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Impact of different irrigation systems on water quality in peri-urban areas of Gujarat, India

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Abstract

The ever-growing population of India, along with the increasing competition for water for productive uses in different sectors – especially irrigated agriculture and related local water systems and drainage – poses a challenge in an effort to improve water quality and sanitation. In rural and peri-urban settings, where agriculture is one of the main sources of livelihood, the type of water use in irrigated agriculture has complex interactions with drinking water and sanitation. In particular, the multi-purpose character of irrigation and drainage infrastructure creates several interlinks between water, sanitation (WATSAN) and agriculture and there is a competition for water quantity between domestic water use and irrigated agriculture. This study looks at the determinants of the microbiological quality of stored drinking water among households residing in areas where communities use different types of irrigation water. The study used multiple tube fermentation method 'Most Probable Number (MPN) technique, a WHO recommended technique, to identify thermotolerant fecal coliforms and E. *coli* in water in the laboratory (WHO 1993). Overall, we found that the microbiological water quality was poor. The stored water generally had very high levels of Escherichia coli (E. coli) contamination, 80% of the households had water in storage that could not be considered potable as per the World Health Organization (WHO) standards, and 73% of the households were using a contaminated water source. The quality of household storage water was largely unaffected by the major household socioeconomic characteristics, such as wealth, education level or social status. Households using surface water for irrigation had poor drinking water quality, even after controlling for hygiene, behavioral and community variables. Drinking water quality was positively impacted by proper storage and water treatment practices, such as reverse osmosis. Hygiene and sanitation indicators had mixed impacts on the quality of drinking water, and the impacts were largely driven by hygiene behavior rather than infrastructures. Community open defaecation and high village-household density deteriorates household storage water quality.

Keywords: Irrigation water; Water Quality; Water Storage; Water Treatment; Sanitation and Hygiene; Health Behaviour; India; Gujarat

JEL classification: C83; C88; D13; I18; O10; O12; O15; Q25; Q50; Q53

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Abbreviations

WATSAN	Water and Sanitation
WHO	World Health Organization
UNICEF	United Nations Children’s Fund
JMP	Joint Monitoring Programme
MPN	Most Probable Number
POS	Point of Source
POU	Point of Use
PSU	Primary Sampling Units
RO	Reverse Osmosis
E. coli	Escherichia coli

1. Introduction

In rural and peri-urban settings, where agriculture is one of the main sources of livelihood, the type of water used in irrigated agriculture has complex interactions with drinking water and sanitation. The multi-purpose character of irrigation and drainage infrastructure creates several interlinks between water, sanitation (WATSAN) and agriculture.

Irrigation water plays an important role in the microbial contamination of domestic drinking water through the interaction of humans and animals with irrigation water. For instance, irrigation canals are used by villagers for domestic purposes and by animals, mainly cattle, and have high levels of faecal coliform bacteria (Rajasooriyar et al. 2013). After sitting in contaminated surface water, livestock return to their shelter with high amounts of faecal coliforms, which could contaminate household drinking water. Farmers working in paddy fields may also contaminate household drinking water. They have to be in water for long hours and without proper protection they are exposed to faecal coliforms, which are very abundant in wastewater. If the farmers do not observe proper protection, handwashing and hygiene, they could contaminate their household drinking water. These are only two of the many examples of the linkages between irrigation and drinking water quality. In his discussion about irrigated agriculture, Reiff noted that water pollution is both a cause and an effect in the linkages between agriculture and human health (Reiff 1987).

Large volumes of urban effluent are discharged without prior treatment into the communal drainage of the peri-urban areas along the water course (Sabarmati River in Ahmedabad), and water contaminated by the effluent are often used for irrigation. Sources of urban effluent include urban household sewage, industrial wastes and hospital effluent (Emmanuel et al. 2005) Microbiological characterization studies in several industrialized countries have found pathogenic microorganisms in hospital effluent, some of which are multi-resistant to antibiotics (Emmanuel, Pierre, and Perrodin 2009). A recent study by (Walsh et al. 2011) gained worldwide attention after finding bacteria that produce purely nosocomial NDM-1 β-lactamase (New Delhi Metallo-beta-lactamase-1) in environmental samples, including some drinking water samples in New Delhi. This enzyme makes bacteria resistant to beta-lactam antibiotics, therefore posing serious threat to public health.

