area, suggesting that dams do not harm but even help to increase agricultural output in the downstream regions. In contrast, the presence of dams has no effect on the NPP in the upstream regions. The results finely align with previous findings in Duflo and Pande (2007) and Strobl and Strobl (2011), and the underlying reason is that the irrigation systems associated with dams in the downstream help to increase the agricultural production, while the reservoirs built in the upstream may force cropland to be submerged. Such distributional effect of dams on agriculture, which has been discussed in previous literature, indicates that downstream regions may not be economically disadvantaged overall with the presence of the dams.

Although agriculture is the primary way of production in SSA, some people also rely on other non-agricultural production. To fully understand how the dams affected their income, we next examine how the presence of dams changed household wealth and belongings.

The results shown in Panel A of Table B.9 indicate that for downstream households, we do not find evidence indicating that the dams reduce their general wealth (column (2)), the access to electricity (column (3)), the possession of radio (column (3)), telephone (column (7)) and vehicles (column (8)), and even increased their likelihood to possessing radio, and television (columns 4 & 5). As for upstream residents, Panel B demonstrates that the presence of dams, on the contrary, reduces their access to electricity significantly (column (3)).

The findings on NPP and answers to DHS survey questions are consistent with each other. We do not find evidence suggesting dams adversely affect the income of downstream households or that the income effect serves as an important mechanism for the negative effect of dams on females' education.

In summary, our exploration of alternative mechanisms, including health effects and income effects, suggests that these potential reasons may not be significant mechanisms of the dams' effect based on our current sample.

7 Did Management Matter? International Treaties and the Dams' Effect

Is there any way to mitigate the gendered negative effect of dams in SSA? In the final part of this study, we try to discuss this question and propose some policy implications.

A previous study by Fan (2022) found a notable divergence in the impact of dams on economic indicators and environmental factors between developed and Global South countries. Dams were associated with increased GDP in developed countries but related to decreased GDP, population, and environmental greenness in the Global South. This raises questions about whether these disparities are rooted in the management and regulation of dams and whether effective management and regulation can alleviate potential adverse effects caused by dams.

To explore this issue, we conducted an analysis by categorizing sampled river basins into two groups: those that had signed international treaties and those that had not. International treaties, as mentioned earlier, typically call for cross-national cooperation, joint management, and the sustainable use of shared water resources within a basin. Therefore, dams located in treaty basins are more likely to benefit from superior management practices, such as precise precipitation forecasting and more responsible water release during dry seasons.

We define an individual as a resident in a treaty basin if, and only if, her residing river basin had signed at least one international treaty before her birth year. Concerns may arise regarding the pre-existing differences between treaty and non-treaty basins. However, our approach exploits time variations to mitigate the concern. A non-treaty basin will become a treaty basin once an international treaty is signed for it, which allows us to compare females living in the same basins but are classified into different types of basins.

We examine the effect of dams on households' time use in water collection, and females' years of schooling by basin types. The results shown in Table 9 suggest that in basins that have not been protected by an international treaty (non-treaty basins), the presence of dams significantly led to increased time use in water fetching (column 1 & 5), and then fewer years of schooling for adult females (column 7). In contrast, for those in basins that have been protected by international treaties (treaty basins), such negative effects associated with dams were mitigated (columns 2, 6, 8).

Table 9: The Effect of Dams on Water Accessibility and Years of Schooling by Management (Downstream)

	Dependent Variables:							
	Log(1+Time Spent on Water Fetching)		I(Water Time > 0)		Log(Time Spent on Water Fetching) | I(Water Time > 0)		Years of Schooling	
By Basin Types:	Non-treaty	Treaty	Non-treaty	Treaty	Non-treaty	Treaty	Non-treaty	Treaty
Nearby	14.552***	−0.068	1.009***	−0.015*	−0.081	−0.024	0.318	0.412**
	(2.641)	(0.054)	(0.279)	(0.009)	(117241.413)	(0.054)	(0.375)	(0.204)
Post	−0.736	0.036	0.038	−0.005	−0.914	0.060		
	(0.464)	(0.085)	(0.027)	(0.010)	(0.569)	(0.090)		
Nearby*Post	0.777*	0.096	0.003	0.008	0.914*	0.086		
	(0.406)	(0.091)	(0.005)	(0.016)	(0.490)	(0.085)		
Exposed_Cohort							1.077***	0.212
							(0.391)	(0.375)
Nearby*Exposed_Cohort							−1.537***	−0.872*
							(0.439)	(0.492)
Mean	2.073	2.472	0.652	0.856	3.113	2.803	5.231	2.353
Household Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Country*Cohort FEs	No	No	No	No	No	No	Yes	Yes
Obs	4895	11644	4895	11644	3085	9966	4135	1635
Adj.R^2	0.839	0.681	0.985	0.959	0.317	0.238	0.698	0.537

