Check for updates

Received: 16 June 2020 | Revised: 25 May 2022 | Accepted: 15 July 2022

DOI: 10.1111/rode.12924

REGULAR ARTICLE

WILEY

# *Drain on your health*: Sanitation externalities from dirty drains in India

**Vikram Dayal**[1] | **Anand Murugesan**[2] | **Tauhidur Rahman**[3]

[1]Institute of Economic Growth, Delhi, India

[2]Department of Public Policy, Central European University, Vienna, Austria

[3]Department of Agricultural and Resource Economics, University of Arizona, Tucson, Arizona, USA

**Correspondence**
Anand Murugesan, Department of Public Policy, Central European University, Vienna, Austria.
Email: murugesana@ceu.edu

**Abstract**

We highlight an overlooked channel of disease transmission in developing countries: dirty drains. We make the case that sanitation efforts should move to improve the condition of drains to build on increased toilet provision since they are a key transmission channel for waterborne diseases. We develop an economic model of sanitation externalities that incorporates the role of drains and then empirically examine the relationship between the sanitary quality of neighborhood drains and household ill-health incidence using a primary survey of 1,530 households from rural Uttarakhand, India. We find a strong and positive association between household ill-health incidence and dirty neighborhood drains, controlling for household toilet usage, community-level toilet availability, and an array of other household attributes. We employ a variety of robustness checks to validate our findings. Our findings suggest that bringing the policy focus to overall sanitation infrastructure will have substantial health returns.

**KEYWORDS**

drain, externality, health, hygiene, toilet, water

**JEL CLASSIFICATION**

D60, H51, I10, I33, O12

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
© 2022 The Authors. *Review of Development Economics* published by John Wiley & Sons Ltd.

## 1 | INTRODUCTION

Over a billion people lack access to clean drinking water, and twice as many do not have access to hygienic sanitation facilities (Unicef et al., 2017). Diarrhea, a waterborne disease, kills 2,195 children every day, more than AIDS, malaria, and measles combined. Over the past two decades, programs and policies in South Asia have acutely emphasized toilet construction combined with personal hygiene. In India, such programs and policies have resulted in a steady decline in reported open defecation rates over the past two decades (Gupta et al., 2019).[1] According to World Development Indicators data, toilet coverage has increased globally (The World Bank, 2020). In contrast, drain infrastructure in developing countries has received less attention.[2]

The effects of access to clean water, personal hygiene, and sanitation on health have been well documented (Gamper-Rabindran, Khan, & Timmins, 2010; Jalan & Ravallion, 2003). Recent policy and scholarly work have mainly focused on the effect of open defecation on individual and community health, including their health externalities (Freeman et al., 2017; Hammer & Spears, 2016; Null et al., 2018; Watson, 2006). This literature suggests that sanitation investments can be cost-effective and can lead to sharp reductions in waterborne gastrointestinal diseases (Watson, 2006), that poor sanitation have long-term consequences on child health (Null et al., 2018), and that open defecation has neighborhood health externalities (Geruso & Spears, 2018). In developing countries, researchers have conducted randomized controlled experiments to study the impacts of various types of sanitation interventions. Cameron, Olivia, and Shah (2019) find that the total sanitation program in Indonesia resulted in a modest increase in toilet construction, decreased community tolerance of open defecation, and reduced roundworm infestations in children. However, the program had no impact on anemia, height, or weight. Freeman et al. (2017), in their meta-analysis, broadly confirm these findings, but underscore that evidence gaps remain, and highlight the need for a better understanding of the underlying mechanisms of waterborne disease transmission.

In this study, we highlight the role of an overlooked mechanism, neighborhood drain quality, particularly in rural and suburban regions of developing countries (see Figure A1 in the Appendix presenting a dirty drain from a village in our sample). It is common to see overflowing open drains in developing countries, particularly during the rainy season. For example, only 22% of the households in our primary survey in rural Uttarakhand reported having roadside drain networks, and even those were mostly open. Nevertheless, even India's most comprehensive household surveys do not systematically collect data on drain availability and quality. For example, the Rural Economic and Demographic Survey in India, an exceptionally exhaustive data set on rural households, contains only two questions on sewers. Similarly, India's latest National Family Health Survey, conducted in 2019–2020, contains only two questions on drains, while its previous rounds had none. Poor quality drains, along with open defecation and poor neighborhood sanitation practices, can be a dangerous vector of bacteriological transmission (Norman, Pedley, & Takkouche, 2010). Pattanayak and Pfaff (2009), in reviewing the issues of behavior, environment, and health in developing countries, develop a general household model to analyze a variety of environmental health risks. We tailor their conceptual model to highlight the importance of drains and toilets in the determination of human health.

We then use a micro-level primary survey of 1,530 households in rural Uttarakhand, a northern state of India, to provide evidence that dirty neighborhood drains are positively associated with household ill-health incidence, after carefully accounting for the influences of household hygiene practices, sanitation infrastructure, and village-level sanitation practices

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

(e.g., open defecation). We build on a previous study that used data from the same primary survey and linked household water and toilet availability with diarrheal incidence (Murugesan, Dayal, & Chugh, 2009). We show that the dirty neighborhood drains, interacting with open defecation, exacerbates household ill-health incidents associated with waterborne diseases. In other words, clean drains reduce the negative externality of open defecation.

Figure 1 captures this central relationship, showing that households with clean neighborhood drains have lower ill-health incidences compared to households with dirty drains. The distribution of ill-health incidence in the households with clean drains lies below the dashed line: 7.5% on the *y*-axis in the bottom panel (clean drains). The *x*-axis represents the number of ill-health incidence associated with waterborne diseases, measuring the severity or intensity of ill-health incidents. The severity is higher in the top panel (dirty drains) as the tail extends up to eight incidents compared to a maximum of three in the bottom panel (clean drains). The figure highlights the association between drain quality and human health.

The remainder of the paper is organized as follows. In Section 2, we briefly describe the background to motivate the study. In Section 3, we present a model of sanitation externality to generate insights on why there may be under-supply of efforts to provide and maintain network goods such as neighborhood drains. In Section 4 we describe the study area and data. Then we

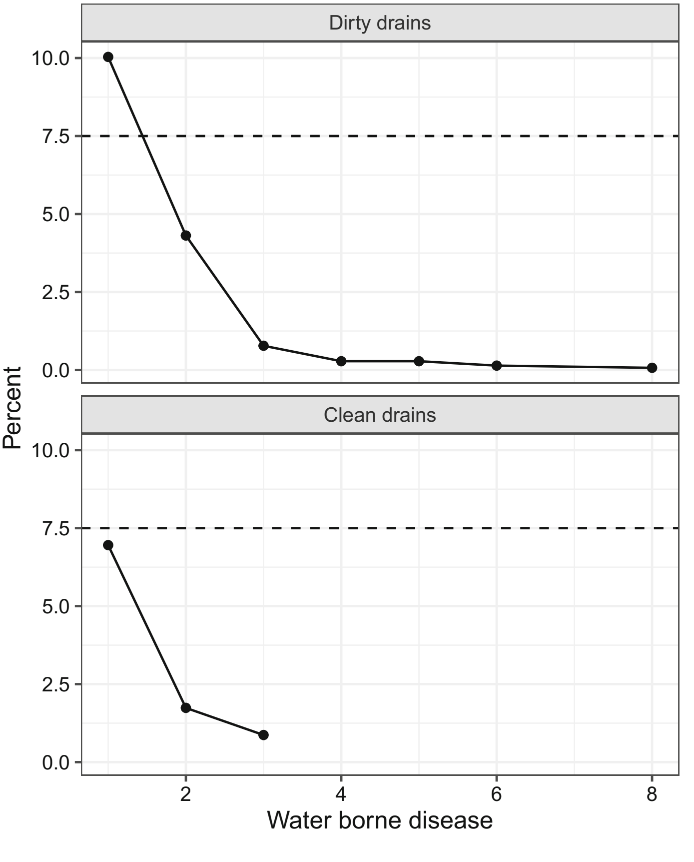


**FIGURE 1** Distribution of ill-health incidence of the households with dirty and clean neighborhood drains, with *dirty drains* (top) and *clean drains* (bottom) [*Source:* Authors' calculation from the survey data of 1,530 households in Uttarakhand, India]

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

discuss the empirical model and estimation strategy in Section 5. The main results are presented in Section 6. We conclude in Section 7.

