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Residential Segregation, Access to Piped Water, and Diarrhea among Children in Rural India

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We use variations of access to piped water based on caste segregation within a village to identify the effects of access to piped water on the incidence of diarrhea among children in rural India. By focusing on residential segregation, we also evaluate the externalities of using a common water source. The empirical results show that, on average, the positive externalities of public water taps outweigh the negative externalities. However, in districts with lower than median rainfall shocks, the benefits of having a public water tap vanish, and only individual piped water connections within the house help prevent diarrhea among children. In districts with better rainfall shocks, we find larger effects of having access to public water taps. We also find that these benefits accrue mainly to boys. However, the burden of seasonal and annual fluctuation of water availability is placed only on girls.

Keywords　Piped Water, Diarrhea, Rural India

1　Introduction

Diarrhea is the second largest cause of childhood mortality worldwide. According to UNICEF (2013), about 590 thousand children under the age of five died from diarrhea in 2012. About a quarter of these premature deaths occurred in India. In the early 1970s, the Government of India started to support state governments to promote the provision of safe drinking water. The Census of India 2011 shows that 85.5% of total households have access to safe drinking water.[1] Under the policy guideline, access to 40 liters of water per capita a day within 500 meters from the household must be provided (Government of India (2010)).

However, being close to a water source does not necessarily translate to accessibility of the water source. One of the salient features of villages in rural India is caste-based residential segregation. Scheduled-caste[2] households tend to live in a colony away from upper-caste households. As

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water sources are strongly associated with the notion of purity and pollution, scheduled castes (SCs) are often denied access to the water sources used by upper castes. Scheduled castes tend to have a lower probability of having access to piped water among villagers in the same village. Even when they have access to piped water, they tend to use public water taps (hereafter referred to as public taps). In this study, we use these differential patterns of piped water access caused by caste-based residential segregation to identify the effects of piped water on the incidence and duration of diarrhea among children in rural India. Specifically, we use a dummy variable for SCs in a village-fixed-effect regression as an instrument for access to piped water.

Sharing a public tap creates externalities among SC households. The externality can be positive when improved water quality benefits all households sharing the same public tap and reduces the risk of contracting diarrhea for all users. However, the externality can be negative when a single user contaminates the facility and the pathogen easily spreads across all users. We empirically evaluate the magnitude of public and private benefits of piped water by comparing the effect of public taps with the effect of piped water within a house.

Our identification strategy heavily relies on the assumption that caste-based differences in access to piped water within the same village do not indicate differences in unobservable health knowledge and behavior affecting health outcomes. We informally test this assumption in two ways. First, we add proxies of health knowledge and behavior in our outcome regressions. We find that, even after controlling for these proxies, the effects of access to piped water remain the same. Second, we regress residuals of the outcome regressions on an SC dummy and other independent variables to see if the SC dummy is correlated with the unobservable factors contained in the residuals of the second-stage regression. The SC dummy is found to be insignificant, indicating that it is not correlated with unobservable characteristics affecting the incidence and duration of diarrhea among children.

Our estimation results show that access to piped water reduces the incidence and duration of diarrhea among children. We also find suggestive evidence that the quantity and quality of drinking water are complementary. In districts with worse rainfall shocks, public taps are ineffective in reducing diarrhea, and only individual access to piped water within the house is effective. In districts with better rainfall shocks, access to public taps brings benefits of shorter duration of diarrhea, and there is no additional gain from having piped water within the house. We also find that these benefits accrue mainly to boys. However, the burden of seasonal and annual fluctuation of water availability is placed only on girls.

The rest of the paper is organized as follows. In the next section, we provide a selective review of previous studies on drinking water and diarrhea among children. Section 3 provides a background on water provision and water access in rural India. Section 4 presents our empirical results on differential access to piped water within a village. In section 5, we show the main results of the effects of piped water access on diarrhea among children. The final section presents the conclusions and policy implications of the study.

2 Literature Review

There is abundant research on how improved water quality reduces diarrhea among children. For example, Cutler and Miller (2005) used historical data of cities in the United States to show that filtration and chlorination of water supply reduced mortality in the early 20th century. Galiani, Gertler and Schargrodsky (2005) analyzed the effects of privatization of water services in Argentina during the 1990s. They found that child mortality fell faster in the privatized areas and most of the reduction occurred in low-income areas. A review article by Zwane and Kremer (2007) summarized that piped water and sanitation can improve health but found little evidence of the impact of communal rural water infrastructure. Another review by Ahuja, Kremer, and Zwane (2010) emphasized the effectiveness of point-of-use treatment of water in rural areas.

As for improvement in terms of water quantity, there are only a few studies. Van der Hoek, Feenstra, and Konradsen (2002) analyzed whether the availability of irrigation water for domestic use affects child health in Pakistan. They found that households with a private water connection in their compounds and those with water-storage facilities show a significantly lower number of days of diarrhea among children. However, in their study of child growth in Lesotho, Esrey, Habicht, and Casella (1992) found complementarity between increased water usage and sanitation facilities. Ahuja, Kremer, and Zwane (2010) cited a randomized controlled trial in Morocco that showed the ineffectiveness of increased water quantity without improvement in quality. It is apparent that more evidence on the effect of increased water usage is necessary.

In this study, we exploit the traditional characteristics of residential segregation in Indian villages to identify the effects of public taps, as well as piped water in the house, on child health. We also investigate how the quantity of available water affects diarrhea among children. According to the World Bank (2010), 85% of rural drinking water supply schemes in India are based on groundwater sources (p. 2). Moreover, the majority of groundwater recharge comes from rainfall. According to the Central Ground Water Board (2013), 68% of the annual recharge comes from rainfall, out of which 57% is rainfall during the monsoon season (p. 40). As irrigation also heavily relies on groundwater in India, the shortage of rain during the monsoon season affects the availability of groundwater for domestic use, as the use of groundwater for irrigation is given priority. Therefore, we use rainfall shocks during the monsoon season to analyze the effects of the available water quantity on diarrhea among children in India.

