Title: *Nature can deliver on the SDGs*

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In 2015 the United Nations adopted 17 Sustainable Development Goals (SDGs), aiming to "protect the planet from degradation... so that it can support the needs of the present and future generations" [1]. The SDGs recognize that conservation, in providing goods like water and fiber and global public goods like habitat for species and mitigation of climate change, directly supports human health and well-being [1,2]. While real tradeoffs can indeed arise between conservation and economic development, the recent *Rockefeller Foundation-Lancet Report on Planetary Health* states unequivocally that "the environment has been the foundation of human flourishing", suggesting that if environmental degradation persists then ongoing improvements in human health are likely to be reversed [3].

The increasing availability of data and improved analytic techniques now enable us to better understand when and where investing in nature can deliver net benefits for people − especially with respect to the most vulnerable populations in developing countries. These advances open the door for efficient interventions that can advance multiple SDGs at once. Recently, we harmonized a suite of global datasets to explore the critical nexus of forests, poverty and human health – an overlap of SDGs 1, 2, 3, 6 and 15. Our approach combined demographic and health surveys for 297,112 children in 35 developing countries with data describing the local environmental conditions for each child[4] (Fig. 1a; see online materials for details). This allowed us to estimate the effect forests may play in supporting human health, while controlling for the influence of important socio-economic differences. We extended this work to look at how forests affect three childhood health concerns of global significance – stunting, anemia, and diarrheal disease.

We found that, for the poorest households in these 35 countries, forest cover is associated with reduced prevalence of all three childhood maladies, after controlling for potential confounding variables (e.g. education, rainfall) (Fig. 1b). Among children in the two lowest wealth quintiles, those who live in areas with more forest cover were significantly less likely to experience these diseases than those living in areas with less forest cover. For children in the two highest wealth quintiles, in contrast, we found no relationship between forest cover and any of these health outcomes. We also found that as the amount of upstream forest cover increases, the benefits of reduced disease prevalence for the poor increase, particularly for those poor households without access to improved water sources (see online materials Figs S1-S8). These findings suggest that the poorest populations are least capable of replacing natural capital with technology or infrastructure, and are therefore disproportionately impacted by the degradation of natural ecosystems.

The particular mechanisms through which forest cover can positively affect health outcomes appear to vary among contexts and diseases[5-7], and gaining a deeper understanding of these causal mechanisms will be critical in making effective environmental or health interventions[2,3]. Nonetheless, the positive signal we get from forests in these analyses is notable, given that the combined global impacts of diarrhea, anemia, and stunting on the world's children are devastating and the world’s forests are steadily disappearing. Diarrheal disease is the second leading cause of childhood mortality globally, killing more children than malaria, AIDS, and measles combined[8]. Iron-deficiency anemia, the world’s most common form of anemia, plays a role in 20% of maternal deaths[7]. Childhood stunting affects over 160 million children worldwide, often limiting physical and cognitive growth for life[8]. Investing in ecosystem conservation and/or restoration, when done right, therefore may not only improve childhood health outcomes across much of the developing world where forests are in decline, but also help to weaken the poverty-health trap in which many of the world's poor find themselves.

Although the forest-health connection demonstrated here is a powerful one, relationships among nature, poverty, and human health go far beyond those we have illustrated. Other empirical studies have quantified relationships between fisheries and nutrient deficiencies[9], between forest protection and malaria[7] and between bushmeat availability and anemia[10]. Given the strong relationships among well-functioning ecological systems, poverty, and human health, it is critical that we understand how natural resource management and conservation can advance multiple SDGs.

Clearly understanding these relationships is not an easy task. The database we built took over three years to build, clean and operationalize. The complexity of the nature-human health relationship necessitated deep thinking around our theoretical models to control for factors that confound these relationships and reflect the differentiated impacts of local versus regional environmental processes. Nonetheless, it must become routine for governments, aid agencies, and other organizations investing in economic development to seek and utilize the data to minimize tradeoffs and seek co-benefits among environmental, human health and equity outcomes.