## 2 | BACKGROUND

While India adopted the Central Rural Sanitation Program in 1986, concurrent with similar programs in other developing countries, sanitation took a backseat to other priorities such as provision of safe drinking water and disease treatment (Dickinson, Patil, Pattanayak, Poulos, & Yang, 2015). However, at the turn of the millennium, the Indian central government adopted a supply-driven approach, under Indira Awaas Yojna, providing subsidies for housing and toilet construction. Thereafter, the focus shifted to promoting demand for sanitation (O'Reilly & Louis, 2014). Community-level programs such as Total Sanitation Campaign and Nirmal Gram Puraskar were introduced to accelerate toilet construction and usage. These programs reward open-defecation-free villages with a cash prize and target behavioral obstacles (e.g., misinformation about toilet technologies and safety) and community resistance (e.g., cultural practices) to toilet adoption and utilization.[3] In recent years, such programs have been aided with popular media campaigns in de-stigmatizing sanitation and hygiene discussions.[4]

Despite these positive developments regarding hygiene and sanitation in rural India, surprisingly, village drainage infrastructure has received little attention from policymakers and researchers studying the determinants of health in rural India. A neighborhood drain in any village is a network good, critical for disposing of water from the neighborhood kitchens and bathroom sinks. Moreover, neighborhood drains are decentralized network goods maintained by a cluster of households for disposal of dirty water from domestic kitchens and bathrooms. The sanitary quality of a neighborhood drain, defined by its technology and maintenance, depends on the collective neighborhood effort, with potential free-rider problems (see Section 3). Therefore, it can vary across neighborhoods within a village, which has direct implications for the health and well-being of the households in the neighborhood network.

The studies on environmental and public health have examined the effects of sewerage systems on diarrhea and enteric infections (see Norman et al., 2010 for a meta-analysis of such studies). However, their focus has been on urban drainage infrastructure. In contrast, we highlight the problem in rural and suburban areas of a developing country (Kiulia et al., 2010). In large parts of India, it is common to see open drainage networks overflowing, especially during the rainy season. Since open drains are used to dispose of wastewater from households, they require continuous cleaning to ensure that they are not clogged and overflowing into the neighborhood lanes. Figure A1 (in the Appendix) shows how the inadequate maintenance of neighborhood drainage leads to the formation of pools of wastewater all around the village, which then turns into a suitable breeding ground for mosquitoes and other vectors of waterborne diseases, including gastrointestinal parasites. Children, in particular, are at higher risks of exposure to this vector of diseases since they play outside and have a weaker immune system.

Table 1 shows the distribution of the type of drains prevalent in our sample of villages. Twenty-nine percent of the households had reported disposing of their domestic wastewater into soak pits and house gardens, which is generally considered safe disposal. Approximately 24% of the households reported diverting their wastewater into the roadside open drain and directly into the stream. Almost half (47%) of the households reported having no drain, which means that wastewater from their homes freely flows outside. Although wastewater disposal into poor-quality soak pits and house gardens can seep into the groundwater, our study

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Type of the drain in the survey households

| Description | Number | Percentage |
|---|---|---|
| Soak pits | 62 | 4 |
| House garden | 385 | 25 |
| Roadside open drain | 342 | 22 |
| Directly into valley/stream | 27 | 2 |
| No drain | 714 | 47 |
| Total | 1,530 | 100 |

*Source*: Primary survey of 1,530 households in Uttarakhand, India.

examines the health externality of open drains, which capture the effect of surface-level wastewater stagnating and flowing around the neighborhood.

## 3 | AN ECONOMIC MODEL OF SANITATION EXTERNALITY

To highlight the network and public good nature of neighborhood drains, and to motivate our empirical model of household ill-health incidence, we present a simple model of household choice related to sanitation. While Pattanayak and Pfaff (2009) provide an excellent discussion of a general model of household behavior for a broader range of environmental risks, we focus on sanitation choices, with a specific emphasis on the sanitary quality of neighborhood drains. We incorporate features from widely used agricultural household models (Bardhan & Udry, 1999) and models of reciprocal externality (Dasgupta, 1993). We assume that there are two identical villagers, A and B. We concentrate on A's choices and point out the resulting externality: what choices by A imply for B. Since villagers are identical, by symmetry the reverse holds for A when B makes choices.

We assume that the villagers enjoy utility arising from the consumption of cooked food $(C_{\mathrm{F}})$, consumption of other goods $(C_{\mathrm{Other}})$, sickness $(S)$, and leisure time $(t_{\mathrm{L}})$.

$$U = U(C_{\mathrm{F}}, C_{\mathrm{Other}}, S, t_{\mathrm{L}}) \tag{1}$$

Sickness is assumed to be a function of bacterial exposure $(E)$, consumption of cooked food, and individual characteristics $(Z^{\mathrm{i}})$.

$$S = S(E, C_{\mathrm{F}}, Z^{i}) \tag{2}$$

Bacterial contamination is a complex phenomenon. For simplicity, we assume that bacterial exposure experienced by A is an additive separable function of a baseline level of exposure $(E_0)$, water supply inside the house of A $(W_{\mathrm{A}})$, toilet not dependent on water inside A's house $(L_{\mathrm{A}}^{\mathrm{NW}})$, and toilet dependent on water inside A's house $(L_{\mathrm{A}}^{\mathrm{W}})$. Besides, bacterial exposure depends on the total level of cleaning of drains in the village, given by $D_{\mathrm{A}} + D_B$, where A pays for $D_{\mathrm{A}}$ and B for $D_{\mathrm{B}}$. Finally, bacterial exposure experienced by A also depends on whether B uses a toilet inside his/her house, whether with water or not. Thus,

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

$$E_{\rm A} = E_0 - g1(W_{\rm A}) - g2\left(L_{\rm A}^{\rm NW}\right) - g3\left(L_{\rm A}^{\rm W}(W_{\rm A})\right) - g4\left(L_{\rm B}^{\rm NW}\right) - g5\left(L_{\rm B}^{\rm W}(W_{\rm B})\right) - g6(D_{\rm A} + D_{\rm B}), \quad (3)$$

where the gs denote functions. We expect $g2$ and $g3$ to have stronger effects than $g4$ and $g5$. By symmetry, B has the same function, with subscripts swapped. Also, if $W_{\rm A}$ is zero, then we would expect $g1$ to be zero, and similarly for the other functions in Equation 3. If the toilet used by A uses water, then the use of that toilet is facilitated by the provision of water supply inside A's house. In writing Equation 3, we are treating water inside the house and the presence of the toilet inside the house as continuous variables, whereas they are discrete. However, we will stay with this for the simplicity of the exposition, and when the first-order conditions are derived, will indicate how the substance of these conditions is not different even if we consider discreteness.