There are a few causal analyses on diarrhea among children in India. They all use non-experimental large-scale household survey data. The main difficulty in evaluating the effects of piped water is that the placement of piped water is not random. For example, if the government attaches high priority to making drinking water available in places where child health outcomes are worse, we may find that higher access to piped water is associated with worse child health outcomes. In this case, ordinary least squares (OLS) estimates would underestimate the true causal effects of piped water.

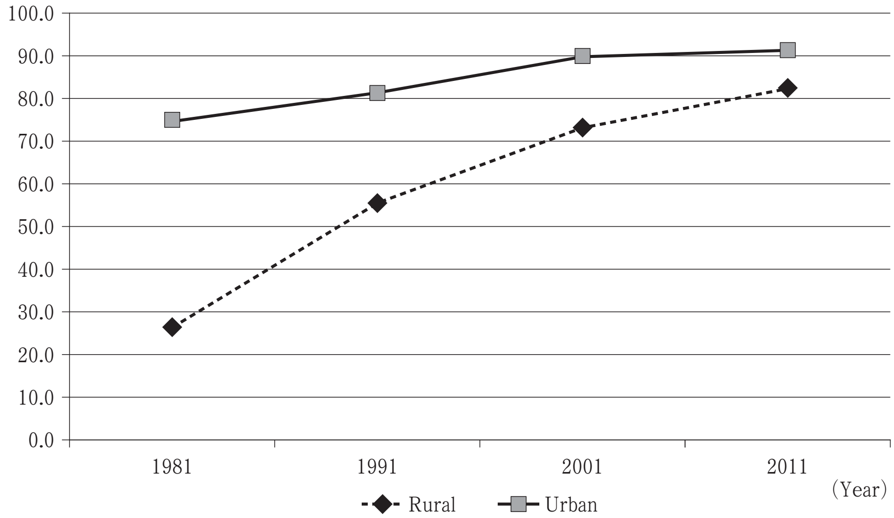
Jalan and Ravallion (2003) used the propensity score matching method to estimate the causal effects of piped water on diarrhea among children in rural India. They found negative and significant effects of piped water on the incidence and duration of diarrhea among children. Fan and Mahal (2011) used the same survey data as Jalan and Ravallion (2003) but employed multiple matching methods to investigate the effects of improved water supply, improved toilets, and hand-washing on child diarrhea in rural India. According to their estimates, hand-washing has large, negative, and highly significant effects across different matching methods. However, effects of improved water supply and sanitation are not robust across different matching methods. Kumar and Vollmer (2013) used the propensity score matching method to estimate effects of access to improved sanitation on diarrhea among children in rural India. Contrary to Fan and Mahal (2011), they found that the mean incidence of diarrhea is significantly reduced when a household has access to improved sanitation. They also found heterogeneity in its effects: beneficial effects are significant only for boys and wealthy households. As these matching estimates produce conflicting results, we contribute to the literature by providing evidence using a completely different methodology.

3 Access to Drinking Water in Rural India

The Government of India started serious efforts to provide drinking water to rural areas in 1972 through the Accelerated Rural Water Supply Programme (ARWSP, Planning Commission (2008), Ch. 5). According to the "11th Five Year Plan" documents, state and central governments have invested to create assets of around 4.2 million hand pumps and 1.6 million public stand posts in rural areas (Planning Commission (2008), p. 163). However, only 88.2% of hand pumps and 93.5% of stand posts are reported to be functional. To enhance the operation and maintenance of these assets, the *Swajardhala* program was launched in 2002 to 2003. This program required communities to contribute 10% of the project cost. A sense of ownership created by the contribution was expected to improve operation and maintenance.

According to the definition of the Census of India, drinking water is considered safe if it is supplied from a tap, a hand pump, or a tube well (Planning Commission (2002), p. 18). Figure 1 shows the progress of providing safe drinking water for the past 30 years. In 1981, the gap between rural and urban areas was enormous. Specifically, while 75.1% of urban households had access to safe drinking water, only 26.5% of rural households had access to safe water sources. Thirty years later, the share of rural households that have access to safe drinking water went up to 82.7%, and the gap between rural and urban areas has narrowed. However, as we saw above, we do not have much evidence for the effectiveness of public water sources on health improvements.

Figure 1: Access to Safe Drinking Water (% of Households)



(Source) Data are taken from Planning commission, *Data for use of Deputy Chariman, Planninc Commission,* 18th October 2013, p. 213., downloaded from http://planningcommission.gov.in accessed on November 24, 2013.

The Government of India adopted the "12th Five Year Plan" for the period 2012 to 2017, and the goal of rural drinking water supply was modified. According to the plan documents, the focus of the National Rural Drinking Water Programme (NRDWP, renamed from ARWSP in 2009) now is the provision of safe *piped* drinking water (Planning Commission (2013a), p. 301). Moreover, the target by 2017 is to provide access to 40 liters per capita a day of piped water supply to at least

50% of the rural population. The 12th five-year plan also aims to provide individual house connections to at least 35% of the rural population. As the emphasis has shifted to piped water, it becomes more important to evaluate the effectiveness of public taps, as well as individual piped water connection, on child health outcomes.

It is worth mentioning here that these targets are set for households without barriers of social or financial discrimination (Planning Commission (2013a), p. 301). An obvious group of people with such barriers are the members of the SCs, who have historically suffered grave social disabilities and educational and economic deprivation (Planning Commission (2013b), p. 222). NRDWP recognized this fact and earmarked 22% to 25% of the fund for provision of safe drinking water to SCs.[3)] Because of the early focus on hand pumps and stand pipes before the 12th plan, SCs tend to have higher access to a public tap within a village, despite their economic disadvantages.

3.1 Residential Segregation and Water Sources

As we use caste-based residential segregation within a village to identify differential access to piped water, it is worth documenting how prevalent caste-based residential segregation is in rural India. According to Thorat (2009),

> Caste-segregated neighbourhoods tend to be the rule rather than the exception in the Indian villages, and the dwellings are usually clustered on a caste basis. However, the SC neighbourhoods are unique in the sense that they are subjected to specific and very severe sanctions that are not imposed on other caste clusters. (pp. 134–5).