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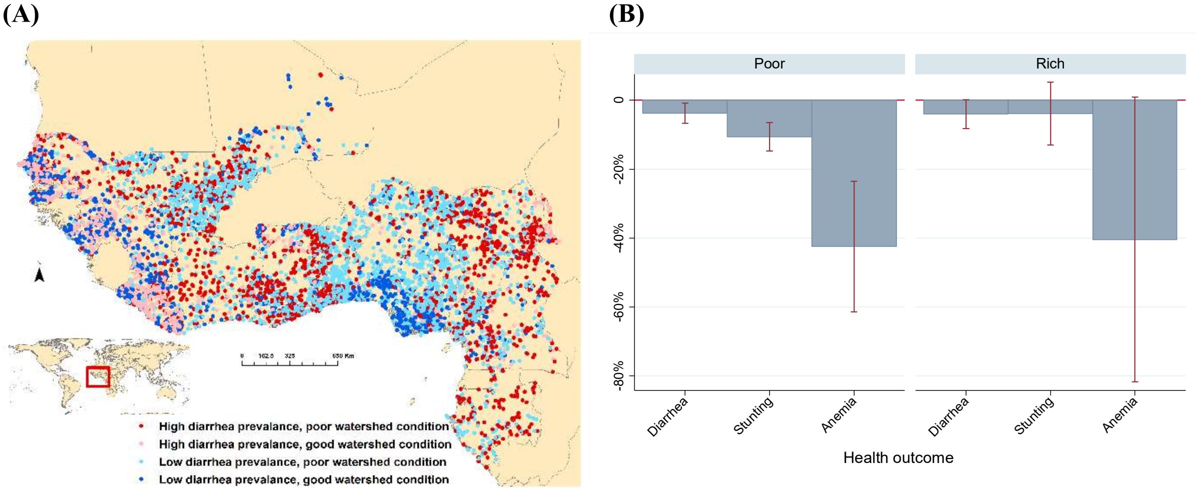
Fig. 1. Nature, health, poverty relationships (A) Diarrhea prevalence and watershed condition for a subset of our database in western Africa. Areas with high diarrhea prevalence and poor watershed conditions (red circles); areas with high diarrhea prevalence and good watershed conditions (pink circles); areas with low diarrhea prevalence and good watershed conditions (dark blue circles); areas with low diarrhea prevalence and poor watershed conditions (light blue circles). **(B)** Percent reduction in the probability of diarrhea, stunting and anemia given a 30% increase in our tree cover variables. Our global model predicts significant reductions in all three childhood diseases in the poorest two quintiles of households, but no such effects on the richest two quintiles. [Error bars - 95% CIs].

(A) **(B)**



Online Materials for
Nature can deliver on the SDGs

This Document Contains:
Materials and Methods
Figures S1-S8

Supplementary Information

Methods

Using a sample of 297,112 children in 35 developing countries we analyzed the determinants of three health outcomes: diarrhea, severe stunting and severe anemia. Our dataset includes key socioeconomic and demographic factors that affect children's health, as well as climatic and environmental conditions of the village where the child was living at the time of the survey. Controlling for these factors we focused on the effect of forest variables across subsets of the data with different levels of household wealth.

Model Variables

Health outcomes. Our three outcome variables for diarrhea, severe stunting and severe anemia are binary and come from the DHS surveys. Diarrhea indicates if the child had diarrhea in the last two weeks. Severe stunting is based on height/age and indicates a level of stunting of more than three standard deviations below the reference level. Cases of severe anemia are identified directly in the DHS surveys be measuring hemoglobin levels.

*Age***.** Age of the child in months.

Wealth. DHS data includes a wealth index, which is a composite measure of a household's living standard based on a set of household assets. We used the categorical version of this variable representing wealth quintiles.

Education. The surveys also provide the level of education of the mother. This is a standardized variable providing level of education in the following categories: No education, Primary, Secondary, Higher. With this information we defined a binary variable for households with secondary education or higher.

Improved Toilet and Water. DHS identifies different types of drinking water infrastructure and toilet for each household. We group these categories into broader improved or unimproved sanitation binary measures based on WHO/JMP definitions which allow comparisons across countries with more confidence.