Surface runoff, and consequently non-point source pollution, contributes significantly to high pathogen levels in surface water bodies. In turn, the seepage of pollutants from surface and subsurface sources of pollution leads to groundwater pollution. A study conducted in an urban setting in India found that none of the groundwater samples were suitable for drinking because they contain a high concentration of total and faecal coliform (Sukumaran, Saha, and Saxena 2015).

Studies have also found a negative relationship between the proximity of latrines to groundwater and the groundwater's microbiological quality in a rural setting (Mahadevan and Krishnaswamy 1984; Megha et al. 2015).Groundwater contamination is an even bigger problem in peri-urban areas, where population is dense, drainage systems are not developed, and water infrastructure is located closely to on-site sanitation systems. Pit latrines and sceptic tanks are common types of on-site sanitation facility in rural areas of India and are sources of groundwater contamination. A study conducted in peri-urban areas of India found seepage of sewage into groundwater from improperly designed rural sanitation facilities (Shivendra and Ramaraju 2015).

In addition, drinking water in distribution systems can suffer serious contamination because of breaches in the integrity of pipework and storage reservoirs. Many outbreaks of waterborne diseases have been attributed to such events. For instance, a study on a cholera outbreak in a Kolkata slum community identified that leakages in the main pipeline, which supplies drinking water to the area, led to E. coli contamination in drinking water at source (Sur et al. 2006). Therefore, safe drinking water could be best achieved by adopting a holistic approach based on design, operational practices, and maintenance procedures that take biological hazards into account.

1.1 WATSAN Infrastructure and water quality

To allow for international comparability, the Joint Monitoring Programme (JMP) for Water Supply and Sanitation by the WHO and UNICEF classifies drinking water sources and sanitation facilities as "improved" or "unimproved". Studies have shown that improved drinking water sources can significantly reduce the occurrence of waterborne pathogens at the source (Cutler and Miller 2005). However, global access to safe drinking water, which the JMP defined as access to improved sources, does not account for measures of water quality. For instance, a systemic review conducted by use (Bain et al. 2014) concluded that international estimates have greatly overstated the rate of safe drinking water use. This is because while an improved source provides a measure of sanitary protection, it does not ensure water is free from fecal contamination. Hence, an enhanced monitoring strategy should combine indicators of sanitary protection with measures of water quality.

Further, the bacteriological quality of drinking water significantly declines after collection in many instances, thus pointing to a more complex issue than the quality of drinking water at source. A systemic review of difference in the level of microbiological contamination between the point of source (POS) and point of use (POU) conducted by Wright et al. (2004) found that the microbiological quality of water declined significantly after water was collected in approximately half of the included studies. The decline in water quality from the POS to the POU, measured in terms of faecal and total coliforms, was proportionately greater when source water is largely uncontaminated, often obtained from “improved” water sources (Wright, Gundry, and Conroy 2004). A study conducted by Satapathy (2014) showed that in urban slums of India, the fecal coliform level in water at the POU was 22% higher than at the POS on average. Clearly, policies that aim to improve water quality through source improvements may be undermined by poor hygiene and post-collection contamination.

1.2 WATSAN infrastructure, water quality and impact on health

The impact of water quality on human health is not the topic of this particular paper, but health and nutrition outcomes will be the subject of an upcoming study on the same set of households studied in this paper. Nevertheless, as health issues are our main motivation for investigating the determinants of water quality, it affected our choice of water quality indicators. Traditionally, the impact of drinking water quality on human health has been assessed via epidemiology (Hunter, Waite, and Ronchi 2002), and in both developing and developed regions, pathogens are generally considered a larger health risk than toxic chemicals (Craun 1993; Downs, Cifuentes-Garcia, and Suffet 1999).

Studies have shown that disease-causing organisms transmitted via drinking water are predominantly of faecal origins (Ashbolt, Grabow, and Snozzi 2001; Hunter et al. 2002) . E. coli is extremely sensitive to disinfection (LeChevallier 2003), and the efficacy of drinking water treatment in removing bacterial pathogens responsible for enteric diseases is well measured by the common faecal indicator bacterium Escherichia coli (E. coli), excreted in the feces of all warm-blooded animals and some reptiles (Edberg et al. 2000; Enriquez, Nwachuku, and Gerba 2001). In this context, microbiological water testing is a key component of WATSAN efforts towards improving health.