Residential segregation naturally implies differential access to basic infrastructure, including water sources. In fact, access to water is the most salient feature of sanctions imposed on SCs.[4)]

> One of the most basic and most harmful ways in which segregation through untouchability is imposed upon Dalits is through denial of access to water. Dalits are not allowed by their higher-caste neighbors to draw water from the same wells or hand-pumps as non-Dalits. (Center for Human Rights and Global Justice (2007), pp. 103).

Survey evidence also supports this observation. Using an all-India survey of 550 villages in 11 states conducted in 2001, Thorat (2009) pointed out that:

> [B]y far the most prevalent practice of untouchability in this realm was related to the denial of access to water sources-48.4 per cent of the villages surveyed reported the presence of this practice in some form or the other. (p. 135).

With these documentations and data in mind, we will confirm caste-based differential access to piped water from a nationally representative household survey in the next section.

4 Differential Access to Piped Water within a Village

In this section, we confirm that SCs have differential access to piped water as compared with other villagers in the same village in rural India. We use data from the 2005 Indian Human Development Survey, a multi-topic household survey conducted jointly by the University of Maryland and the National Council of Applied Economic Research. We limit our analysis to rural households.[5] Our basic empirical specification is a linear probability model with village-level fixed effects as follows:

$$D_{ij}=\gamma.SC_{ij}+\boldsymbol{X}'_{ij}\boldsymbol{\beta}+\eta_j+\varepsilon_{ij}, \qquad (1)$$

where D_{ij} is a dummy variable that takes the value of one if household i in village j has access to piped water, SC_{ij} is a dummy variable for SC households,[6] $\boldsymbol{X}_{ij}$ contains other variables of household characteristics and asset ownership, η_j is a village fixed effect, and ε_{ij} is an error term. Household characteristics include dummy variables for Scheduled Tribes (STs)[7], Muslim, Christian, Sikh, and other non-Hindu religious groups, as well as variables on household size and composition, age and gender of the household head, highest educational levels among male and female adult members, and the number of years of residence in the village. Asset ownership variables include size of owned land, and variables indicating the number of owned assets such as a tractor, motorcycle, black and white TV, color TV, telephone, and refrigerator. We include a dummy variable for summer months (i.e., March to May) to see if access to piped water changes during the hot and dry season.

Table 1 shows the OLS estimates of equation (1). For comparison, the first column shows the estimation result without village fixed effects. Hence, the results in column (1) reflect variations both within and across villages. We find that those who belong to SC, ST, Muslim, and Sikh

Table 1: Access to Piped Water

Dependent variable:	(1) Piped Water	(2) Piped Water	(3) Piped Water	(4) Piped Water	(5) Piped Water in the House	(6) Public Tap
SC	−0.0431 ***	−0.0300 ***	−0.0229 ***	−0.0204 ***	−0.0325 ***	0.0180 ***
	(0.0137)	(0.0073)	(0.0075)	(0.0075)	(0.0063)	(0.0062)
ST	−0.1326 ***	−0.0302 **	−0.0207	−0.0175	−0.0259 ***	0.0023
	(0.0238)	(0.0123)	(0.0127)	(0.0124)	(0.0090)	(0.0100)
Muslim	−0.1483 ***	−0.0128	−0.0088	−0.0091	−0.0100	0.0052
	(0.0240)	(0.0122)	(0.0128)	(0.0127)	(0.0103)	(0.0087)
Christian	0.0291	−0.0360 *	−0.0400 *	−0.0405 **	0.0114	−0.0113
	(0.0468)	(0.0193)	(0.0205)	(0.0205)	(0.0130)	(0.0124)
Sikh	−0.1637 ***	−0.0426	−0.0367	−0.0418	−0.0119	−0.0161
	(0.0339)	(0.0382)	(0.0384)	(0.0387)	(0.0312)	(0.0172)
Other Non-Hindu	0.0108	0.0035	−0.0030	−0.0045	0.0035	−0.0189
	(0.0506)	(0.0233)	(0.0243)	(0.0245)	(0.0115)	(0.0169)
Summer	−0.0358	−0.0522 *	−0.0533 *	−0.0536 *	−0.1029 ***	−0.1621 ***
	(0.0222)	(0.0271)	(0.0284)	(0.0285)	(0.0257)	(0.0303)
Village-fixed Effects	No	Yes	Yes	Yes	Yes	Yes
Other Household Characteristics	No	No	Yes	Yes	Yes	Yes
Asset Ownership	No	No	No	Yes	Yes	Yes
Number of Obs.	26,585	26,585	24,497	24,333	24,333	24,333
R^2	0.0171	0.6642	0.6645	0.6659	0.5072	0.4687

(Note) Clustered standard errors at the village level are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

groups have a lower probability of access to piped water. Once we include village fixed effects in column (2), only the SCs, STs, and Christian groups have statistically significant and negative coefficients. As we add other household characteristics in column (3) and asset ownership variables in column (4), the SC dummy variable remains a strong and robust predictor of lower access to piped water within the village. When we separate access to piped water into private and public accesses in columns (5) and (6), we find that SCs have a lower probability of access to piped water in the house, but a higher probability of access to public taps. These results are consistent with the patterns of caste-based residential segregation and government assistance explained above.

One additional point we need to emphasize is that in all village-fixed-effect regressions, a dummy variable for summer months has negative and significant coefficients. This implies that access to piped water depends on seasonal weather conditions. When the temperature is high and rainfall is scarce, people tend to lose access to piped water, even in the same village where they have access to piped water in other seasons. Moreover, the magnitude of negative effects is larger for access to public taps. As weather shocks may affect child health outcomes, we include rainfall shock variables and the dummy for summer months in our second-stage estimations below.