Precipitation and Temperature. The temperature variable in our dataset is the mean temperature in the cluster during the survey month in degrees Celsius. Precipitation is measured in mm and represents the mean precipitation in each cluster during the survey month. Both variables were included in the model as standardized z scores.

Watershed conditions: influence of upstream livestock and people (human activity) and influence of upstream tree cover. We develop two hydrologic measures of watershed condition and their influence on water quality. These metrics estimate the percent of water at any point in a river network that fell as rain on any defined land use category. The first variable measures the potential influence of upstream people and livestock on water quality. Index values of 0 mean no presence of human or livestock inputs *or* no water. A value of 100% indicates that all water in the current pixel fell as rain on land used for human population or livestock. The second variable measures the potential influence of upstream tree cover on water quality. Similar to human activity, for each pixel the percent of water falling as rain on forested areas is calculated and cumulated downstream as a percentage of the total cumulated water. Values of 0 for this variable mean that there is no presence of local and upstream trees or no water.

Population density in the village. Average population density in sampling cluster.

Tree cover in the cluster. Percentage tree cover in sampling cluster.

For full description of database used for this analysis see Herrera et al. (2017).

Analysis

We use mixed effects logit models with interactions between forest variables and wealth quintiles. We ran models for the three health outcomes, one including a wealth dummy variable for the two highest (variable=1) and two lowest (variable=0) wealth quintiles, i.e. *Poor vs Rich* analysis. We used random intercepts at the household and cluster level *(1)*.

For the analysis of diarrhea, the key forest variables are the watershed conditions, influence from upstream human activity and influence of upstream tree cover. This choice was made since these variable have been shown to affect water quality downstream, a major determinant of diarrhea *(1)*.

For the analysis of anemia and stunting the key environmental conditions are population density and tree cover in the cluster, since these can approximate the degree of human activity and availability of natural resources in surrounding areas.

The coefficients of non-linear models differ from the marginal effects of the explanatory variables on the outcome, as it is the case in our models. We therefore calculate marginal effects using Stata's *margins* command (values of explanatory variables held at means) after estimating the models to compare the magnitude of the change in health outcomes given a 10, 20, 30 percent change in the tree variables for *Poor vs Rich* quintiles.

For diarrhea we split the poor and rich subsets into those with improved and unimproved water infrastructure to test a particular mechanism by which upstream tree cover could be influencing health outcomes.

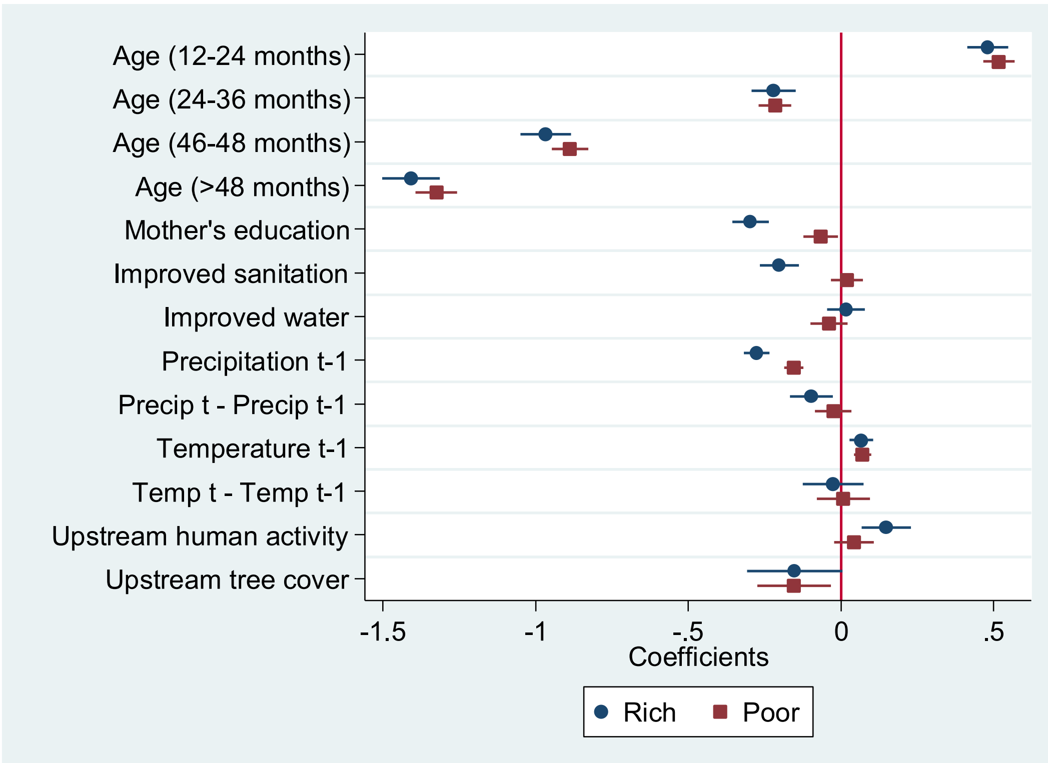
Rich vs Poor: model coefficients and marginal effects