We assume that A and B have two sources of income: wage income and self-production of agricultural goods. We denote time spent working outside by $t_{\rm W}^{\rm O}$, and the wage received by $p_{\rm W}$. We expect $p_{\rm W}$ to depend on educational characteristics $\left(Z^{\rm E}\right)$ and occupation $\left(Z^{\rm O}\right)$. We denote time spent working on the villager's land by $t_{\rm W}^{\rm I}$. We expect output on this land, O, to be a function of:

$$O = O\left(t_{\rm W}^{\rm I} k(S), Z^{\rm L}\right), \quad (4)$$

where $k$ is a shift operator depending on sickness, and $Z^{\rm L}$ is the land owned. The dependence of the villager's labor productivity on his/her health is a feature of efficiency wage models (Bardhan & Udry, 1999).

We assume that the villager sells all his/her agricultural output, and together with his/her wage earnings, buys food, other consumables, water supply, toilet, and village drain cleaning. Thus the budget constraint, denoting prices by $p$ with suitable subscripts, is:

$$t_{\rm W}^{\rm O} p_{\rm W} + t_{\rm W}^{\rm I} p^{\rm O} = p_{\rm F} C_{\rm F} + p_{\rm Other} C_{\rm Other} + p_{\rm water} W + p_{\rm L}^{\rm NW} L^{\rm NW} + p_{\rm L}^{\rm W} L^{\rm W} + p_{\rm D} D \quad (5)$$

Since water supply inside the house and toilet have important discrete and durable components, their "prices" in Equation 5 can be thought of as annualized costs. The villager's time constraint is:

$$T = t_{\rm L} - S - t_{\rm W}^{\rm O} - t_{\rm W}^{\rm I} \quad (6)$$

The villager aims to maximize his/her utility subject to the time and budget constraints. We substitute for $t_{\rm L}$ from Equation 6 into the utility function and then maximize the resulting utility subject to the budget constraint. Denoting the Lagrange by $J$, the first-order conditions are listed and discussed below.

$$\frac{\partial J}{\partial C_{\rm F}} = \frac{\partial U}{\partial C_{\rm F}} + \frac{\partial U}{\partial S}\frac{\partial S}{\partial C_{\rm F}} - \lambda p_{\rm F} = 0 \quad (7)$$

In Equation 7, the villager gets two kinds of benefits from consuming an extra unit of food: the direct utility from eating and the utility from lower sickness. The cost of the extra unit of food in utility terms is the product of the multiplier and the price of food.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

In the case of other consumption, there is only a direct utility benefit, and so first-order conditions:

$$\frac{\partial J}{\partial C_{\text{Other}}} = \frac{\partial U}{\partial C_{\text{Other}}} - \lambda p_{\text{Other}} = 0 \tag{8}$$

$$\frac{\partial J}{\partial W_{\text{A}}} = \left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_{\text{L}}} + \lambda \frac{\partial O}{\partial t_{\text{W}}^{\text{I}}} \frac{\partial k}{\partial S}\right] \frac{\partial S}{\partial E}\left[-\frac{\partial g1}{\partial W_{\text{A}}} - \frac{\partial g1}{\partial L_{\text{A}}^{\text{W}}} \frac{\partial L_{\text{A}}^{\text{W}}}{\partial W_{\text{A}}}\right] - \lambda p_{\text{water}} = 0 \tag{9}$$

In the condition 9 we see that having water in the house leads to the following benefits through less sickness, a direct utility benefit, greater leisure time, and greater productivity of the villager in agricultural production. The reduction in sickness is through a reduction in bacterial exposure, which in turn is through the direct effect of water in the house and the indirect effect of water availability on toilets that use water.

As we have described earlier, water supply inside the house versus getting water supply inside the house has an important discrete and durable component. Our interest is in tracing the pathways of effects between health and poverty and in embedded externality. It is easy to see the discrete version of Equation 9, in which the household will go in for the water supply if the benefits exceed the costs. The discrete version of Equation 9 is:

$$\left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_{\text{L}}} + \lambda \frac{\partial O}{\partial t_{\text{W}}^{\text{I}}} \frac{\partial k}{\partial S}\right] \frac{\partial S}{\partial E}\left[-\Delta E1W_{\text{A}} - \Delta E3W_{\text{A}}\right] > XW_{\text{A}}, \text{if } W_{\text{A}} > 0, \tag{10}$$

where $\Delta E1W_{\text{A}}$ denotes the reduction in bacterial contamination due to water supply inside A's house, and $\Delta E3W_{\text{A}}$ denotes the reduction in B due to water supply inside A's house (via encouraging water toilets). Also, $XW_{\text{A}}$ denotes the expenditure of $W_{\text{A}}$. For the rest of the first-order conditions, we will treat the discrete choices as continuous.

If A only considers the effect of water supply on his utility, he/she will ignore the positive externality of water supply inside his/her house on B. This is (since the agents are identical) equal to:

$$\left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_{\text{L}}} + \lambda \frac{\partial O}{\partial t_{\text{W}}^{\text{I}}} \frac{\partial k}{\partial S}\right] \frac{\partial S}{\partial E}\left[-\frac{\partial g5}{\partial L_{\text{A}}^{\text{W}}} \frac{\partial L_{\text{A}}^{\text{W}}}{\partial W_{\text{A}}}\right] \tag{11}$$

The increase in toilet use inside A's house by A reduces bacterial exposure of B through the function $g5$ in Equation 11. This lower bacterial exposure reduces B's sickness and affects B's utility directly, through increased leisure and greater productivity when B works on his/her farm.

The condition arising out of the choice of toilets is similar to Equation 9, and these choices are also going to generate externalities similar to Equation 11.

$$\frac{\partial J}{\partial L_{\text{A}}^{\text{NW}}} = \left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_{\text{L}}} + \lambda \frac{\partial O}{\partial t_{\text{W}}^{\text{I}}} \frac{\partial k}{\partial S}\right] \frac{\partial S}{\partial E}\left[-\frac{\partial g2}{\partial L_{\text{A}}^{\text{NW}}}\right] - \lambda p_{\text{LNW}} = 0 \tag{12}$$

$$\frac{\partial J}{\partial L_{\text{A}}^{\text{W}}} = \left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_{\text{L}}} + \lambda \frac{\partial O}{\partial t_{\text{W}}^{\text{I}}} \frac{\partial k}{\partial S}\right] \frac{\partial S}{\partial E}\left[-\frac{\partial g3}{\partial L_{\text{A}}^{\text{W}}}\right] - \lambda p_{\text{LW}} = 0 \tag{13}$$

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

The condition for choice of $D_A$ is:

$$\frac{\partial J}{\partial D_A} = \left[\frac{\partial U}{\partial S} - \frac{\partial U}{\partial t_L} + \lambda \frac{\partial O}{\partial t_W^I}\frac{\partial k}{\partial S}\right]\frac{\partial S}{\partial E}\left[-\frac{\partial g6}{\partial D_A}\right] - \lambda p_D = 0 \tag{14}$$

The choice of level of cleaning of drains by a household ($D_A$) affects the sanitary quality of drains, a key channel of transmission as we find in our empirical results. It is far more likely to suffer from sub-optimal provision than that of water supplied in A's house or toilet inside A's house, because A will be tempted to free-ride on B's provision of $D_B$, a tendency that will be strengthened if the number of agents is large.

Finally, we have the conditions relating to choice of how much time is spent in earning wages or in agricultural production.

$$\frac{\partial J}{\partial t_W^O} = -\frac{\partial U}{\partial t_L} + \lambda p_W = 0 \tag{15}$$

In Equation 15 there is a loss of utility from less leisure, while the benefit is income earned.

$$\frac{\partial J}{\partial t_W^I} = -\frac{\partial U}{\partial t_L} + \lambda\left[\frac{\partial O}{\partial t_W^I}k(S)\right] = 0 \tag{16}$$

In Equation 16 the income earned is affected by the level of sickness, and the cost is the loss of utility from reduced leisure.