4.1 Empirical Strategy

As we confirmed that the SC dummy variable in the village-fixed-effect regression is a strong predictor of piped water access, we use the SC dummy as an instrumental variable (IV) for piped water access to evaluate effects of piped water on diarrhea among children. Specifically, we use the predicted value of piped water access from equation (1), $\hat{D}_{ij}$, in the second-stage estimation as follows:

$$H_{ij} = \alpha\hat{D}_{ij} + \boldsymbol{X}'_{ij}\boldsymbol{\delta} + \boldsymbol{V}'_{j}\boldsymbol{\xi} + v_{ij}. \quad (2)$$

As we use the incidence or duration of diarrhea among children under five as an outcome variable, H_{ij}, the second-stage regression is estimated with individual child-level data. As we want to add rainfall variables at the district level, we use a set of village- and district-level variables, V_j, instead of village dummies in the second-stage estimation. The village-level variables contain several variables of distance measures: distances to the nearest town, district headquarter, paved (*pucca*) road, bus stop, railway station, market, bank branch/office, postal office; primary, middle, and secondary schools; primary health center; and district hospital. Additionally, dummy variables for accessibility to telephone and mobile phone service at the village level are included. The district-level variables include population density in rural areas (taken from Census of India, 2001[8]), average monsoon rainfall during 1950 to 2005, and a monsoon rainfall shock measured by deviation of total rainfall during the monsoon season (prior to the interview) from the long-run average. We use GIS map data to estimate these rainfall variables at the centroid of each district, using global monthly precipitation data estimated by Matsuura and Willmott.[9] To take into account the possible nonlinearity of effects of rainfall shocks, we also include dummy variables, flood and drought, that indicate districts having monsoon shocks of greater or less than twice the standard deviation of monsoon rainfalls during 1950 to 2005 in each district.

5 Empirical Results on Diarrhea among Children

We use two outcome variables, the incidence and duration of diarrhea, to estimate equation (2) using two-stage least squares. The first-stage estimation results are in columns (4) to (6) of Table 1 for each treatment variable: access to piped water, individual piped water connection, or access to public taps, respectively. The results of the second-stage estimation for the incidence of diarrhea are shown in Table 2, and the results for the duration of diarrhea are in Table 3. In each table, we present results using the whole sample in columns (1) to (3), results for districts with below-median monsoon shocks in columns (4) to (6), and results for districts with above-median monsoon shocks in columns (7) to (9). For the estimation with access to a public tap as a treatment variable, we drop households with an individual piped water connection from the sample so that the comparison is between children with access to public taps and those without public taps (not those with private piped water connection).

From column (1) of Table 2, we find that access to piped water reduces the incidence of diarrhea by 4.2%. As the average incidence of diarrhea among children under five is 10.4% in this sample, the effect of piped water access is large. When we compare the effects of access to piped water between two sub-samples in columns (4) and (7), we find that the effects are larger in districts with worse rainfall shocks. The protective role of having access to piped water is more important among areas with scarce rainfall.

When we separate the treatment variable into private and public access, we find that the estimates of the effect of each water access are statistically insignificant for the whole sample. However, for the sub-sample of households with worse rainfall shocks, we confirm that almost all benefits of access to piped water come from private individual connections. In districts with scarce rainfall, securing safe water is the first priority, and having a tap in the house brings large

Table 2: Effects of Water Access on Incidence of Diarrhoea

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment variable	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
Treatment	-0.0419 ***	-0.0220	-0.0120	-0.0462 **	-0.0521 *	-0.0075	-0.0373 **	0.0221	-0.0211
	(0.0141)	(0.0218)	(0.0256)	(0.0228)	(0.0283)	(0.0500)	(0.0168)	(0.0354)	(0.0295)
Summer	0.0190 *	0.0170	0.0165	0.0234	0.0202	0.0207	0.0007	0.0007	-0.0029
	(0.0099)	(0.0105)	(0.0109)	(0.0164)	(0.0179)	(0.0172)	(0.0126)	(0.0130)	(0.0138)
Population Density	0.0043	0.0046	0.0090 ***	0.0040	0.0042	0.0102 **	0.0077 ***	0.0090 ***	0.0091 ***
	(0.0030)	(0.0031)	(0.0025)	(0.0046)	(0.0046)	(0.0042)	(0.0027)	(0.0027)	(0.0027)
Average Monsoon	0.0006	0.0010	0.0009	-0.0009	-0.0010	-0.0013	0.0010	0.0015	0.0017
	(0.0010)	(0.0010)	(0.0011)	(0.0015)	(0.0015)	(0.0018)	(0.0012)	(0.0012)	(0.0013)
Monsoon Shock	-0.0033	-0.0043 *	-0.0071 ***	-0.0194	-0.0185	-0.0301 *	-0.0114 ***	-0.0132 ***	-0.0145 ***
	(0.0024)	(0.0024)	(0.0026)	(0.0148)	(0.0151)	(0.0159)	(0.0031)	(0.0031)	(0.0033)
Flood	0.0059	0.0064	0.0238				0.0606 *	0.0608 *	0.0682
	(0.0400)	(0.0391)	(0.0537)				(0.0357)	(0.0355)	(0.0418)
Drought	0.0072	0.0129	0.0072	-0.0338	-0.0258	-0.0464			
	(0.0454)	(0.0451)	(0.0437)	(0.0635)	(0.0627)	(0.0625)			
Village Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Asset Ownership	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs.	10,684	10,684	9,595	5,985	5,985	5,346	4,699	4,699	4,249
Residual Regression									
SC	-0.0030	-0.0033	-0.0041	-0.0072	-0.0076	-0.0089	0.0048	0.0056	0.0050
t-stat.	-0.33	-0.36	-0.42	-0.57	-0.60	-0.66	0.38	0.44	0.37