The results of the Rich vs Poor analysis show that both socioeconomic and environmental factors are significant determinants of health outcomes. Upstream influence of trees and tree cover are statistically significant for the three health outcomes.

We then split the full sample into two groups: households in the two highest and the two lowest wealth quintiles.

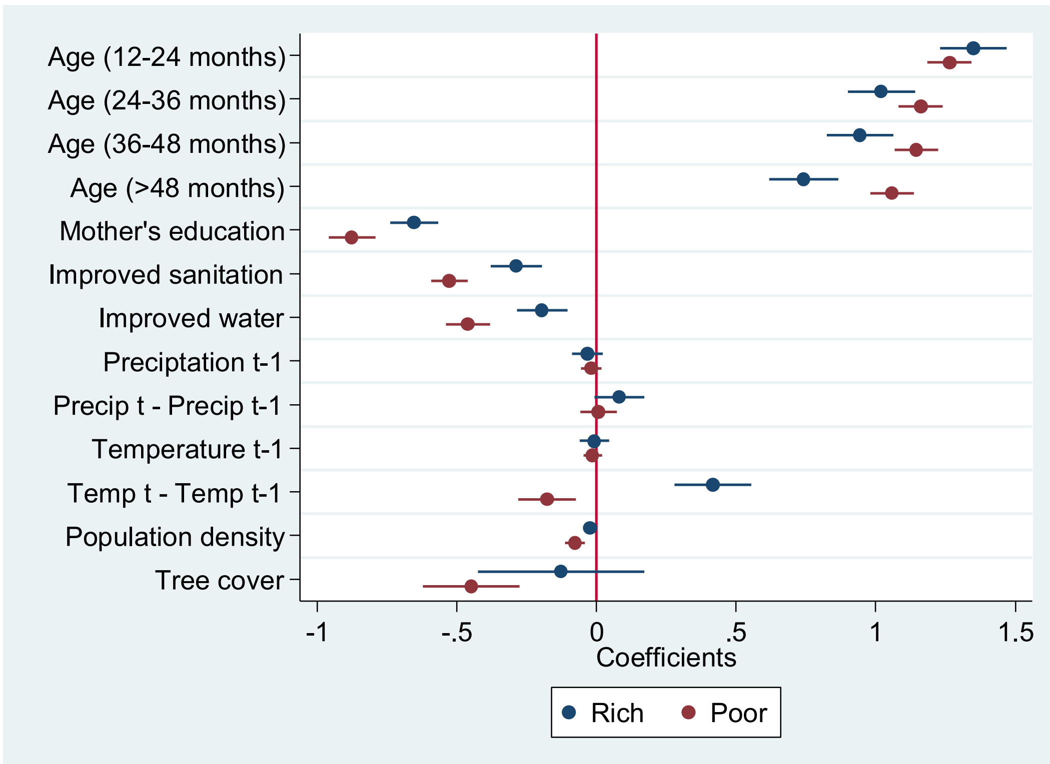
Model coefficients – Probability of Diarrhea

Fig S1. Factors associated with probability of diarrhea for rich and poor quintiles. Variables reducing the probability of diarrhea have means to the left of the red vertical line. Bars show 95% CIs.