Our study used the multiple tube fermentation method ‘Most Probable Number (MPN) technique, a WHO recommended technique, to identify thermotolerant fecal coliforms and E. coli in water in the laboratory (WHO 1993). WHO considers a water sample non-potable if one or more E. coli are present in the water sample. WHO also classifies drinking water into five risk categories according to the E. coli count per 100 ml of water sample: 0 (in conformity with WHO guidelines), 1-10 (low risk), 10-100 (intermediate risk), 100-1000 (high risk), >1000 (very high risk) (WHO 1997).

The current study explores the determinants of the microbiological quality of drinking water among households in Ahmedabad, a peri-urban area with different WATSAN infrastructures and different irrigation water types. WATSAN infrastructure, hygiene, directly or indirectly impacts health outcomes in households through improving water quality at the point of use. Type of water used in irrigation can further have an effect on household water quality through its human and animal interactions and groundwater contamination, for 90% of the water is used mainly in irrigation. The study hypothesis is that the communities exposed to different types of irrigation water are affected differently on their household water quality status due to the interaction of irrigation water with sanitation and hygiene. The hygiene and sanitation behavior of the community and their use of information regarding linkages between WATSAN to irrigation would improve household water quality and health outcomes and eventually to identify better strategies of linking water uses for 'WATSAN' and irrigation agriculture activities to improve health and nutrition status.

Many studies have looked at the impact of WATSAN and hygiene on health. Studies have shown that health benefits of access to clean drinking water only occur when proper sanitation and hygiene facilities are in place and when a community adopts proper hygiene practices (Brick et al. 2004; Checkley et al. 2004). For example the systemic reviews to assess the impact of inadequate water and sanitation on diarrhoeal disease in low and middle-income settings have shown that overall improvements in drinking water and sanitation were associated with decreased risks of diarrhoea. However greater reductions in diarrhoea were seen with interventions as the use of water filters, provision of high-quality piped water and sewer connections (Fink, Günther, and Hill 2011; Kumar and Vollmer 2012; Wolf et al. 2014) (Waddington et al. 2009). In another randomized controlled trial experiment in urban Morocco the study suggested that improved water infrastructure did not improve the water quality and health benefit rather improved the time saving and intra-household conflict (Devoto et al. 2011).

Many studies on wastewater and its impact on health have been conducted. In a study on impact of irrigation water quality on human health found higher rates of morbidity in the wastewater irrigated villages when compared to the control village(Srinivasan and Reddy 2009) The research report by the Winrock Foundation (2005) mentions the health risks associated with wastewater use for irrigation (Gupta 2005). A study by (Reiff 1987) noted that water pollution is both a cause and an effect in the linkages between agriculture and human health (Reiff 1987).

This paper differs from the previous studies in terms of study setting and microbiological quality of water. The contribution of this paper is to analyze the impact of irrigation water on household water quality by investigating the E. coli, water, sanitation and hygiene, in the peri urban setting. WHO recommended 'Most Probable Number' (MPN) technique to test the E coli in household water was performed in a laboratory setting. The importance of this study lies in the fact that previous studies have analyzed these factors in isolation, thus ignoring the inherent linkages and trade-offs between them. Our contribution to this field of study lies in identifying the nexus between water, sanitation infrastructure, hygiene and irrigation agriculture and assessing their implication for prioritizing investments in improving water quality and health among communities exposed to different irrigation types, while taking into account context-specific constraints.

The next section describes our sampling design and the setting in which our survey took place. Section 3 presents the descriptive statistics, Section 4 outlines our empirical strategy, Section 5 presents the estimation results, Section 6 concludes this paper with the discussion of the results, Section 7 presents recommendations and potential policy implications and section 8 briefly discusses the strengths and the limitations of our study.