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

Table 3: Effects of Water Access on Duration of Diarrhoea

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment variable	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
Treatment	−0.4014 ***	−0.3378 *	−0.4073 **	−0.4965 **	−0.5357 **	−0.3947	−0.2959 **	−0.0763	−0.4443 **
	(0.1338)	(0.1750)	(0.1952)	(0.2105)	(0.2574)	(0.3741)	(0.1314)	(0.2143)	(0.2142)
Summer	0.1104	0.0741	0.0504	0.1330	0.1016	0.0756	−0.0074	−0.0387	−0.0863
	(0.0900)	(0.0963)	(0.0978)	(0.1626)	(0.1778)	(0.1688)	(0.1083)	(0.1098)	(0.1205)
Population Density	0.0391	0.0424	0.0842 ***	0.0349	0.0372	0.0958 **	0.0715 ***	0.0791 ***	0.0763 ***
	(0.0289)	(0.0299)	(0.0213)	(0.0440)	(0.0442)	(0.0378)	(0.0238)	(0.0239)	(0.0234)
Average Monsoon	0.0050	0.0082	0.0038	−0.0097	−0.0100	−0.0200	0.0110	0.0151	0.0154
	(0.0086)	(0.0089)	(0.0096)	(0.0139)	(0.0148)	(0.0164)	(0.0123)	(0.0126)	(0.0141)
Monsoon Shock	−0.0553 ***	−0.0648 ***	−0.0866 ***	−0.1942	−0.1827	−0.3074 *	−0.0917 ***	−0.1013 ***	−0.1146 ***
	(0.0214)	(0.0210)	(0.0244)	(0.1574)	(0.1612)	(0.1660)	(0.0225)	(0.0226)	(0.0260)
Flood	−0.1418	−0.1203	−0.0399				0.2202	0.2333	0.2494
	(0.2641)	(0.2536)	(0.3630)				(0.2146)	(0.2141)	(0.2633)
Drought	−0.0892	−0.0441	−0.0891	−0.4393	−0.3487	−0.6169			
	(0.3774)	(0.3777)	(0.3648)	(0.5787)	(0.5859)	(0.5758)			
Village Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Asset Ownership	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs.	10,684	10,684	9,595	5,985	5,985	5,346	4,699	4,699	4,249
Residual Regression									
SC	−0.0529	−0.0579	−0.0413	−0.1240	−0.1273	−0.1073	0.0511	0.0485	0.0602
t-stat.	−0.59	−0.64	−0.43	−0.98	−1.00	−0.79	0.45	0.42	0.49

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

benefits.

When we use duration of diarrhea as an outcome variable in Table 3, we find similar conclusions. An average duration of diarrhea among children under five who contracted diarrhea is 7.9 days, and access to piped water is found to reduce the duration by 0.4 days (column (1)). When we compare two sub-samples, the effects of piped water access are larger among households with worse rainfall shocks (columns (4) and (7)). Access to piped water reduces the duration of diarrhea by 0.5 days in those regions.

In columns (2) and (3), we find that the effects are larger for access to public taps than for individual connections. Specifically, public access reduces the duration by 0.41 days, while individual access reduces the duration by 0.34 days. On average, the positive externalities of access to public taps seem to be larger than its negative externalities. However, higher population density is an additional burden for public-tap users, possibly because of higher risk of recontamination and contagion.

The results of two sub-samples bring out the contrast between two areas with different rainfall shocks. In districts with worse rainfall shocks, only individual connections have significant negative effects. However, in districts with better rainfall shocks, access to public taps brings benefits of shorter duration. Additionally, having individual access to public taps does not bring any gain in those areas. These results suggest that quantity and quality of drinking water are complementary. The complementarity is also suggested by the fact that better rainfall shocks reduce both the incidence and duration of diarrhea, especially among public-tap users, and the effects are larger for households in areas with scarce rainfall.

5.1 Estimation Results for Boys and Girls

When we separate the sample by gender of children, we find the same pattern of effects of piped water only among male children. Due to limitations of space, we only show the results on duration of diarrhea (Tables 4 and 5). Access to piped water reduces the duration by 0.5 days for male children. However, the effect is much smaller among female children; the gain to girls is 0.3 days in the duration.

As for estimation with sub-sample of districts with different rainfall shocks, again, we find the same pattern of effects only among male children. Table 4 shows that benefits of individual piped water connection are very large among boys in districts with worse rainfall shocks. In districts with better rainfall shocks, access to public taps is sufficient to reduce the duration of diarrhea among boys. However, as presented in Table 5, we do not find any significant effect of access to

Table 4: Effects of Water Access on Duration of Diarrhoea among Boys

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment variable	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
Treatment	-0.4992 ***	-0.4905 **	-0.4266	-0.5719 **	-0.7371 **	-0.1917	-0.4297 **	-0.0650	-0.5686 *
	(0.1594)	(0.2236)	(0.2601)	(0.2489)	(0.3088)	(0.4377)	(0.1825)	(0.3215)	(0.3119)
Summer	-0.0345	-0.0923	-0.1001	-0.0864	-0.1448	-0.1463	-0.0978	-0.1394	-0.1867
	(0.0998)	(0.1091)	(0.1121)	(0.1610)	(0.1764)	(0.1682)	(0.1289)	(0.1376)	(0.1513)
Population Density	0.0401	0.0441	0.0970 ***	0.0383	0.0411	0.1225 ***	0.0690 **	0.0814 **	0.0835 **
	(0.0268)	(0.0276)	(0.0211)	(0.0419)	(0.0419)	(0.0365)	(0.0333)	(0.0341)	(0.0328)
Average Monsoon	0.0069	0.0103	0.0108	-0.0215	-0.0230	-0.0263	0.0160	0.0218	0.0228
	(0.0135)	(0.0137)	(0.0152)	(0.0152)	(0.0159)	(0.0177)	(0.0203)	(0.0206)	(0.0233)
Monsoon Shock	-0.0799 ***	-0.0918 ***	-0.1100 ***	-0.3076 *	-0.3012 *	-0.4055 **	-0.1614 ***	-0.1755 ***	-0.1875 ***
	(0.0241)	(0.0231)	(0.0254)	(0.1661)	(0.1673)	(0.1714)	(0.0316)	(0.0314)	(0.0369)
Flood	-0.3689	-0.3410	-0.2155				0.0717	0.0686	0.0917
	(0.3288)	(0.2928)	(0.2995)				(0.3076)	(0.2768)	(0.3298)
Drought	-0.0492	-0.0010	-0.0228	-0.5217	-0.4424	-0.6360			
	(0.4669)	(0.4711)	(0.4602)	(0.6318)	(0.6380)	(0.6063)			
Village Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Asset Ownership	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs.	5,538	5,538	4,985	3,133	3,133	2,799	2,405	2,405	2,186
Residual Regression									
SC	-0.0342	-0.0391	-0.0098	-0.1265	-0.1293	-0.1151	0.1096	0.1125	0.1626
t-stat.	-0.30	-0.34	-0.08	-0.88	-0.89	-0.75	0.63	0.64	0.88