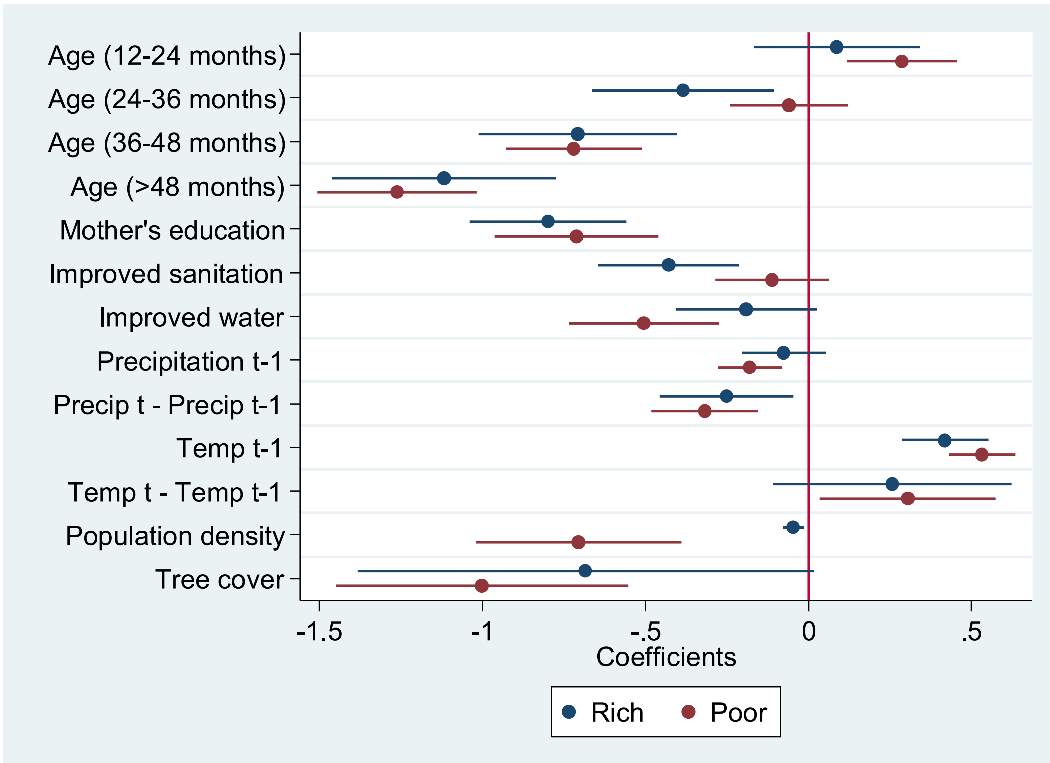
Model coefficients – Probability of Severe Stunting

Fig S2. Factors associated with probability of severe stunting for rich and poor quintiles. Variables reducing the probability of severe stunting have means to the left of the red vertical line. Bars show 95% CIs. Here we substituted the watershed variables with population density and forest cover.



Model coefficients – Probability of Severe Anemia

Fig S3. Factors associated with probability of severe anemia for rich and poor quintiles. Variables reducing the probability of severe anemia have means to the left of the red vertical line. Bars show 95% CIs. Here we substituted the watershed variables with population density and forest cover.



Marginal effects of Tree Cover

Marginal effects (reductions in the probability of each disease given 10, 20 30% changes in tree variables) show a similar trend as the model coefficients. Increases in tree cover reduce the probability of diarrhea (Fig. S4), stunting (Fig. S5) and anemia (Fig. S6) for households in the poorest two wealth quintiles, but not for household in the highest two wealth quintiles.