2. Sampling Design and Setting

The survey sampling was designed to ensure that the sample was random and representative of the overall population exposed to irrigation farming and its produce. The overall sample size was determined by taking into account the prevalence of key indicators, the subgroups for which the indicators are required, the desired precision of the estimates, the availability of resources, and logistical considerations. According to the Coverage Evaluation Survey 2009, India, the national incidence of acute diarrhea in children aged 0-2 years was 24% (UNICEF 2010). Applying the expected diarrhea incidence and a precision of 0.05, the sample size for children was calculated to be 280. Both the control and treatment groups in this study included 300 under-five children. The prevalence of malnutrition in Gujarat in 2006 was 45% (IIPS 2007).Therefore, a sample size of 380 was needed for each group to achieve a precision of 0.05; however, because a lower precision (0.06) was chosen, a sample size of 280 for each group was sufficient. For the adult group, the age- and gender-specific incidence of acute diarrhea and other acute illnesses were to be calculated. With 330 households in each of the five groups, the expected sample size was sufficient (the average family size in a village household was five on an average).

The sample selection was done in two stages. First, primary sampling units (PSU) were randomly chosen from peri-urban villages in which irrigation was performed. Second, systemic random selection was performed to select households from each PSU for sampling. The sampling frame included the census 2011 administrative atlas and map, using which the peri-urban areas along the upstream, downstream and midstream of the Sabarmati River were identified. A total of 16 PSUs were chosen from the peri-urban areas of Ahmedabad and Gandhinagar. All PSUs are located around 15-20 km away from the Sardar Patel Ring Road. A total of 660 households were selected from the 16 PSUs, with 330 households in the treatment group using wastewater as their main water source for irrigation, 165 households using water from tube well for irrigation, and 165 households using water from the Narmada Canal for irrigation (Figure 1).