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

Table 5: Effects of Water Access on Duration of Diarrhoea among Girls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment variable	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap	Piped Water	Piped Water in the House	Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
Treatment	−0.2943 *	−0.1587	−0.4247 *	−0.3960	−0.3065	−0.5020	−0.1488	0.0005	−0.3977
	(0.1708)	(0.2135)	(0.2423)	(0.2559)	(0.3419)	(0.5173)	(0.1899)	(0.2556)	(0.2731)
Summer	0.2716 **	0.2594 **	0.2089 *	0.3856 *	0.3810 *	0.3169	0.1246	0.1141	0.0437
	(0.1115)	(0.1170)	(0.1149)	(0.2082)	(0.2265)	(0.2182)	(0.1482)	(0.1564)	(0.1646)
Population Density	0.0378	0.0403	0.0737 **	0.0325	0.0343	0.0785	0.0807 ***	0.0847 ***	0.0788 ***
	(0.0333)	(0.0343)	(0.0311)	(0.0505)	(0.0508)	(0.0574)	(0.0248)	(0.0246)	(0.0248)
Average Monsoon	0.0034	0.0065	−0.0036	0.0039	0.0052	−0.0142	0.0038	0.0060	0.0055
	(0.0096)	(0.0099)	(0.0094)	(0.0207)	(0.0219)	(0.0205)	(0.0114)	(0.0113)	(0.0123)
Monsoon Shock	−0.0290	−0.0364	−0.0611	−0.0786	−0.0620	−0.2315	−0.0185	−0.0248	−0.0332
	(0.0333)	(0.0339)	(0.0402)	(0.1904)	(0.1958)	(0.2034)	(0.0394)	(0.0421)	(0.0508)
Flood	0.1058	0.1237	0.1578				0.3267	0.3440	0.3461
	(0.4000)	(0.3986)	(0.5464)				(0.3534)	(0.3550)	(0.5015)
Drought	−0.1324	−0.0896	−0.1657	−0.4049	−0.3026	−0.7094			
	(0.5764)	(0.5753)	(0.5605)	(0.7826)	(0.7858)	(0.7550)			
Village Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Asset Ownership	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs.	5,146	5,146	4,610	2,852	2,852	2,547	2,294	2,294	2,063
Residual Regression									
SC	−0.0595	−0.0633	−0.0487	−0.1059	−0.1075	−0.0786	−0.0174	−0.0189	−0.0386
t-stat.	−0.47	−0.50	−0.36	−0.56	−0.57	−0.39	−0.12	−0.13	−0.25

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

piped water among girls in the results with sub-sample of districts.

Another difference in these results by gender is that the coefficients of the summer dummy are positive and significant only among girls, while the coefficients on monsoon shocks are negative and significant only among boys. These results suggest that access to piped water, as well as better rainfall shocks, brings the most benefits only to boys, but the burden of seasonal fluctuation in drinking water availability is imposed only on girls.

5.2 Robustness Check

The validity of the SC dummy as an IV for piped water access depends on the assumption that the SC dummy is uncorrelated with unobservable factors contained in the error term v_{ij} in equation (2). As caste is determined by birth, it seems natural to assume that, given household characteristics and asset ownership, differential access to piped water caused by residential segregation is random within the same village. Although we cannot perform a test of overidentifying restriction with a single instrument, we try to test validity in two ways. First, we include a variable on health knowledge and behavior as an additional control in equation (2) to check robustness of estimation results. We use four variables as proxies for unobservable health knowledge and behavior, possibly contained in v_{ij}. For health knowledge, we use a dummy variable that takes the value of one if the respondent answers correctly the question about the amount of fluid intake when children have diarrhea. For health behavior, we use two dummy variables and one continuous variable. The two dummy variables include one for hand-washing with soap after defecation and another for usually or always treating/purifying drinking water. The continuous proxy variable for health behavior is the share of medical expenditure in total monthly household expenditure. This variable captures the pattern of actual utilization of health services.

Tables 6 and 7 show the results of the comparison between OLS and IV estimates. Most of the IV estimates are larger in absolute value than the OLS estimates, indicating underestimation of causal effects of piped water in OLS. The reason can be the endogenous placement of water infrastructure. These tables also show IV estimates with additional control variables. The inclusion of an additional proxy for health knowledge and behavior does not change the results qualitatively.

The second way to test exogeneity is to regress the residual $\hat{v}_{ij}$ from the second-stage estimation of equation (2) on the SC dummy and other independent variables. By testing the significance of the coefficient on SC, we can check if unobservable factors affecting diarrhea among children in $\hat{v}_{ij}$ are uncorrelated with the SC dummy. The results of residual regressions are shown at the bottom of Tables 2 to 5. We find that all t-values of the null hypothesis of the coefficient