Fig S4. Percent reduction in the probability of diarrhea given 10, 20 and 30 percent increase in upstream tree cover and 95% CIs

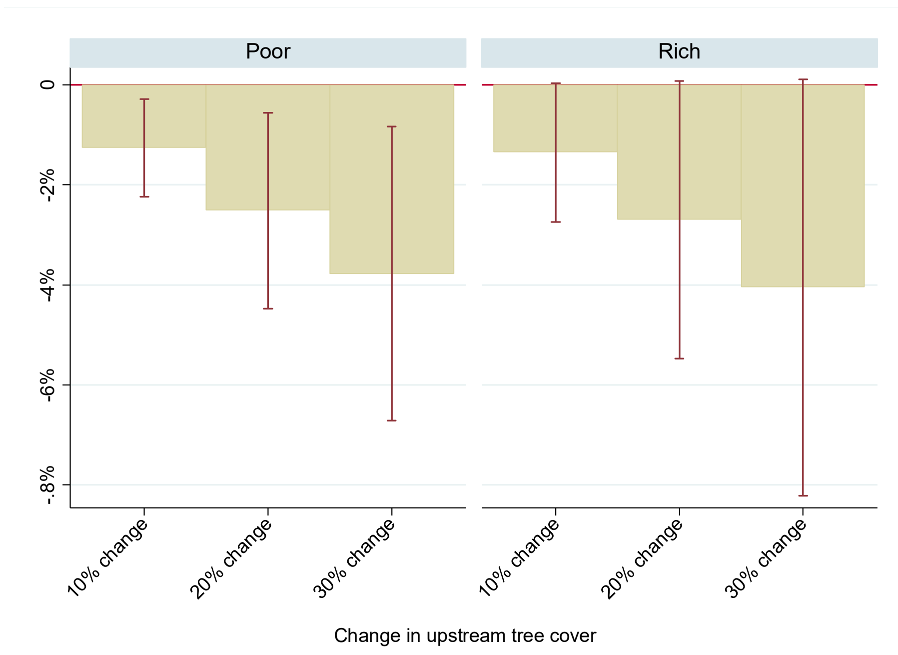


Fig S5. Percent reduction in the probability of Severe Stunting given 10, 20 and 30 percent increase in tree cover and 95% CIs

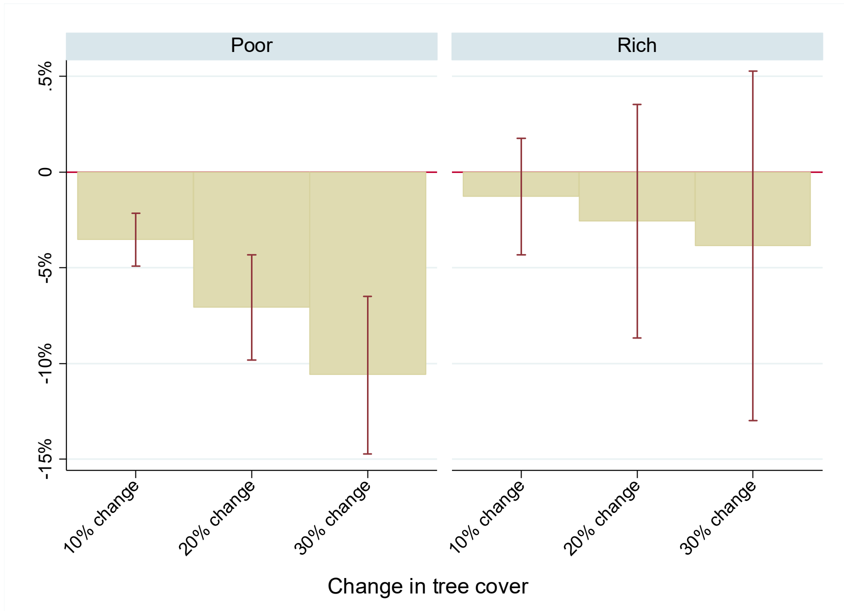
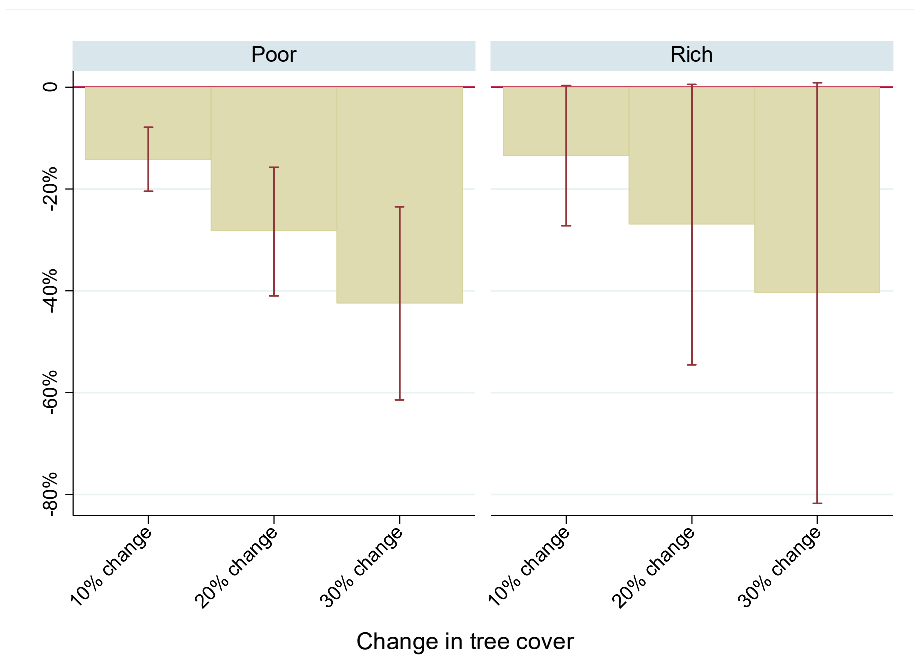