## 4 | STUDY AREA AND DATA

Our village samples are from Uttarakhand, a state in the northern part of India. Uttarakhand was carved out of Uttar Pradesh, geographically the largest state of India, on November 9, 2000. It has 13 districts (equivalent to counties in the US), which fall under three distinct geographical regions: the high mountain, the mid-mountain, and the *Terai* plains. It is spread over 55,845 km$^2$ and has 16,826 inhabited villages. According to the 2011 census, the total population was just over 10 million, with an average density of 159 persons per square kilometer; the density varied significantly among districts. About 89% of the villages had a population of less than 500. The decadal population growth rate in the last census was 20.41%, slightly lower than 21.54% for the country. In terms of health outcomes, since its inception, Uttarakhand has been a poorly performing state in India, with infant and maternal mortality rates of 24 (per 1,000 births) and 192 (per 100,000 births), respectively in 2020 (GOI, 2022).

What distinguishes Uttarakhand from many other states of India is its geographic features. Approximately 93% of its geographical area is hilly and 63% is covered with forests. Therefore, it has starting disadvantages in the modernization of agriculture and access to safe drinking water. Only about half of the state was fully covered by functioning water supply schemes. Moreover, about 30% of the schemes suffer from water shortage, especially during the summer months. As a result, some villagers spend 1 to 3 h a day in collecting water for domestic uses. Water-related diseases are a significant health problem, particularly for infants and children.

According to our survey data, most of the toilets in Uttarakhand are pour-flush-type toilets. Though this technology is widely considered suitable for rural areas, special considerations are

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

needed given the challenges related to the area's topography (Wagner & Lanoix, 1958). Geological explorations are required to ascertain the risk of groundwater contamination from such toilets. A study assessing water quality in one of the districts (Nainital) in Uttarakhand finds that coliforms exceeded the permissible limits in 6 of the 28 samples (Jain, Bandyopadhyay, & Bhadra, 2010). Another study underscores that the structural inequalities in Uttarakhand are deeply intertwined with the practice of open defecation and limited update of sanitation (O'Reilly, Dhanju, & Goel, 2017).

We use data on 1,530 rural households from Uttarakhand, collected by The Energy and Resources Institute in 2004–2005, to investigate the relationship between the sanitary quality of neighborhood drains and household ill-health incidence associated with waterborne diseases. Our study covers 43 villages from 39 *gram panchayats*, the smallest administrative unit in India, spread across all 13 districts of Uttarakhand.[5] The 39 *gram panchayats* were selected from a list of representative *gram panchayats* provided by the state's Water and Sanitation Mission. Then a representative sample of 43 villages was selected, keeping in mind the representation of the villages with and without the presence of Swajal program. Swajal was a World Bank–assisted Government of India project to improve water supply and environmental sanitation services in some of the water-scarce regions of the state (Prokopy, 2005). More specifically, 12 of the 39 *gram panchayats* are covered under the Swajal program. Nine of the 39 *gram panchayats* are in the topographically plain region of the state. The survey collected data on household demographic characteristics, income, expenditures, poverty status, health, sanitation, and hygiene practices.

Table 2 presents the summary statistics of the variables in the study.[6] About 21.1% households have had ill-health incidences related to waterborne diseases in the 12 months preceding the survey. Alternatively, 4.1% of the household members are reported to have any of the six ill-health incidences associated with waterborne diseases. Approximately 59% of the households self-report to be poor, below the poverty line. Around 39.4% of the household heads have no formal schooling, 22.6% have a high school education, and only 6.0% of all household heads have a college education.

Approximately 51% of the households have a toilet inside their house, and 41% have access to drinking water inside their house. About 7.5% of the households reported that their neighborhood drains were clean, and 20.5% of the households reported that the toilets were constructed with the support of the government's toilet subsidies scheme.[7] About 38% of the sampled villages were located on plain terrain, and almost 30% of the villages were part of the Swajal program.

## 4.1 | Sanitary quality of neighborhood drains

The sanitary quality of neighborhood drain is measured at the household level. The survey respondents were asked to report the sanitary quality of their neighborhood drains by selecting one of the four given alternatives: very dirty, dirty, moderate, and clean.[8] Accordingly, 52% of the households report having dirty or very dirty neighborhood drains, and only 8% report having clean drains. However, there is a significant variation in the sanitary quality of drains across the districts. Approximately 57% of the households report dirty drains in the district of Pauri, followed by 41% in Nainital. The districts of Almora, Bageshwar, and Uttarkashi have relatively cleaner neighborhood drains.

For the empirical analysis, we define the sanitary quality of the neighborhood drain as a binary variable, which takes the value of 1 if the sanitary quality is reported to be clean;

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

**TABLE 2** Summary statistics

| Variable | Mean | Std. dev. |
|---|---|---|
| *Measures of ill-health* | | |
| Household's ill-health | 0.211 | 0.554 |
| Household's ill-health index | 0.041 | 0.113 |
| *Socioeconomic characteristics* | | |
| Poverty status | 0.578 | 0.494 |
| Male-headed household | 0.951 | 0.216 |
| Age of household head | 47.003 | 13.842 |
| Household size | 5.242 | 2.015 |
| Caste | 0.262 | 0.44 |
| No formal schooling | 0.394 | 0.489 |
| Primary school | 0.312 | 0.464 |
| High school | 0.226 | 0.418 |
| College or above | 0.067 | 0.251 |
| Occupation: agriculture | 0.324 | 0.468 |
| Occupation: casual labor | 0.263 | 0.441 |
| Occupation: services | 0.241 | 0.428 |
| Occupation: others | 0.171 | 0.377 |
| Land ownership | 0.691 | 0.462 |
| Distance to road | 0.322 | 0.467 |
| *Hygiene and sanitation* | | |
| Household toilet availability | 0.512 | 0.5 |
| Village toilet availability | 0.512 | 0.268 |
| Clean neighborhood drain | 0.075 | 0.267 |
| Toilet scheme | 0.205 | 0.404 |
| Water source away from toilet | 0.841 | 0.366 |
| Covered drinking water | 0.895 | 0.306 |
| Soap washing | 0.857 | 0.350 |
| Household water availability | 0.41 | 0.492 |
| *Others* | | |
| Plain | 0.379 | 0.485 |
| Swajal program | 0.297 | 0.457 |

otherwise, it takes the value of 0. Village drains transporting wastewater from household kitchens and bathrooms are decentralized network goods maintained by the corresponding cluster of rural households.[9] While we do not have data on water quality in each drain, we note that the likelihood of exposure to contamination due to leakage in the septic tank or the flush toilets is higher if open drains are poorly maintained (Jain et al., 2010).

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

## 4.2 | Household- and village-level toilet availability

To account for household- and community-level sanitation influences, we control for household- and village-level toilet availability (i.e., the percentage of households with toilets in a village). On average, 51% of the households have a toilet in our sampled villages.[10] It is reasonable to assume that, on average, a village with a higher percentage of households with toilets would have a lower level of open defecation. From the theoretical model in Section 3, it follows that the toilet availability in a village inversely approximates the village contamination load. In other words, it captures the effect of one household's lack of a toilet on other households' health due to increased contamination load resulting from open defecation. This prediction is consistent with recent studies documenting the health externality of open defecation (Hammer & Spears, 2016).

## 4.3 | Household ill-health incidence

The water and sanitation-related ill-health incidence of a household can be measured in different ways. We measured it by counting the household members with self-reported incidence of these six illnesses (diarrhea, cholera, typhoid, dysentery, worm infestation, and jaundice) in the 12 months preceding the survey date. More specifically, a household member was assigned the value of 1 if he or she had reportedly suffered from any (or more) of the six illnesses in the preceding 12 months.[11] A household's ill-health incidence is equal to the count of household members with at least one incidence of any of the six illnesses.[12] Since we add up the count of incidents across members in a household, our measure of household ill-health incidence is a count variable. Taking into account the distribution of our dependent variable, we specify and estimate suitable count data models.