Note: The table reports the differetial effect of dams construction on households' time spent on water collection, and years of schooling of females in Africa by basins have/have not been protected by international freshwater treaty. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

Overall, the findings underscore the negative impact of dams is particularly severe in non-treaty basins, where the regulation of dams' operation is not sound. This highlights the critical role of effective dam management and regulation in mitigating adverse consequences.

8 Conclusion

In conclusion, our study provides important insights into the unintended consequences of dam construction on gender dynamics and women's education in Africa. We find that dams have a significant negative impact on the education of females residing in downstream areas, leading to a reduction in their years of schooling. The decrease in schooling later led to increased total fertility and less satisfied spouse of females . However, males were not affected by dams. Our findings further indicate that the gender unbalanced effect is larger for societies with entrenched patriarchal gender norms.

We identify a primary mechanisms through which dams discourage females to get education: increased time use in water collection due to the reduced groundwater storage led by dams. We also find that the disruption of education caused by dams usually happened at the age of 8-10.

The promising part of this story is that sound management of dams can largely alleviate the adverse effect of dams on both environment and local females' education. We find in river basins that had been protected by international freshwater treaties, the negative effect of dams are smaller and less significant.

The findings of our study have significant policy implications. Addressing the gender inequalities arising from dam construction is crucial for achieving the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 5 (Gender Equality). Policymakers and stakeholders need to consider the broader social and economic implications of dam construction and prioritize strategies that promote gender equality and empower women. This includes improving water accessibility, and addressing patriarchal norms that hinder girls' educational opportunities. By aligning dam construction with the goals of sustainable development, African countries can foster inclusive and equitable development.

Moreover, this paper emphasizes the pivotal role of water in developing countries, and its policy implications extend beyond the scope of dams or infrastructure. For example, low-carbon technologies, except wind and solar photovoltaic (PV), are relatively water-intensive. This paper underscores the importance of carefully evaluating the gender-asymmetric costs associated with such projects.

While our study provides valuable insights, there are avenues for further research. Future studies can explore the long-term impacts of dam construction on women's educational attainment and their later life outcome — marriage and fertility. Additionally, investigating the differential effects of dams across different regions and countries in Africa would provide a more nuanced understanding of the issue. Furthermore, examining the potential interactions between dam construction and other factors influencing gender inequality, such as access to healthcare and economic opportunities, would contribute to a comprehensive understanding of the challenges faced by women in the context of development projects.