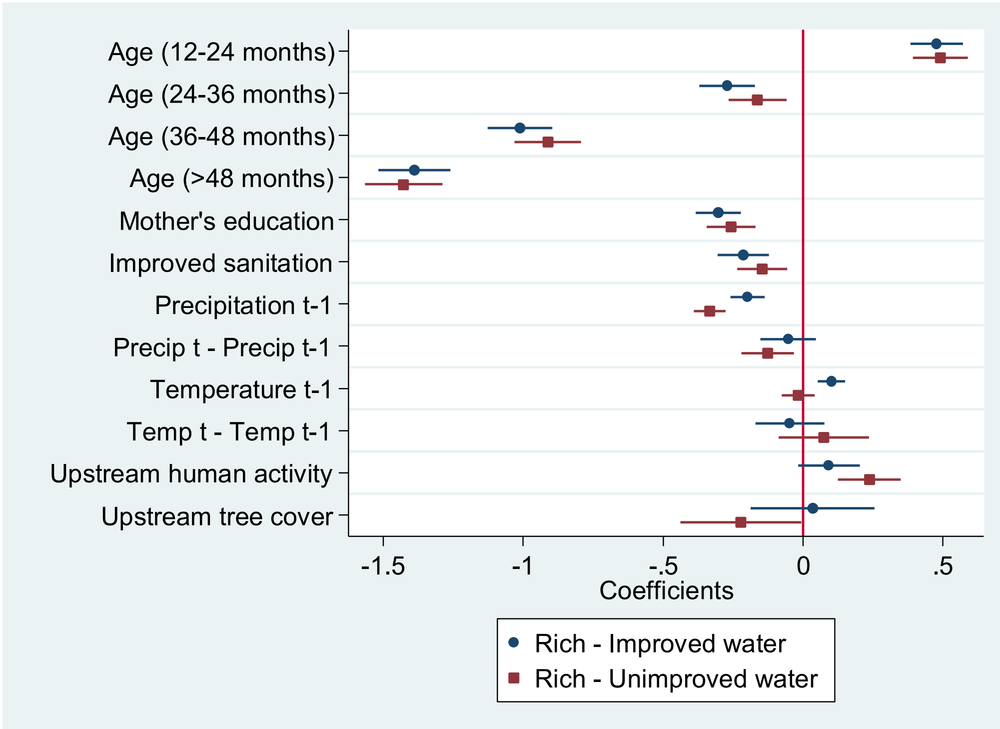
Fig S6. Percent reduction in the probability of Anemia given 10, 20 and 30 percent increase in tree cover and 95% CIs



Diarrhea: Rich – Improved/Unimproved water split

After selecting all households in the upper two wealth quintiles, we split the remaining sample into households with an improved water source (e.g. piped water), and an unimproved water source (e.g. surface water). Results show that wealthier households regardless of whether or not they have an improved water source, do not show a benefit from increased forest cover upstream (Fig S7.)