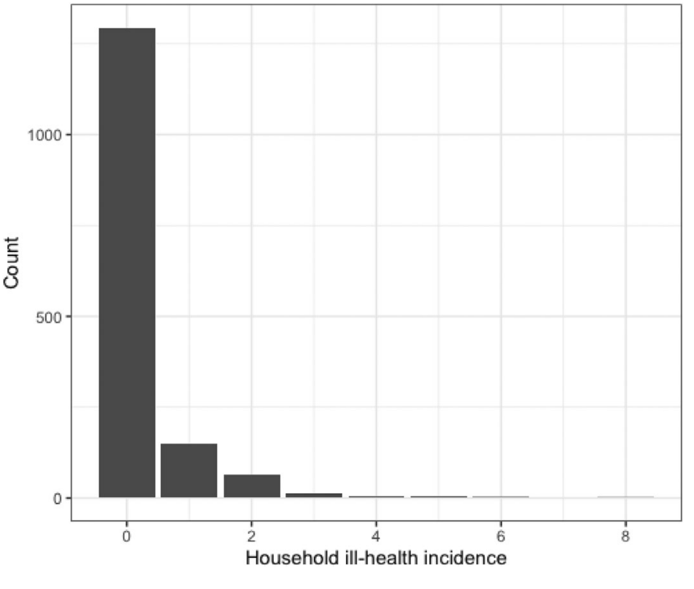


**FIGURE 2** Household ill-health incidence

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 3 Drain quality and proportion of households with waterborne disease

| Drain quality | Households reporting waterborne disease (%) |
|---|---|
| Very dirty | 17 |
| Dirty | 13 |
| Moderate | 16 |
| Good | 10 |

Figure 2 shows the distribution of household ill-health incidence. Most households report no such incident in the past year, but there are positive cases with some households reporting up to eight incidents in the past year. Table 3 emphasizes the relationship in Figure 2 by cross-tabulating the sanitary quality of neighborhood drains and the percentage of households with ill-health incidence. Approximately 17% of the households with "very dirty" neighborhood drains have ill-health incidences, whereas only about 10% of the household with "clean" neighborhood drains have ill-health incidences.

### 4.4 | Other potential determinants of households ill-health incidence

Table 2 provides the summary statistics of other potential determinants of household ill-health incidence, which has been informed by the F-diagram that shows the sanitary barriers to the movement of pathogens (Kawata, 1978; Kolsky, 1993). The diagram illustrates the several pathways for pathogen movement. It has been widely adopted as a principle in designing barriers for disease transmission, including soap washing, safe toilets, and drainage (WHO, 2005).

In our estimations we control for household size because larger households are more likely to have higher ill-health incidence, and they are more likely to have children and elderly, who are more vulnerable to bacteriological exposure. Access to a toilet at the household level is represented by a binary variable that takes the value of 1 if the household has access to a private toilet; otherwise, it takes the value of 0. There is a large economics literature on the health effect of income (Deaton, 2008). Therefore, to account for a household's economic status, we include a binary variable, poverty status,[13] which takes the value of 1 if a household is self-reported below the poverty line; otherwise, it takes the value of 0. Education is an important factor in health (see, e.g., Pritchett and Summers, 1996). Therefore, we control for a household's educational attainment by including the household head's educational attainment. We define four dummy variables to capture four levels of educational attainment (i.e., no formal school, primary school, high school, and college), respectively. The household heads without formal schooling serve as the baseline comparison group.

## 5 | EMPIRICAL MODEL OF HOUSEHOLD ILL-HEALTH INCIDENCE

We estimate the relationship between dirty neighborhood drains and household ill-health incidence using Equation 17, as specified below. Our dependent variable is household ill-health incidence ($H_{ij}$). Our key independent variable is the self-reported sanitary quality of the neighbourhood

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

drain ($NDrain_{ij}$). We exploit the variation in $NDrain_{ij}$ within a village $j$ at the household level to examine its association with household ill-health incidence, $H_{ij}$. From our theoretical model in Section 3, there will be an under-supply of household effort required for keeping the neighborhood drain clean, as a household may free-ride on the provision of efforts by other households in the neighborhood. Our baseline estimating equation is:

$$H_{ij} = \beta_0 + \beta_1{}^{*}NDrain_{ij} + \beta_2{}^{*}VL_j + \beta_3{}^{*}HHSize_{ij} + \delta^{*}OHC_{ij} + \gamma^{*}OVC_j + \varepsilon_i \tag{17}$$

where $H_{ij}$ denotes the ill-health incidence of household $i$ in village $j$, $NDrain_{ij}$ is the reported quality of the neighborhood drain of the household $i$ in village $j$, $VL_j$ is the extent of toilet availability in the village $j$, $HHSize_{ij}$ denotes household size, $OHC_{ij}$ is the vector of other household characteristics, $OVC_j$ is the vector of other village characteristics, and $\varepsilon_i$ is the stochastic error. We also control for an array of covariates, $OHC_{ij}$ including household poverty status, occupation, educational attainment, toilet inside the house, whether drinking water source is away from the toilet, and whether drinking water is covered.

Since $H_{ij}$ is a count variable, we estimate count data models. The natural choice for modeling a discrete count variable is Poisson model, but it is not suitable for our data given the over-dispersion in household ill-health incidence. The over-dispersion parameter is estimated to be 2.56, and a likelihood ratio test conclusively rejects that the null is equal to 0. Therefore, we use a negative binomial model to estimate our main empirical model, given that it is consistent with over-dispersion generated by a Poisson-gamma mixture, and it is considered to be a more flexible form for over-dispersed count data (Cameron & Trivedi, 2010). Throughout the estimations, the standard errors are clustered at the *gram panchayat* level.

## 6 | HYPOTHESIS AND RESULTS

We begin by discussing the results of the baseline estimating equation, examining the association between clean drains and household ill-health incidence. We expect a negative association between clean drains and household ill-health incidence. Then, we examine the association of household ill-health incidence with (1) lack of toilets in the village interacted with dirty drains and (2) safe drains (e.g., soak pits) interacted with drain quality. We expect the lack of toilets combined with dirty drains to be positively associated with ill-health incidence, as the exposure to contamination from open defecation is exacerbated by dirty drains. On the contrary, safe and clean drains are expected to be negatively associated with ill-health incidence. The mechanism could be that safe drains, such as soak pits, when clean, can further reduce the chance of exposure to bacteriological contamination. We then discuss a variety of robustness checks on the results.

### 6.1 | Main results

Table 4 presents the results of the negative binomial model (specified in Equation 17). The first row shows the relationship between our network good, the reported quality of the neighborhood drain, and household ill-health incidence. Empirically, a neighborhood drain is clean if its reported sanitary quality is clean (rather than moderately clean, dirty, or very dirty). The association between *clean neighborhood drain* and *household ill-health incidence* is consistently negative and statistically significant across specifications (Columns 1–4). As we move from Column

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4 Clean drains and household ill-health incidence

| Household ill-health incidence | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Clean neighborhood drain | −1.010* | −0.943* | −0.916* | −1.109** |
| | (0.400) | (0.410) | (0.426) | (0.372) |
| HH toilets | | −0.596** | −0.451+ | −0.654** |
| | | (0.205) | (0.232) | (0.214) |
| Village toilets (%) | | | −0.537 | −1.135** |
| | | | (0.654) | (0.376) |
| HH size | | | | 0.236** |
| | | | | (0.0454) |
| DW source away from toilet | | | | −0.933** |
| | | | | (0.282) |
| Drinking water covered | | | | −0.430* |
| | | | | (0.202) |
| Highest education (dummy) | | | | −0.962* |
| | | | | (0.488) |
| Other controls[a] | | | | Yes |
| Constant | −1.398** | −1.142** | −0.950** | −1.137* |
| | (0.147) | (0.157) | (0.258) | (0.533) |
| Observations | 1,431 | 1,431 | 1,431 | 1,431 |

*Note*: Standard errors in parentheses and clustered at GP level.
[a]Occupation, poverty status, Swajal, soap washing, plain, age, household head male, toilet scheme.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$.