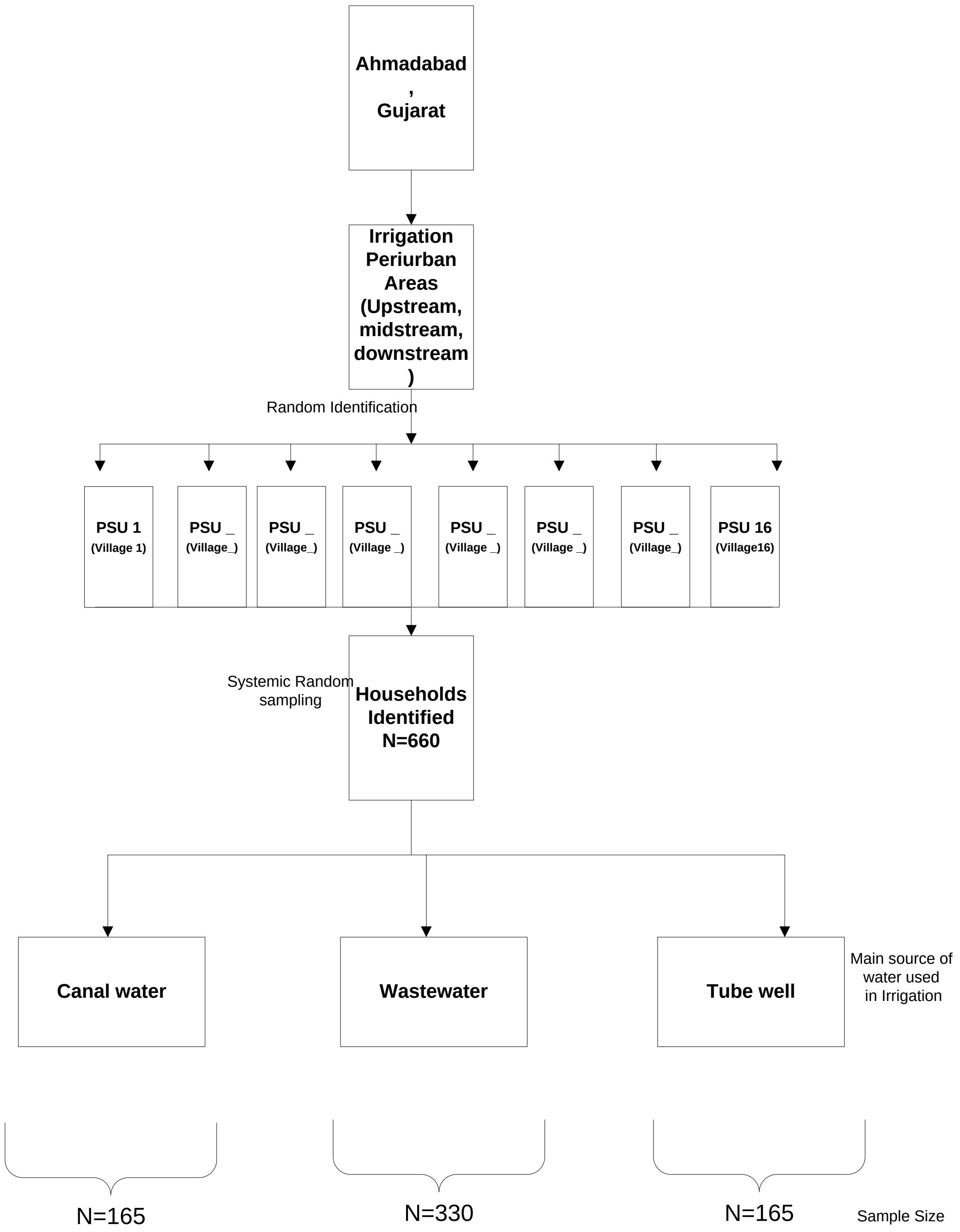

Figure 1 Survey Design

A total of 45 villages along the downstream of the Sabarmati River in Ahmedabad and 7 villages in Gandhinagar used wastewater for irrigation (Palrecha, Kapoor, and Malladi 2012). In our study sample, four villages in the Ahmedabad district (Timba, Miroli, Navapura and Khodiyar) and two villages in the Gandhinagar district (Sabaspur and Jaspur) used wastewater for irrigation. Timba, Miroli and Navapura obtained wastewater from the downstream of the Sabarmati River using lift irrigation. Other sources of irrigation water for agriculture in Ahmedabad and Gandhinagar include the Narmada Canal, freshwater tube wells and rain-water. Ten villages were chosen from these fresh water areas for the survey. The villages using mainly water from tube wells for irrigation include Shahpur and Amiyapur in the North along the upstream of the Sabarmati River, and Rancharda and Palodiya villages located in the Northwest. A few households in Jaspur, a village that mainly relied on tube-well water for irrigation, were included in the sample. Some farmers in the villages Unali, Rancharda, Sanavad, Santej, Rajnagar, Khatraj and Jaspur also used water from the Dholka branch of the main Narmada Canal. Some farmers had access to canal water, while others used diesel pumps to pump water from the canal for irrigation. The survey samples had single use water-systems where Irrigation and domestic water supply were separate.

The survey was divided into two parts: a baseline survey and a follow-up survey. The baseline survey comprised a household module, a WATSAN infrastructure module, an expenditure module, a child Module, and a hygiene module. The household module collected basic socioeconomic and demographic information of household members. The expenditure module collected information on household expenditure, including their non-food expenditure in the past month and past 12 months, and their food expenditure in the seven days prior to the survey. The WATSAN module collected information on a household's source of drinking water, the location of the source, the individual collecting water, water collection time, water charges, washing frequency of water storage container, storage coverage, cleanliness, waste disposal methods, hand-washing practices and hygiene behavior. The hygiene module consisted of a spot check on household hygiene, which is a subjective approach to assessing household hygiene behavior (Webb et al. 2006). The spot check included a check list divided into five broad categories, namely environment, sanitation, water, food and personal. The child module collected information on birth weight, breastfeeding, immunization and a brief food intake of under-five children. The height and weight measurements of under-five children were taken from each sample household during the data collection period. The parameters of weight-for-age, height-for-age, and weight-for-height/length were then calculated based on the WHO 2006 child growth standards.

The source and storage water quality in each household were assessed for E. coli in a laboratory using the WHO recommended MPN method. Water samples were filled in sterile containers, which were labeled with a unique household ID, and transported in a cool box to the laboratory, where the samples were analyzed for thermotolerant faecal coliforms and E. coli (WHO 1993).coli. In the MPN method, a series of tubes containing a suitable selective broth medium is inoculated with a water sample. After a specified incubation time at a given temperature, any tubes showing gas formation are regarded as "presumptive positive" since the gas indicates the possible presence of coliforms. For the confirmatory test, a more selective culture medium is inoculated with material taken from the positive tubes. The confirmatory tests consisted of the eosin methylene blue sheen test, the indole-negative test and the citrate-positive test. The MPN of bacteria present in a sample was then estimated from the number of tubes inoculated and the number of positive tubes obtained in the confirmatory test, using specially devised statistical tables (Collee et al. 1996).