Table 6: Comparison of Estimation Results

Treatment variable	(1) Piped Water	(2) Piped Water in the House	(3) Public Tap	(4) Piped Water	(5) Piped Water in the House	(6) Public Tap	(7) Piped Water	(8) Piped Water in the House	(9) Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
A. Incidence									
Coefficients on Treatment in Table 2	-0.0419 ***	-0.0220	-0.0120	-0.0462 **	-0.0521 *	-0.0075	-0.0373 **	0.0221	-0.0211
	(0.0141)	(0.0218)	(0.0256)	(0.0228)	(0.0283)	(0.0500)	(0.0168)	(0.0354)	(0.0295)
OLS estimates	-0.0342 ***	-0.0042	-0.0211 *	-0.0339 ***	-0.0171	-0.0227	-0.0328 ***	0.0165	-0.0207
	(0.0083)	(0.0109)	(0.0116)	(0.0116)	(0.0129)	(0.0182)	(0.0100)	(0.0162)	(0.0145)
IV estimates with additional control									
Control 1: purify water before use	-0.0418 ***	-0.0220	-0.0113	-0.0460 **	-0.0522 *	-0.0060	-0.0376 **	0.0229	-0.0205
	(0.0141)	(0.0219)	(0.0256)	(0.0230)	(0.0285)	(0.0502)	(0.0169)	(0.0354)	(0.0298)
Control 2: handwash with soap	-0.0420 ***	-0.0221	-0.0121	-0.0463 **	-0.0521 *	-0.0078	-0.0372 **	0.0217	-0.0210
	(0.0141)	(0.0219)	(0.0256)	(0.0229)	(0.0282)	(0.0500)	(0.0168)	(0.0357)	(0.0295)
Control 3: health knowledge	-0.0411 ***	-0.0247	-0.0093	-0.0476 **	-0.0556 **	-0.0100	-0.0335 **	0.0230	-0.0157
	(0.0140)	(0.0218)	(0.0255)	(0.0226)	(0.0282)	(0.0500)	(0.0165)	(0.0357)	(0.0296)
Control 4: Share of medical exp.	-0.0379 ***	-0.0136	-0.0118	-0.0426 *	-0.0458 *	-0.0097	-0.0342 **	0.0305	-0.0193
	(0.0138)	(0.0215)	(0.0252)	(0.0223)	(0.0274)	(0.0505)	(0.0174)	(0.0365)	(0.0286)
B. Duration									
Coefficients on Treatment in Table 3	-0.4014 ***	-0.3378 *	-0.4073 **	-0.4965 **	-0.5357 **	-0.3947	-0.2959 **	-0.0763	-0.4443 **
	(0.1338)	(0.1750)	(0.1952)	(0.2105)	(0.2574)	(0.3741)	(0.1314)	(0.2143)	(0.2142)
OLS estimates	-0.3770 ***	-0.0751	-0.3697 ***	-0.3853 ***	-0.1453	-0.3807 ***	-0.3315 ***	0.0394	-0.3537 ***
	(0.0771)	(0.1107)	(0.0881)	(0.1135)	(0.1536)	(0.1385)	(0.0827)	(0.1245)	(0.1045)
IV estimates with additional control									
Control 1: purify water before use	-0.4004 ***	-0.3379 *	-0.4013 **	-0.4940 **	-0.5366 **	-0.3776	-0.2977 **	-0.0711	-0.4414 **
	(0.1341)	(0.1760)	(0.1950)	(0.2125)	(0.2582)	(0.3748)	(0.1322)	(0.2143)	(0.2159)
Control 2: handwash with soap	-0.4018 ***	-0.3377 *	-0.4096 **	-0.4899 **	-0.5249 **	-0.4009	-0.2957 **	-0.0817	-0.4438 **
	(0.1344)	(0.1771)	(0.1952)	(0.2121)	(0.2591)	(0.3734)	(0.1302)	(0.2149)	(0.2126)
Control 3: health knowledge	-0.3954 ***	-0.3593 **	-0.3865 **	-0.5080 **	-0.5642 **	-0.4133	-0.2671 **	-0.0691	-0.4059 *
	(0.1334)	(0.1752)	(0.1963)	(0.2097)	(0.2573)	(0.3733)	(0.1327)	(0.2151)	(0.2171)
Control 4: Share of medical exp.	-0.3542 ***	-0.2396	-0.4050 **	-0.4526 **	-0.4596 *	-0.4179	-0.2621 *	0.0158	-0.4237 **
	(0.1299)	(0.1710)	(0.1943)	(0.2074)	(0.2526)	(0.3835)	(0.1366)	(0.2204)	(0.2031)