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Appendix A Data Source

Table A.1: Data Source and Variable Description

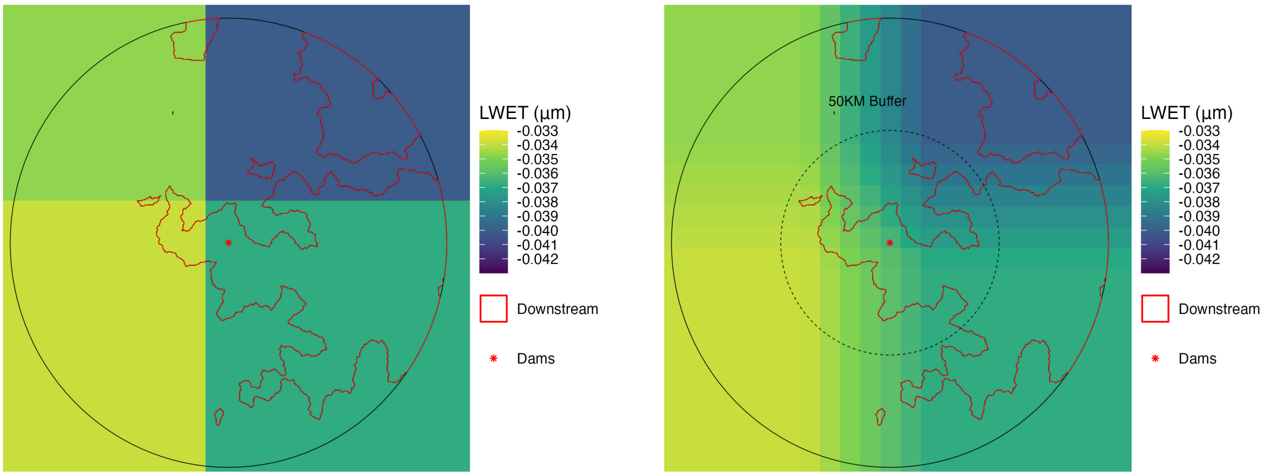
Variable Name	Description	Data Source
Panel A: Topography and Climate Data		
cropland	Share of cropland	Global Agro-Ecological Zones v4 Theme 1
irrland	Share of irrigated land	Global Agro-Ecological Zones (GAEZ) v4 Theme 1
GloSlopesCl1_30as	Share of land whose terrain slope belongs to $0\% \leq slope \leq 0.5\%$	Harmonized World Soil Database v1.2
GloSlopesCl2_30as	Share of land whose terrain slope belongs to $0.5\% \leq slope \leq 2\%$	Harmonized World Soil Database v1.2
GloSlopesCl3_30as	Share of land whose terrain slope belongs to $2\% \leq slope \leq 5\%$	Harmonized World Soil Database v1.2
GloSlopesCl4_30as	Share of land whose terrain slope belongs to $5\% \leq slope \leq 10\%$	Harmonized World Soil Database v1.2
GloSlopesCl5_30as	Share of land whose terrain slope belongs to $10\% \leq slope \leq 15\%$	Harmonized World Soil Database v1.2
GloSlopesCl6_30as	Share of land whose terrain slope belongs to $15\% \leq slope \leq 30\%$	Harmonized World Soil Database v1.2
GloSlopesCl7_30as	Share of land whose terrain slope belongs to $30\% \leq slope \leq 45\%$	Harmonized World Soil Database v1.2
GloSlopesCl8_30as	Share of land whose terrain slope belongs to $slope > 45\%$	Harmonized World Soil Database v1.2
climates_f	Climate Zone Classification	Digitized World Map of the Köppen-Geiger Climate Classification
Lithology	Classification of ecological lithology	African Surface Lithology
Panel B: Socioeconomic Data		
male_domnt_h	Degree of male dominance in main production activity (1-5)	Atlas of Pre-Colonial Societies (Atlas)
patri_descent	Had partilineal descent	Atlas of Pre-Colonial Societies (Atlas)

Continued on the next page

Table A.1 Data Source and Variable Description (Cont′)

Variable Name	Description	Data Source
patri_heir	Had partilineal heir	Atlas of Pre-Colonial Societies (Atlas)
pop	Population count (1990, 1995, 2000, 2005, 2010, 2015, and 2020)	Gridded Population of the World Version 3 and 4 (GPW v3 and v4) datasets sourced by NASA.
dist_roads_m	Distance to the nearest road (m)	Global Roads Open Access Data Set (gROADSv1)
num_school	# schools	"My School Today" project hosted by OpenStreatMap
NPP	Net primary production	Terra Net Primary Production Gap-Filled Yearly Global 500m sourced by MODIS
Panel C: International Freshwater Treaties Data		
treaty_cohort	Whether the basin was protected by an international treaty at the time an individual was at school age	The International Freshwater Treaties Database, hosted by Oregon State University, and Bakker (2007)

Appendix B Figure and Tables



(a) LWET at a resolution of 0.5*0.5 degrees

(b) LWET at a resolution of 0.1*0.1 degrees

Figure B.1: Illustration of re-scaling of LWET grid cells.