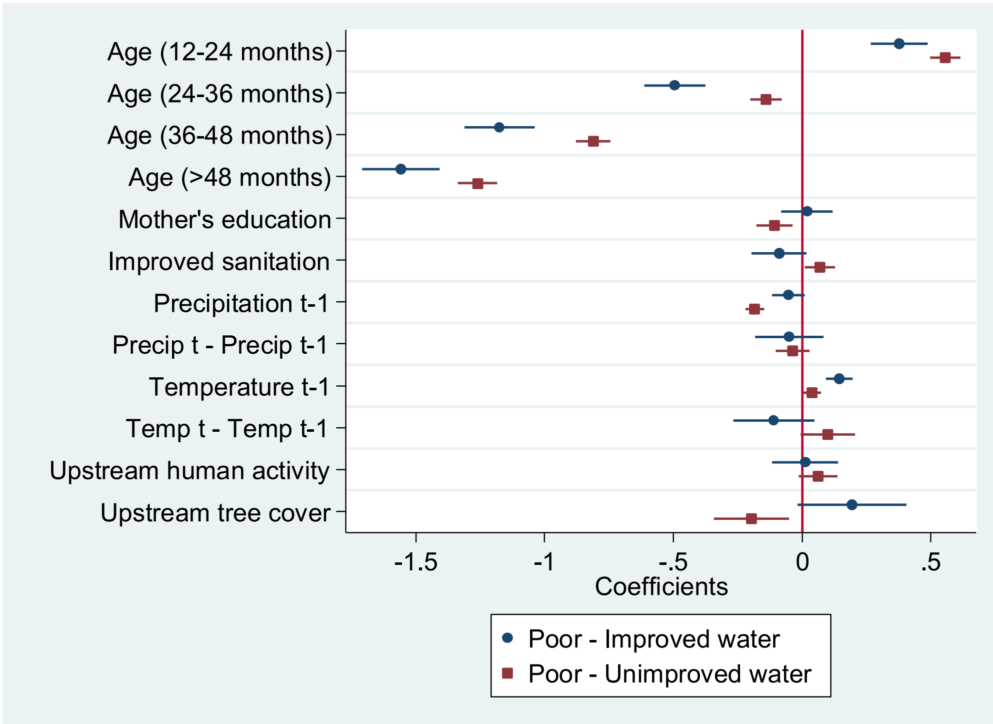
Fig S7. Factors associated with probability of diarrhea for households in the top two wealth quintiles dependent on whether or not they have an improved source of drinking water. Variables reducing the probability of diarrhea have means to the left of the red vertical line. Bars show 95% CIs.



Diarrhea: Poor – Improved/Unimproved water split

After selecting all households in the bottom two wealth quintiles, we split the remaining sample into households with an improved water source (e.g. piped water), and an unimproved water source (e.g. surface water). Results show that households without an improved water source benefit, in the form of reduced prevalence of diarrhea, from increased upstream tree cover. Households with an improved water source do not show a benefit from increased forest cover upstream (Fig S8.)

Fig S8. Factors associated with probability of diarrhea for households in the bottom two wealth quintiles dependent on whether or not they have an improved source of drinking water. Variables reducing the probability of diarrhea have means to the left of the red vertical line. Bars show 95% CIs.



Age (12-24 months)
Age (24-36 months)
Age (36-48 months)
Age (>48 months)
Mother's education
Improved sanitation
Precipitation t-1
Precip t - Precip t-1
Temperature t-1
Temp t - Temp t-1
Upstream human activity
Upstream tree cover
-1.5
-1
-.5
0
.5
Coefficients
Poor - Improved water
Poor - Unimproved water