2.1 The setting and background facts

The Sabarmati, one of the major rivers in the western region of India, is a monsoon-fed river that flows mainly in Gujarat except for its initial 9.5 km. Settlements of communities have settled along the river bank and the river has been an integral part of Ahmedabad since the city was founded. Initially, the river was the city's primary source of water. Today, water is supplied from many distant sources. Nonetheless, the river continues to be an important source of irrigation water for farms situated along the banks, mainly in the downstream of the river. However, through the years of use and abuse, along with rampant urban growth, the Sabarmati River has become polluted and neglected. Sewage-contaminated storm water outfalls and the dumping of industrial waste in the river pose a major health and environmental hazard.

In 2010, the Central Pollution Control Board of India listed the Sabarmati as the third most polluted river in the country, with the highest levels of faecal coli in the country. The faecal coli level in the river was estimated to be 2.8 million MPN per 100 ml. The Comptroller and Auditor General (CAG) conducted random checks on the river with regards to its pollution indicators and declared in early 2012 that "faecal coliform and total coliform bacteria were beyond permissible limit"; the fecal coli level in the river had increased by 860%, and the total coliform level by 480% beyond the permissible limits. The WHO guideline for the microbiological quality of treated wastewater used in agriculture for restricted irrigation is 0.1 million faecal coliform bacteria/100 ml (Blumenthal et al. 2000).

Water flows from rivers, canals and tube wells to irrigation farms. In turn, wastewater from urban households is disposed of into rivers after primary treatment, and the river water is used for agricultural production. The water sanitation and drainage systems in a village are interlinked, and on-site sanitation systems are a possible source of groundwater contamination. Figure 2 shows a schematization of water linkages in the context of village irrigation and WATSAN systems.