1 to Column 4, we sequentially include additional controls. Note that the inclusion of controls enhances the precision of our estimates, particularly in Column 4, where we control for an array of household covariates, including reported water quality, hygiene, age, and gender of the household head.

We interpret the estimate from Column 4, since it accounts for the determinants theorized and explored in the literature and outlined in our model. The result shows that households that reported having clean neighborhood drains are associated with significantly lower ill-health incidence.[14] More specifically, by the incidence rate ratio interpretation of the estimates, the households living in the network of a clean neighborhood drain have 0.33 times lower ill-health incidence. The results on the association between clean drains and household ill-health incidence estimated using a generalized negative binomial model are identical.

Village toilet availability, which proxies for community-level sanitation and open defecation, has a statistically significant negative association with household ill-health incidence. The incidence rate ratio interpretation of the estimated association suggests that if villages were to increase toilet availability by one point, the average ill-health incidence of households would decline by a factor of 0.36, accounting for the contribution of other factors. Although our results should not be interpreted as a causal effect, they are in line with findings of previous studies (see Section 1). Despite the marginally higher significance of the village toilet availability, the negative association of the neighborhood drain quality and household ill-health incidence

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

persists. This substantive significance is the point we reiterate in this paper. Among other findings, household hygiene (covered drinking water) and sanitation (own toilet) are negatively associated with household ill-health incidence. These results are consistent with our model and the findings of the previous studies.

## 6.2 | Interaction effect

It is possible that the sanitary quality of the neighborhood drain and village open defecation rate, captured by village toilet availability, interact and reinforce each other in the determination of household ill-health incidence. For example, a clogged and overflowing drain exacerbates the problem of open defecation. Our theoretical model in Section 3 demonstrates this interaction effect.

Table 5 presents evidence for the positive association of household ill-health incidence with a proxy for the open defecation rate in the village (percentage of households with no toilet) interacted with dirty drains (Columns 1 and 2). In Columns 3 and 4, we examine the association of household ill-health incidence with the interaction between safe drains (i.e., soak pits and draining into the house garden) and the reported sanitary quality of the drain measured as an ordinal variable going from very dirty (1) to clean (4). The result is consistent with our hypothesis that the interaction between the two will have a negative effect on household ill-health where the safe and clean drains are negatively associated with ill-health incidents in the household.

## 6.3 | Validation and robustness checks

A potential concern is that both neighborhood drain quality and household ill-health incidence are self-reported measures. To mitigate it, we use an alternative measure of neighborhood drain

**TABLE 5** Dirty drains aggravate ill health, safe and clean drains mitigate

| Household ill-health incidence | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Village no toilets × drain dirty | 0.713** | 0.694** | | |
| | (0.253) | (0.248) | | |
| Drain clean | −0.986 | −1.025* | | |
| | (0.663) | (0.517) | | |
| Safe drain × drain quality | | | −0.243* | −0.224* |
| | | | (0.0982) | (0.0982) |
| Drain quality | | | −0.196+ | −0.228* |
| | | | (0.116) | (0.106) |
| Other controls | | Yes | | Yes |
| Village dummies | Yes | Yes | Yes | Yes |
| Constant | 0.561* | 0.325 | 0.580* | 0.336 |
| | (0.229) | (0.253) | (0.234) | (0.253) |
| Observations | 1,343 | 1,343 | 1,343 | 1,343 |

*Note*: Standard errors in parentheses and clustered at GP level.
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

quality and estimate its association with household ill-health incidence. For the validity of the result on association between the self-reported measures of neighborhood drain quality and household ill-health, the results obtained from using the alternative measures should be consistent. Furthermore, we examine related variables, reported toilet (a private good inside the household) maintenance and frequency of its cleaning to see if the associations with household ill-health incidence are similar. If the associations are similar, they may suggest reporting biases driving the association between neighborhood drain quality and household ill-health incidence. If the associations are not similar, they may strengthen the validity of our finding of strong associations between household ill-health incidence and neighborhood drain quality.

Further, we use additional measures of neighborhood drain quality and open defecation to provide additional robustness check on our findings. First, we define it as a dummy variable representing a dirty drain (i.e., very dirty or dirty rather than moderate or clean) compared to clean drains (i.e., clean rather than moderately clean, dirty, or very dirty). Second, we define it as an ordinal measure of drain quality (1–4). Third, we use a direct measure of reported open defecation as opposed to the toilet availability in the village.[15]

### 6.3.1 | Self-reports of drain maintenance versus toilet maintenance

The survey data also collected information about maintenance of neighborhood drains. Households were asked how the drains were maintained (good, moderate, bad) and the frequency of their cleaning (from daily to never). We classified the responses on the frequency of cleaning as drains that were regularly maintained (daily to at least once a week) to not regularly maintained (less than once a week to never). The corresponding results are presented in Table 6 (Columns 1 and 2), and they are qualitatively similar to the results obtained from using the self-reported measure of neighborhood drain quality.

**TABLE 6** Drain (maintenance and cleaning) versus toilet

| Household ill-health incidence | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Drain maintenance good | −0.506* | | | |
| | (0.199) | | | |
| Drain cleaning (regular) | | −0.541+ | | |
| | | (0.307) | | |
| Toilet maintenance good | | | 0.150 | |
| | | | (0.192) | |
| Toilet cleaning (regular) | | | | −0.414 |
| | | | | (0.309) |
| Other controls | Yes | Yes | Yes | Yes |
| Constant | −4.742** | −2.916** | −1.867* | −1.294 |
| | (0.873) | (1.044) | (0.902) | (0.899) |
| Observations | 692 | 692 | 724 | 724 |

*Notes*: Standard errors in parentheses and clustered at GP level; other controls as in Table 4 (Col. 4).
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Similarly, we estimate the results using a variable representing household toilet maintenance (good, moderate, bad) and the frequency of toilet cleaning, and we find that they have no significant association with household ill-health incidence. This suggests that the neighborhood drain quality variable in our main estimation captures neighborhood sanitation externalities and it is less likely from household reporting bias. If the household reported measure of neighborhood drain quality was biased in a particular direction, one would expect it to be similar for other self-reported measures such as toilet maintenance. Our results suggest that self-reporting bias may not be driving the results. The reported drain maintenance and cleaning variables remain significantly associated with household ill-health. In contrast, the reported toilet maintenance and their frequency of cleaning are insignificant (Columns 3 and 4 in Table 6).

### 6.3.2 | Alternative coding of drain quality and open defecation

As another robustness check, we vary the construction of the neighborhood drain quality measure. To reiterate, the households had to report their neighborhood drain quality on a scale going from very dirty to clean. We use it as an ordered categorical variable measuring neighborhood drain quality.[16] As yet another (third) alternative, we define a *dirty drain* dummy variable if the neighborhood drains were reported to be very dirty or dirty (as opposed to being moderate or clean) compared to clean drain in the main estimation. If clean drains reduce household ill-health incidence, then dirty drains should increase it.