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

Table 7: Comparison of Estimation Results by Gender

Treatment variable	(1) Piped Water	(2) Piped Water in the House	(3) Public Tap	(4) Piped Water	(5) Piped Water in the House	(6) Public Tap	(7) Piped Water	(8) Piped Water in the House	(9) Public Tap
Sample	All	All	All	Low rain	Low rain	Low rain	High rain	High rain	High rain
A. Boys									
Coefficients on Treatment in Table 4	-0.4992 ***	-0.4905 **	-0.4266	-0.5719 **	-0.7371 **	-0.1917	-0.4297 **	-0.0650	-0.5686 *
	(0.1594)	(0.2236)	(0.2601)	(0.2489)	(0.3088)	(0.4377)	(0.1825)	(0.3215)	(0.3119)
OLS estimates	-0.4409 ***	-0.0608	-0.4551 ***	-0.4300 ***	-0.1826	-0.4371 **	-0.4154 ***	0.1775	-0.4228 ***
	(0.0988)	(0.1489)	(0.1213)	(0.1497)	(0.1984)	(0.1796)	(0.1188)	(0.2166)	(0.1464)
IV estimates with additional control									
Control 1: purify water before use	-0.5007 ***	-0.4930 **	-0.4269	-0.5689 **	-0.7402 **	-0.1877	-0.4362 **	-0.0648	-0.5686 *
	(0.1605)	(0.2246)	(0.2602)	(0.2510)	(0.3111)	(0.4395)	(0.1846)	(0.3209)	(0.3131)
Control 2: handwash with soap	-0.5035 ***	-0.5003 **	-0.4244	-0.5745 **	-0.7399 **	-0.1934	-0.4294 **	-0.0758	-0.5659 *
	(0.1594)	(0.2257)	(0.2601)	(0.2463)	(0.3062)	(0.4374)	(0.1822)	(0.3284)	(0.3068)
Control 3: health knowledge	-0.4943 ***	-0.5194 **	-0.4086	-0.5852 **	-0.7770 **	-0.2238	-0.3986 **	-0.0609	-0.5296 *
	(0.1579)	(0.2239)	(0.2597)	(0.2483)	(0.3116)	(0.4371)	(0.1845)	(0.3246)	(0.3216)
Control 4: Share of medical exp.	-0.4458 ***	-0.3919 *	-0.4303 *	-0.5397 **	-0.6688 **	-0.2128	-0.3668 *	0.0470	-0.5488 *
	(0.1577)	(0.2220)	(0.2578)	(0.2504)	(0.3112)	(0.4494)	(0.1888)	(0.3361)	(0.2994)
B. Girls									
Coefficients on Treatment in Table 5	-0.2943 *	-0.1587	-0.4247 *	-0.3960	-0.3065	-0.5020	-0.1488	0.0005	-0.3977
	(0.1708)	(0.2135)	(0.2423)	(0.2559)	(0.3419)	(0.5173)	(0.1899)	(0.2556)	(0.2731)
OLS estimates	-0.3054 ***	-0.0717	-0.2864 **	-0.3539 **	-0.1157	-0.3205 *	-0.2110 *	-0.0496	-0.2498 *
	(0.0998)	(0.1476)	(0.1132)	(0.1404)	(0.2167)	(0.1881)	(0.1182)	(0.1451)	(0.1430)
IV estimates with additional control									
Control 1: purify water before use	-0.2918 *	-0.1571	-0.4079 *	-0.3960	-0.3066	-0.4643	-0.1467	0.0091	-0.3926
	(0.1709)	(0.2144)	(0.2403)	(0.2602)	(0.3414)	(0.5165)	(0.1887)	(0.2590)	(0.2717)
Control 2: handwash with soap	-0.2897 *	-0.1482	-0.4305 *	-0.3752	-0.2766	-0.5136	-0.1488	0.0000	-0.3983
	(0.1712)	(0.2175)	(0.2424)	(0.2595)	(0.3464)	(0.5135)	(0.1891)	(0.2542)	(0.2714)
Control 3: health knowledge	-0.2881 *	-0.1731	-0.4030 *	-0.4068	-0.3274	-0.5115	-0.1279	0.0081	-0.3655
	(0.1718)	(0.2141)	(0.2441)	(0.2554)	(0.3415)	(0.5179)	(0.1915)	(0.2535)	(0.2707)
Control 4: Share of medical exp.	-0.2554	-0.0612	-0.4187 *	-0.3381	-0.2230	-0.5210	-0.1416	0.0711	-0.3820
	(0.1648)	(0.2078)	(0.2415)	(0.2451)	(0.3285)	(0.5133)	(0.1916)	(0.2509)	(0.2708)

(Note) Cluster bootstrap standard errors are shown in the parentheses.
***: significant at the 1 percent level, **: significant at the 5 percent level, and *: significant at the 10 percent level.

equal to zero are less than or equal to one in absolute value. Thus, we can be confident that the SC dummy is not correlated with unobservable factors affecting diarrhea among children.

6 Conclusions

We used caste-based residential segregation as a source of variation in the access to piped water within a village and identified effects of access to piped water on diarrhea among children in rural India. The empirical results show that access to piped water reduces the incidence and duration of diarrhea among children. We also find suggestive evidence that the quantity and quality of drinking water are complementary. In districts with worse rainfall shocks, public taps are ineffective in reducing diarrhea, and only individual access to piped water within the house is effective. In districts with better rainfall shocks, access to public taps brings benefits of shorter duration, and there is no gain from having piped water within the house. We also find that these benefits accrue mainly to boys. However, the burden of seasonal fluctuation of water availability is placed only on girls.

As the Government of India started to focus on piped water provision, we need to recognize the nature of seasonal and annual fluctuations in the availability of piped water. Especially for public-tap users and female children, we need a mechanism to provide the safety net of an alternative source of drinking water when they receive negative rainfall shocks or during summer months.

Notes

Comments from participants of "the International Conference on Patterns of Social and Economic Change in Colonial and Independent India" at Jawaharlal Nehru University and of the Development Economics Workshop at the University of Wisconsin-Madison are gratefully acknowledged. The usual disclaimer applies.

1) See the web site of Office of the Registrar General & Census Commissioner, India, at http://censusindia.gov.in/.

2) Scheduled castes, or *Dalits,* were once called untouchables and have been among the target groups of affirmative actions in India.

3) Planning Commission (2002), p. 411; Planning Commission (2013b), p. 301.

4) Iversen, Kalwij, Verschoor and Dubey (2014) also mentioned that, as is well known, SC hamlets tend to be separate from the main village and often have their own drinking water source (p. 426).

5) The survey document mentioned that the survey was conducted from November 2004 and ended mostly in October 2005. As we need information on year and month of an interview, we limit the sample to households with correct information on month and year of the interview after November 2004. We drop 149 households from the sample in this process. Later, we use the interview year and month

to match households and individuals with monsoon variables prior to the interview. As questions about diarrhea among children are related to the past one month of the interview date, we use a dummy variable of summer months that takes the value of one if the interview took place between April and June. As the survey has separate questions about water source during summer and other seasons, a dummy variable for access to piped water is also adjusted to match the month prior to the interview.

6) As we have seen above, among the Hindu caste, the distinction between SC and non-SC is the only crucial factor determining access to water sources. The addition of a Brahmin dummy does not change the results qualitatively.

7) Scheduled Tribes (STs), sometimes called *Adivasis,* are another group of targets of affirmative action in India. They are not strictly within the caste system, and their disadvantage largely comes from the physical isolation of their habitation. As isolation might affect their access to piped water, we include the ST dummy as one of our control variables.

8) Details of the Census of India 2001 can be found at http://www.censusindia.gov.in/2011-common/census_data_2001.html.

9) Terrestrial Precipitation: 1900 to 2010 Gridded Monthly Time Series (version 3.02), available at http://climate.geog.udel.edu/~climate/. The data contains monthly precipitation estimated at a 0.5 × 0.5 latitude/longitude degree grid. We take the four nearest estimates to each centroid of a district, and calculate a weighted average with weights given by an inverse of the distance.

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