Table B.1: Summary Statistics

Statistic	**Mean**	**St. Dev.**	**N**
Panel A: Dams Characteristics			
Height (m)	40.400	33.554	30
Reservoir capacity (million m3)	81.161	153.490	47
Reservoir area (km2)	15.904	25.418	15
Panel B: Children Characteristics (Age 6-14)			
Female	0.481	0.500	129,535
Age	9.656	2.564	129,535
Age at dam completion	4.327	10.022	129,535
Post	0.742	0.437	129,535
Years of schooling	1.528	2.082	129,535
Mother alive	0.979	0.144	129,535
Father alive	0.961	0.193	129,535
# sisters	1.982	1.618	129,535
# brothers	2.403	1.911	129,535
Panel C: Geographical Characteristics of Villages			
Elevation	570.657	625.490	2,095
Land slope (%):			
0%-0.5%	9.231	7.999	2,095
0.5%-2%	56.983	27.072	2,095
2%-5%	21.868	19.255	2,095
5%-10%	5.991	14.164	2,095
10%-15%	2.568	7.691	2,095
15%-30%	2.510	9.438	2,095
30%-45%	0.621	4.084	2,095
Land cover (%):			
Cropland	36.468	19.230	2,095
Irrigated Land	0.853	4.050	2,095
Distance to (m):			
Dams	58,818.480	25,697.360	2,095
Rivers	3,228.201	4,241.147	2,095
Stem rivers	44,447.450	37,548.600	1,967
Roads	2,586.735	2,913.019	2,095

Continued on the next page

Table B.1 Summary Statistics (Cont′)

Statistic	**Mean**	**St. Dev.**	**N**
Groundwater storage (%):			
Lowest	68.4	0.465	2,095
Medium low	14.7	0.355	2,095
Medium	11.8	0.323	2,095
High	5.0	0.218	2,095
Very high	0.05	0.022	2,095
Panel D: Water, Grain Production, and Population			
Land Water Equivalent Thickness (μm)	0.614	20.696	460,708
Precipitation (mm)	56.498	74.052	460,708
Water Body (%)	0.005	0.036	460,708
Net Primary Production (gC/m2yr)	2,005.166	4,058.043	92,293
Population size	416.924	2,204.497	109,704
# Schools	0.468	3.779	15,672

Table B.2: Balance Check

Variables	**0-50 KM**	**50-100 KM**	**Diff. in Mean**	**Diff. (+FEs)**
Panel A: Individual Characteristics (Age 15-35)				
Female	0.513 (0.5)	0.429 (0.495)	0.09	0.005 (0.014)
Age	26.411 (8.335)	28.594 (9.348)	-2.18	-0.063 (0.115)
Age at dam completion	24.69 (5.691)	24.353 (5.806)	0.34	0 (0)
Years of schooling	5.795 (5.157)	2.474 (3.991)	3.32	0.119 (0.137)
Maritus:				
Single	0.504 (0.5)	0.308 (0.462)	0.20	0.007 (0.011)
Married/Cohabit	0.445 (0.497)	0.643 (0.479)	-0.20	-0.013 (0.012)
Divorced	0.041 (0.199)	0.033 (0.178)	0.01	0.004 (0.003)
Widowed	0.01 (0.1)	0.016 (0.125)	-0.01	0.001 (0.003)
Females Only				
Height at age percentiles	21.99 (23.297)	29.547 (27.102)	-7.56	1.599 (2.45)
Age at first marriage	17.273 (4.489)	16.06 (3.397)	1.21	0.32 (0.189)*
Underage marriage	0.409 (0.492)	0.688 (0.463)	-0.28	-0.011 (0.033)
Age at first birth	19.12 (4.348)	18.397 (3.559)	0.72	0.201 (0.306)
Total fertility	1.979 (2.696)	4.083 (3.159)	-2.10	0.097 (0.152)
Husband Characteristics:				
Age	38.729 (12.064)	42.946 (12.278)	-4.22	0.061 (0.686)
Years of schooling	4.554 (5.497)	2.31 (4.338)	2.24	0.122 (0.289)
Land ownership	0.737 (0.632)	0.659 (0.588)	0.08	-0.035 (0.083)
Panel B: Children Characteristics (Age 6-14)				
Female	0.466 (0.499)	0.473 (0.499)	-0.01	0.005 (0.006)
Age	9.7 (2.55)	9.612 (2.551)	0.09	0.024 (0.024)
Age at dam completion	16.972 (4.653)	18.413 (5.212)	-1.44	0.024 (0.024)
Years of schooling	1.671 (2.171)	1.114 (1.849)	0.56	-0.005 (0.07)
Mother alive	0.972 (0.164)	0.976 (0.154)	-0.00	-0.002 (0.003)
Father alive	0.954 (0.209)	0.968 (0.176)	-0.01	0.005 (0.004)
# Sisters	1.915 (1.523)	1.995 (1.627)	-0.08	-0.059 (0.064)
# Brothers	2.343 (1.824)	2.472 (1.883)	-0.13	-0.088 (0.084)
Panel C: Household Characteristics				
# Members	5.532 (3.133)	6.012 (3.37)	-0.48	0.039 (0.115)