**TABLE 7** Alternative coding: robustness checks

| | **Dependent variable: HH ill-health incidence** | | |
|---|---|---|---|
| | **(1)** | **(2)** | **(3)** |
| Drain quality | −0.264** | | |
| | (0.089) | | |
| Dirty drain | | 0.475* | |
| | | (0.220) | |
| Clean drain | | | −1.172** |
| | | | (0.358) |
| Open-defecation (reported) | | | −0.565 |
| | | | (0.551) |
| Other controls | Yes | Yes | Yes |
| Constant | −0.481 | −1.216* | −1.587** |
| | (0.720) | (0.535) | (0.547) |
| Constant | 0.866** | 0.936** | 0.969** |
| | (3.88) | (4.68) | (5.70) |
| Observations | 1,343 | 1,431 | 1,431 |

*Notes*: Ordered drain quality coding: 1 very dirty, 2 dirty, 3 moderate, 4 clean; standard errors in parentheses and clustered at GP level; other controls as in Table 4 (Col. 4).
$^{+}p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

The corresponding results are presented in Table 7. Accordingly, the drain quality (ordered measure of neighborhood drains quality) is statistically significant. The dirty drain dummy is also statistically significant and has the expected positive sign (Column 2). To interpret, the incidence rate increases to 1.91 times the base rate (the group with drains not reported as dirty). Essentially households with dirty drains have twice the waterborne disease incidents compared to other households.

As a final robustness exercise, we construct another measure of open defecation in the village as a covariate in our model. The survey asked the households to report the number of own household members defecating in the open. We use this measure to construct the percentage of members in the sample from the villages reporting open defecation. Although the aggregate of reported open defecation is not a significant predictor of household ill-health incidence, the sign and substantive significance of clean drains, our variable of interest, is very similar (Column 3, Table 7) to the coefficient on the main estimation (Column 4, Table 4).

## 7 | CONCLUSIONS

We argue that sanitary quality of neighborhood drains, in addition to toilets, is associated with household ill-health incidence in developing countries. We make the case that dirty neighborhood drains are a key vector of pathogen transfer by focusing on household behavior under environmental risks. We provide the empirical support for our argument by examining the association between household ill-health incidence and dirty neighborhood drains using a primary survey of 1,530 households from Uttarakhand, India. We find that households reporting clean drains in their neighborhood have about one-third the incidence rate of waterborne diseases compared to those reporting that their drains to be dirty. This result persists even after controlling for a variety of observable covariates, and the estimated coefficients do not vary substantially in the robustness checks. Our result provides empirical support for bringing policy attention to the sanitary quality of village drains in India and other developing countries. Our findings suggest that improving drain quality, along with increased access to sanitation facilities, could address sanitation externalities in rural health in India.

Our study provides further insights into the policy of toilet construction in India, which has been a focus of the central government to eliminate open defecation. Given social and cultural norms around open defecation, toilet construction alone is unlikely to eradicate open defecation and improve health outcomes. As a result, multi-pronged strategies, including information campaigns to nudge toilet use, have been advocated and implemented in many parts of India. While such a strategy has shown promise, our findings highlight another crucial factor—*investment in improving the neighborhood drains*, a network good. Improving neighborhood drains is potentially a more effective strategy since it contributes directly to household ill-health incidence and has the potential to mitigate the disease burden of open defecation. The public investment in constructing and maintaining low-cost drainage systems in rural areas is a challenge. However, advances in wastewater treatment technologies, such as locally constructed wetlands, that are easily operated and maintained have lowered these costs, and they have been adopted successfully by small rural communities in many developing countries (Kivaisi, 2001; Vymazal, 2011).

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

## ACKNOWLEDGMENTS

We thank the numerous seminar participants at the Delhi School of Economics, the International Institute of Social Studies, Norwegian University of Life Sciences, the University of Chicago, Resources for the Future and, the World Bank for helpful discussions and comments.

## DATA AVAILABILITY STATEMENT

Our data are publicly available for fair use on Mendeley Data and should be cited as: Murugesan, Anand (2020), Drains, Sanitation and Health in Uttarakhand, India, Mendeley Data, V1, doi: https://doi.org/10.17632/2c3kzy4v93.3.

## ORCID

*Vikram Dayal* https://orcid.org/0000-0001-6411-7783
*Anand Murugesan* https://orcid.org/0000-0002-4372-7803

## ENDNOTES

[1] The Government of India had worked toward a goal of eliminating open defecation by 2019 through the Swachh Bharat Mission. Nonetheless, India still accounts for the largest share of the open defecation in the world, with more than 500 children under age five dying each day from diarrhea.

[2] Although recent magazine and newspaper articles have begun highlighting the issue of dirty drains, for example, Rajagopalan (2018), the academic and policy focus has emphasized toilets and overlooked drains.

[3] For instance, greater cultural acceptance of toilets by Muslim community in India partly explains lower infant mortality rates in Muslim neighborhoods (Geruso & Spears, 2018).

[4] Two recent movies, *Toilet: Ek Prem Katha* (translates to *Toilet: A Love Story*) in 2017 and *Padman* in 2018 brought further attention to sanitation and use of sanitary pads, especially in rural India.

[5] Anand Murugesan supervised the data collection.

[6] See Table A1 in the Appendix for more detailed variable definitions.

[7] As described in Section 2, the Government of India program *Indira Awas Yojana* was implemented by the state rural development department and provided subsidies for toilet construction across the state.

[8] The survey enumerators also visually inspected and verified the reported sanitary quality of drains.

[9] The sewage management problem extends to urban India as well, where typically it is centrally managed at the city level and arguably worse due to population density. For more information, see https://www.indiawaterportal.org/articles/sewage-management-govts-elephant-room.

[10] The 2001 Census estimates it to be 31% and according to a survey by the Rajiv Gandhi National Drinking Water Mission (RGNDWM), it was approximately 22% in 2003. Our estimate is higher than the Census estimate because a push for toilet construction at the turn of the millennium coincided with the Census. The discrepancy between the Census and RGNDWM estimates can be attributed to their different definitions of household toilets. The RGNDWM counts only sanitary toilets, excluding pit and other types of toilets counted by the Census.

[11] There is a trade-off between shorter and extended recall periods. Twelve-month recall period was used because of the survey's focus on incidence of waterborne illnesses, which vary seasonally during a year. For an excellent discussion on this issue, see Kjellsson, Clarke, and Gerdtham (2014).

[12] This does not account for the frequency and duration of ill-health incidence. In our measurement, a member of the household was assigned 1 if he suffered at least once from any of the six illnesses.

[13] We do not study the causal effect of poverty or income on health. Rather, we examine the association between drain quality and ill-health incidence, while controlling for poverty status.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

[14] We estimate the main specification with the inclusion of village or district dummies to control for time-invariant characteristics at that region's level. The results on drain quality are very similar. The results in the specification are robust to the inclusion of variables accounting for the age distribution of the members in the household: the number of children and the age of the oldest member to capture the household's vulnerability to infections and disease.

[15] We also estimate our main model with alternative probability models (Poisson, OLS, Generalized Negative Binomial) and find qualitatively similar results. Additionally, the estimated coefficients are stable across specifications which we check by using the procedure developed by Altonji, Elder, and Taber (2005) and formalized by Oster (2019).

[16] The full scale of options available to the respondents in the survey were very dirty, dirty, moderate, clean.

## REFERENCES

Altonji, J. G., Elder, T. E., & Taber, C. R. (2005). Selection on observed and unobserved variables: Assessing the effectiveness of catholic schools. *Journal of Political Economy*, *113*(1), 151–184.

Bardhan, P., & Udry, C. (1999). *Development microeconomics*. Oxford: Oxford University Press.

Cameron, A. C., & Trivedi, P. K. (2010). *Microeconometrics using stata* (Vol. 2). College Station, TX: Stata press.

Cameron, L., Olivia, S., & Shah, M. (2019). Scaling up sanitation: Evidence from an rct in Indonesia. *Journal of Development Economics*, *138*, 1–16.

Dasgupta, P. (1993). *An inquiry into well-being and destitution*. Oxford: Clarendon Press.