Continued on the next page

Table B.2 Balance Check (Cont′)

Variables	**0-50 KM**	**50-100 KM**	**Diff. in Mean**	**Diff. (+FEs)**
# Women	1.323 (0.809)	1.298 (0.835)	0.02	-0.007 (0.034)
# Children	1.063 (1.093)	1.421 (1.197)	-0.36	0.034 (0.035)
Water Sources:				
Piped	0.39 (0.488)	0.154 (0.362)	0.23	0.002 (0.01)
Well	0.463 (0.499)	0.669 (0.471)	-0.21	0.022 (0.025)
Surface	0.122 (0.328)	0.159 (0.366)	-0.04	-0.02 (0.016)
Rainfall	0.003 (0.052)	0.004 (0.066)	-0.00	-0.003 (0.002)
Water on premises	0.113 (0.316)	0.043 (0.203)	0.07	-0.007 (0.005)
Water time (mins)	29.603 (50.457)	30.828 (47.53)	-1.23	2.056 (1.036)**
Materials of floor:				
Earth	0.646 (0.478)	0.741 (0.438)	-0.10	-0.018 (0.014)
Rudimentary	0.019 (0.137)	0 (0.021)	0.02	0 (0)
Polished	0.335 (0.472)	0.258 (0.438)	0.08	0.018 (0.014)
Electricity	0.289 (0.454)	0.044 (0.206)	0.24	0.03 (0.02)
Appliances	0.587 (0.493)	0.477 (0.5)	0.11	0.002 (0.008)
Vehicles	0.211 (0.408)	0.355 (0.479)	-0.14	0.016 (0.015)
Wealth	3.035 (1.65)	2.425 (1.403)	0.61	2.375 (0.402)***

Table B.3: Triple DID: The Effect of Dams on the Years of Schooling

	Dependent Variable: Years of Schooling	
	Females	Males
Nearby	-0.349	0.146
	(0.361)	(0.104)
Downstream	-0.423	0.048
	(0.267)	(0.087)
Exposed_Cohort	0.431	0.423^{**}
	(0.375)	(0.177)
Nearby*Downstream	1.189^{***}	0.067
	(0.362)	(0.103)
Nearby*Exposed_Cohort	0.095	-0.325
	(0.506)	(0.253)
Downstream*Exposed_Cohort	0.268	-0.042
	(0.393)	(0.226)
Nearby*Downstream*Exposed_Cohort	-1.485^{**}	-0.094
	(0.586)	(0.374)
Mean	3.918	4.071
Personal Controls	Yes	Yes
Geographic Controls	Yes	Yes
Dam FEs	Yes	Yes
Subbasin FEs	Yes	Yes
Phase FEs	Yes	Yes
Country*Cohort FEs	Yes	Yes
Obs	8784	12385
Adj.R^2	0.660	0.521

Note: The table reports the effect of dams construction on the years of schooling of girls and boys in Africa. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

Table B.4: The Effect of Dams on Children's Years of Schooling within Households

	Dependent Variables: Years of Schooling					
	Girls		Boys			
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Nearby	0.666^{**}	0.087	0.398	0.033	−0.024	−0.010
	(0.303)	(0.233)	(0.273)	(0.232)	(0.019)	(0.023)
<=Age12	−0.023	0.190	−0.045	0.185		
	(0.159)	(0.143)	(0.166)	(0.136)		
Nearby*<=Age12	-0.687^{**}	−0.088	−0.409	−0.033		
	(0.311)	(0.239)	(0.283)	(0.237)		
Girl					−0.463	−0.541
					(249.442)	(398.649)
Post					-0.073^{***}	-0.068^{***}
					(0.022)	(0.021)
Nearby*Post					0.045	−0.009
					(0.028)	(0.030)
Nearby*Girl					0.055	0.018
					(0.041)	(0.046)
Girl*Post					0.165^{***}	0.142^{***}
					(0.048)	(0.043)
Nearby*Girl*Post					-0.103^{*}	0.022
					(0.061)	(0.060)
Mean	1.959	1.62	2.034	1.781	2.002	1.677
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes
Household FEs	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	No	No
Country*Year FEs	No	No	No	No	Yes	Yes
Obs	18861	23918	22167	27918	65676	77124
Adj.R^2	0.729	0.701	0.683	0.668	0.675	0.637

Note: The table reports the effect of dams on children's years of schooling within households. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

Table B.5: The Effect of Dams on Migration and School Distribution

	Dependent Variables:							
	Log(1+Population)		I(Post Migration)		Years of Schooling		# of Schools	
	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream	Downstream	Upstream
Nearby	0.036***	0.012*	−0.005	−0.002			−0.010	0.086
	(0.009)	(0.006)	(0.006)	(0.007)			(0.017)	(0.083)
Post	0.016	0.005	0.003	−0.007				
	(0.010)	(0.006)	(0.006)	(0.006)				
Nearby*Post	−0.059***	−0.019*	0.007	0.007				
	(0.014)	(0.010)	(0.010)	(0.010)				
PostDamMigration					−0.167	0.037		
					(0.129)	(0.123)		
Mean	4.327	4.449	0.912	0.908	4.166	3.028	0.323	0.602
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FEs	Yes	Yes	No	No	No	No	No	No
Subbasin FEs	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Obs	52724	56980	790917	619382	27273	21358	7532	8140
Adj.R^2	0.960	0.977	0.186	0.207	0.418	0.384	0.431	0.572

Note: The table reports the migration pattern after dam construction in Africa. All standard errors are clustered at the village level. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table B.6: Alternative Choices of Treatment Buffers

	Dependent Variable: Years of Schooling							
	Downstream				Upstream			
	Baseline	30KM	40KM	60KM	Baseline	30KM	40KM	60KM
Buffer_50	0.959***				−0.727			
	(0.325)				(0.671)			
Exposed_Cohort	0.712**	0.540**	0.537**	0.677**	−0.135	−0.318	−0.333	0.078
	(0.283)	(0.258)	(0.273)	(0.299)	(0.416)	(0.404)	(0.408)	(0.445)
Buffer_50*Exposed_Cohort	−1.218***				−0.142			
	(0.346)				(0.480)			
Buffer_30		0.263				−0.562		
		(0.424)				(0.759)		
Buffer_30*Exposed_Cohort		−1.523***				1.490**		
		(0.400)				(0.692)		
Buffer_40			0.313				−1.306**	
			(0.405)				(0.564)	
Buffer_40*Exposed_Cohort			−1.052***				0.826	
			(0.356)				(0.554)	
Buffer_60				−1.065*				−0.433
				(0.604)				(0.677)
Buffer_60*Exposed_Cohort				−0.972***				−0.621
				(0.342)				(0.446)
Mean	4.416	4.416	4.416	4.416	2.964	2.964	2.964	2.964
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	5770	5770	5770	5770	3014	3014	3014	3014
Adj.R^2	0.673	0.674	0.673	0.674	0.627	0.629	0.629	0.628

Note: The table reports the effect of dams construction on the years of schooling of adult females in Africa. All standard errors are clustered at the sub-basin level. *p<0.1; **p<0.05; ***p<0.01

Table B.7: Robustness Checks on Sample Restrictions (Downstream)

	Dependent Variable: Years of Schooling							
	Distance to Dams					Distance to Stem Rivers	Dam Sequence	
	No 0-1KM	No 0-2KM	No 0-3KM	No 0-4KM	No 0-5KM	Within 30KM	First Dam	Second Dam
Nearby	1.148***	1.148***	1.150***	1.198***	1.198***	0.953***	−6.141	13.857
	(0.378)	(0.378)	(0.378)	(0.382)	(0.382)	(0.349)	(3.877)	(11.848)
Exposed_Cohort	0.719**	0.719**	0.727**	0.716**	0.716**	0.320	0.910***	−1.969*
	(0.283)	(0.283)	(0.283)	(0.283)	(0.283)	(0.350)	(0.337)	(1.016)
Nearby*Exposed_Cohort	−1.225***	−1.225***	−1.231***	−1.235***	−1.235***	−0.956**	−1.429***	0.311
	(0.348)	(0.348)	(0.348)	(0.349)	(0.349)	(0.407)	(0.387)	(0.734)
Mean	4.414	4.414	4.406	4.4	4.4	3.378	4.686	1.686
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Cohort FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	5765	5765	5758	5736	5736	3258	5251	519
Adj.R^2	0.673	0.673	0.673	0.673	0.673	0.618	0.669	0.557