Deaton, A. (2008). Income, health, and well-being around the world: Evidence from the Gallup world poll. *Journal of Economic Perspectives*, *22*(2), 53–72.

Dickinson, K. L., Patil, S. R., Pattanayak, S. K., Poulos, C., & Yang, J.-H. (2015). Nature's call: Impacts of sanitation choices in Orissa, India. *Economic Development and Cultural Change*, *64*(1), 1–29.

Freeman, M. C., Garn, J. V., Sclar, G. D., Boisson, S., Medlicott, K., Alexander, K. T., et al. (2017). The impact of sanitation on infectious disease and nutritional status: A systematic review and meta-analysis. *International Journal of Hygiene and Environmental Health*, *220*(6), 928–949.

Gamper-Rabindran, S., Khan, S., & Timmins, C. (2010). The impact of piped water provision on infant mortality in Brazil: A quantile panel data approach. *Journal of Development Economics*, *92*(2), 188–200.

Geruso, M., & Spears, D. (2018). Neighborhood sanitation and infant mortality. *American Economic Journal: Applied Economics*, *10*(2), 125–162.

GOI. (2022). *Sample registration system bulletin*. Retrieived from https://censusindia.gov.in/nada/index.php/catalog/42687/study-description. Last accessed July 19, 2022.

Gupta, A., Khalid, N., Desphande, D., Hathi, P., Kapur, A., Srivastav, N., … Coffey, D. (2019). Changes in open defecation in rural North India: 2014–2018. *IZA Discussion Paper*.

Hammer, J., & Spears, D. (2016). Village sanitation and child health: Effects and external validity in a randomized field experiment in rural India. *Journal of Health Economics*, *48*, 135–148.

Jain, C., Bandyopadhyay, A., & Bhadra, A. (2010). Assessment of ground water quality for drinking purpose, district Nainital, Uttarakhand, India. *Environmental Monitoring and Assessment*, *166*(1–4), 663–676.

Jalan, J., & Ravallion, M. (2003). Does piped water reduce diarrhea for children in rural India? *Journal of Econometrics*, *112*(1), 153–173.

Kawata, K. (1978). Water and other environmental interventions—The minimum investment concept. *The American Journal of Clinical Nutrition*, *31*(11), 2114–2123.

Kiulia, N., Netshikweta, R., Page, N., Van Zyl, W., Kiraithe, M., Nyachieo, A., … Taylor, M. (2010). The detection of enteric viruses in selected urban and rural river water and sewage in Kenya, with special reference to rotaviruses. *Journal of Applied Microbiology*, *109*(3), 818–828.

Kivaisi, A. K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: A review. *Ecological Engineering*, *16*(4), 545–560.

Kjellsson, G., Clarke, P., & Gerdtham, U.-G. (2014). Forgetting to remember or remembering to forget: A study of the recall period length in health care survey questions. *Journal of Health Economics*, *35*, 34–46.

Kolsky, P. (1993). Water, sanitation and diarrhoea: The limits of understanding. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *87*, 43–46.

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Murugesan, A., Dayal, V., & Chugh, S. (2009). An empirical study of sanitation and health in rural Uttarakhand, India. *International Journal of Ecological Economics & Statistics*, *10*(W08), 91–99.

Norman, G., Pedley, S., & Takkouche, B. (2010). Effects of sewerage on diarrhoea and enteric infections: A systematic review and meta-analysis. *The Lancet Infectious Diseases*, *10*(8), 536–544.

Null, C., Stewart, C. P., Pickering, A. J., Dentz, H. N., Arnold, B. F., Arnold, C. D., et al. (2018). Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Kenya: A cluster-randomised controlled trial. *The Lancet Global Health*, *6*(3), e316–e329.

O'Reilly, K., & Louis, E. (2014). The toilet tripod: Understanding successful sanitation in rural India. *Health & Place*, *29*, 43–51.

O'Reilly, K., Dhanju, R., & Goel, A. (2017). Exploring "the remote" and "the rural": Open defecation and latrine use in Uttarakhand, India. *World Development*, *93*, 193–205.

Oster, E. (2019). Unobservable selection and coefficient stability: Theory and evidence. *Journal of Business & Economic Statistics*, *37*(2), 187–204.

Pattanayak, S. K., & Pfaff, A. (2009). Behavior, environment, and health in developing countries: Evaluation and valuation. *Annual Review Resource Economics*, *1*(1), 183–217.

Pritchett, L., & Summers, L. H. (1996). Wealthier is healthier. *Journal of Human Resources*, *31*(4), 841–868.

Prokopy, L. S. (2005). The relationship between participation and project outcomes: Evidence from rural water supply projects in India. *World Development*, *33*(11), 1801–1819.

Rajagopalan, S. (2018). India needs sewage systems, not free toilets. *Live Mint*. Retrieved from https://www.livemint.com/Opinion/P4KqJAVPAcXdnRgFtnHpIK/India-needs-a-sewage-system-not-free-toilets.html.

The World Bank. (2020). *World development indicators online database*.

Unicef et al. (2017). *Progress on drinking water and sanitation: 2014 update*. New York: United Nations Children's Fund.

Vymazal, J. (2011). Constructed wetlands for wastewater treatment: Five decades of experience. *Environmental Science & Technology*, *45*(1), 61–69.

Wagner, E. G., & Lanoix, J. N. (1958). *Excreta disposal for rural areas and small communities*. Geneva: World Health Organization.

Watson, T. (2006). Public health investments and the infant mortality gap: Evidence from federal sanitation interventions on us indian reservations. *Journal of Public Economics*, *90*(8–9), 1537–1560.

WHO. (2005). *Sanitation and hygiene promotion: Programming guidance*. Geneva: World Health Organization.

**How to cite this article:** Dayal, V., Murugesan, A., & Rahman, T. (2022). *Drain on your health*: Sanitation externalities from dirty drains in India. *Review of Development Economics*, *26*(4), 2251–2273. https://doi.org/10.1111/rode.12924

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

## APPENDIX

**FIGURE A1** An overflowing drain in one of the sampled villages (Haridwar, Uttarkhand) [Colour figure can be viewed at wileyonlinelibrary.com]

**TABLE A1** Variable definitions

| Variables | Definition |
|---|---|
| *Measure of ill-health* | |
| Household's ill-health | Number of members in the family with incidence of illness in the last 12 months |
| *Socioeconomic characteristics of households* | |
| Poverty status | Household is below the poverty line |
| Male-headed household | Head of the household is male |
| Age of household head | Age of the household head (in years) |
| Household size | Total members in the household |
| Caste | Scheduled caste or scheduled tribe household |
| No formal schooling | No formal schooling of the household head |
| Primary school | The household head has primary school education |
| High school | The household head has high school education |
| College and above | The household head has at least college education |
| Agriculture | The primary occupation of the household is agriculture |
| Casual labor | The primary occupation of the household is casual labor |
| Services | The primary occupation of the household is services |

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE A1 (Continued)

| Variables | Definition |
|---|---|
| Others | The primary occupation of the household is others |
| Land ownership | Household owns some amount of land |
| Distance to road | The distance between the household and the main road is greater than 1 km (0.62 mile) |
| *Hygiene behavior* | |
| Household toilet availability | Household has a toilet in the house |
| Village toilet availability | Percentage of toilet availability in the village |
| Clean neighborhood | Neighborhood drainage is clean or very clean |
| Water source away from toilet | Household's water source is 10 m away from toilet |
| Covered drinking water | Household covers stored drinking water |
| Soap washing | Household reports hand washing with soap |
| Household water availability | Water is available inside the house |
| *Others* | |
| Plain | The terrain of the village is plain |
| Swajal program | The village had the Swajal program |
| Toilet scheme | The household toilet construction was subsidized |

14679361, 2022, 4, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/rode.12924, Wiley Online Library on [30/06/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License