Note: The table reports the effect of dams construction on the years of schooling of girls in Africa. All standard errors are clustered at the village level. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table B.8: The Effect of Dams on Health (Downstream)

	Girls				Boys				Females (15-35)
Dependent Variables:	Diarrhea	Fever	Cough	Anemia	Diarrhea	Fever	Cough	Anemia	Height for Age Percentiles
Nearby	0.015	0.011	0.022^{*}	0.003	0.013	−0.004	−0.002	0.027^{**}	13.032
	(0.011)	(0.013)	(0.013)	(0.009)	(0.013)	(0.013)	(0.012)	(0.011)	(229.025)
Post	0.003	-0.038^{*}	−0.030	0.008	−0.023	−0.019	−0.020	0.011	
	(0.020)	(0.022)	(0.023)	(0.016)	(0.022)	(0.023)	(0.019)	(0.019)	
Nearby*Post	-0.026^{*}	−0.020	−0.006	−0.014	−0.024	−0.007	0.012	-0.027^{*}	
	(0.014)	(0.017)	(0.017)	(0.013)	(0.018)	(0.018)	(0.017)	(0.015)	
Exposed_Cohort									−65.473
									(176.865)
Nearby*Exposed_Cohort									365.932^{**}
									(178.256)
Mean	0.172	0.273	0.192	0.134	0.194	0.291	0.200	0.148	2034.601
Personal Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country*Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
Country*Cohort FEs	No	No	No	No	No	No	No	No	Yes
Obs	14943	14932	14926	14979	15710	15715	15715	15753	5770
Adj.R^2	0.082	0.107	0.117	0.373	0.090	0.115	0.113	0.389	0.198

Note: The table reports the effect of dams construction on individual's health in Africa. All standard errors are clustered at the village level. *p<0.1; **p<0.05; ***p<0.01

Table B.9: The Income Effect of Dams

	Production	Household Asset Ownership						
Dependent Variable:	NPP	Wealth	Electricity	Radio	Refrigerator	Television	Telephone	Vehicles
Panel A: Downstream								
Nearby	-10.540^{**}	-0.187	0.026	-0.012	-0.023	-0.065^{***}	0.007	-0.023
	(4.541)	(0.268)	(0.029)	(0.023)	(0.017)	(0.023)	(0.014)	(0.021)
Post	-60.076^{***}	-0.017	0.075^{**}	0.020	0.018	0.011	0.017	-0.007
	(9.347)	(0.241)	(0.033)	(0.030)	(0.017)	(0.022)	(0.018)	(0.033)
Nearby*Post	17.816^{**}	0.312	-0.007	-0.022	0.062^{***}	0.124^{***}	0.013	-0.023
	(7.675)	(0.285)	(0.041)	(0.036)	(0.024)	(0.029)	(0.019)	(0.031)
Mean	2385.387	2.831	0.287	0.575	0.108	0.22	0.045	0.34
Obs	43078	12202	16872	16871	16060	16858	15437	16773
Adj.R^2	0.996	0.678	0.620	0.193	0.320	0.474	0.189	0.353
Panel B: Upstream								
Nearby	5.827	0.294^{**}	0.024	0.042	0.011	0.039^{*}	-0.010	-0.022
	(4.881)	(0.135)	(0.045)	(0.036)	(0.018)	(0.023)	(0.013)	(0.025)
Post	146.552^{***}	-0.057	-0.020	-0.033	-0.007	-0.028	-0.008	0.022
	(11.663)	(0.285)	(0.047)	(0.050)	(0.023)	(0.028)	(0.015)	(0.027)
Nearby*Post	-8.668		-0.106^{*}	-0.062	-0.021	-0.026	0.003	-0.017
	(7.260)		(0.061)	(0.059)	(0.016)	(0.026)	(0.015)	(0.028)
Mean	1678.06	2.534	0.211	0.572	0.068	0.166	0.021	0.496
Obs	49215	8601	11632	11682	11447	11676	10521	11615
Adj.R^2	0.996	0.641	0.475	0.189	0.306	0.328	0.090	0.389
Household Controls	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Dam FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Subbasin FEs	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cell FEs	Yes	No	No	No	No	No	No	No
Country*Year FEs	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Note: The table reports the effect of dams construction on the water sources of households in Africa. All standard errors are clustered at the village level. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$