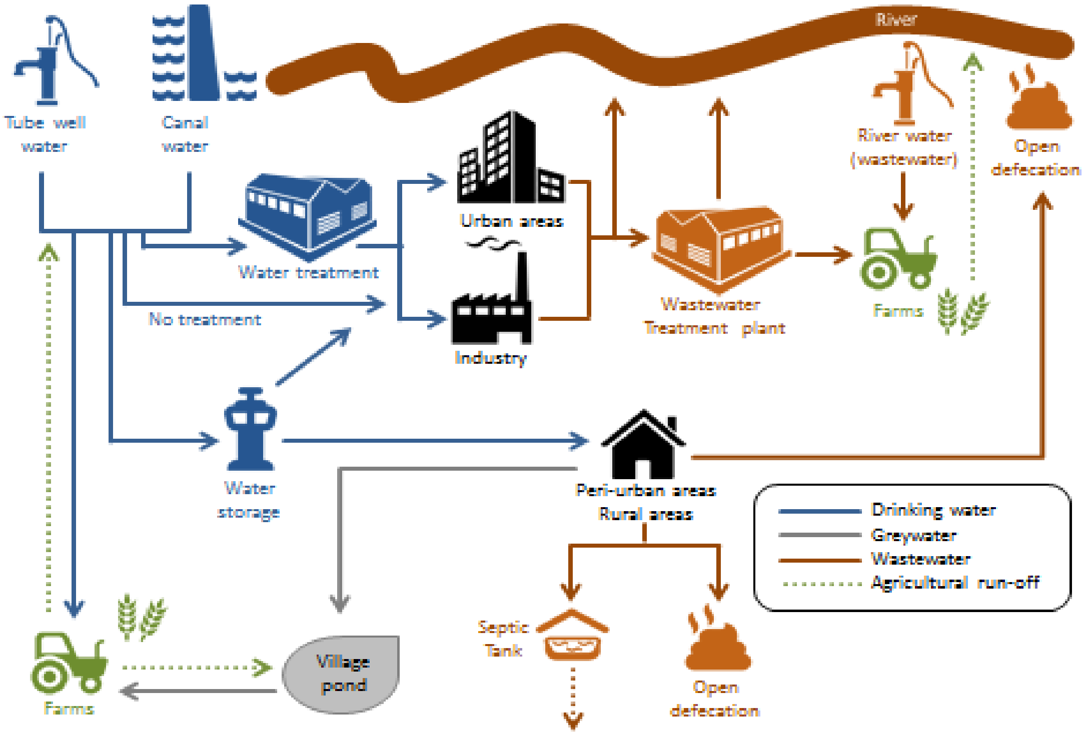

Figure 2 Schematization of the water and sanitation system in the study area

Source: Based on observation, logos source: Design Samantha Antonini at ZEF

3. Descriptive Statistics

In this study, the outcome variable of interest is POU drinking water quality. It is expressed in two ways: First, as log(1+e.coli) of E. coli count (MPN) for a continuous variable in one model specification; Second, as a categorical variable (contaminated/not contaminated) in another specification. The determinants of water quality and other confounding factors include agricultural characteristics, household characteristics, WATSAN infrastructure, hygiene and behavior, and community characteristics. The main characteristics used in the subsequent analysis are reported in Table 1.

The control variables (i.e., determinants of water quality which are not directly linked to the WATSAN context) include wealth quintile calculated from household assets using a factor analysis, and the caste and education level of a household. At community level, village household density was used as another control variable. Households were divided into five wealth quintiles using a factor analysis as employed in the DHS. Asset variables were taken into consideration when computing household wealth quintile. On the other hand, improved WATSAN infrastructures was not considered when determining household wealth quintile. This is to avoid collinearity problems because variables concerning WATSAN infrastructure were later used as explanatory variables in the regression models to explain the outcome.

Table 1 Main drivers of drinking water quality used in the analysis

	Variable	Category
Agricultural Characteristics	**Irrigation water**	Canal Tube well / Rain Wastewater No farm involvement
	Land area	Continuous
	Livestock ownership	No Yes
Household Characteristics-Sanitation	**Improved Toilet (Based on JMP definition)**	No Yes
Household Characteristics-Water Treatment	**Water Treatment: Reverse Osmosis (RO) water plant**	No Yes
Hygiene	**Hygiene Score (Based on Environment, water, sanitation, food and personnel hygiene)**	1 Poor 2 Average 3 Good
	Soap use (self-reported)	No Yes
	Handwashing post defecation	No Yes
Community Characteristics	**Garbage collected by town panchayat**	No Yes
	Open defaecation prevalence	0 <=25% 1 >25%
	Community drainage type	Closed/ Open Pucca Open Kuccha/No drainage

Garbage collection, drainage type and open defaecation prevalence were used as community-level variables. Garbage collection was defined as community-level waste collection services put in place by the town panchayat. Open defaecation was computed as a binary variable with more than or less than 25% open defaecation in the community. The boundary was set at 25% based on our observation of the survey areas. None of the communities in the survey areas was completely free from open defaecation. Open defaecation stats in an area were calculated based on Census 2011 data, our sample data as well as the information given by the village head. Existing literature suggests open defecation is a “public bad”, meaning that it has spill over effect even on those who use improved sanitation. According to (Spears 2013), even the richest 2.5% of the children in

India, who all live in urban areas and have access to improved toilets, were on average shorter than the healthy norm. We applied a data-driven observatory approach when defining the open-defecation variable. The minimum open defecation prevalence was 25% across the different study areas, a rate which applied to 33% of our survey data; therefore, we used this value as a benchmark to form a categorical variable for open defecation.

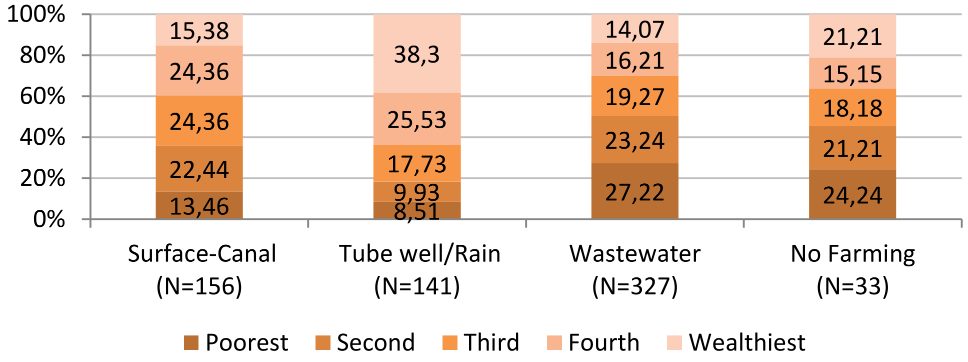

Figure 3 a Household with Irrigation water type by wealth quintile

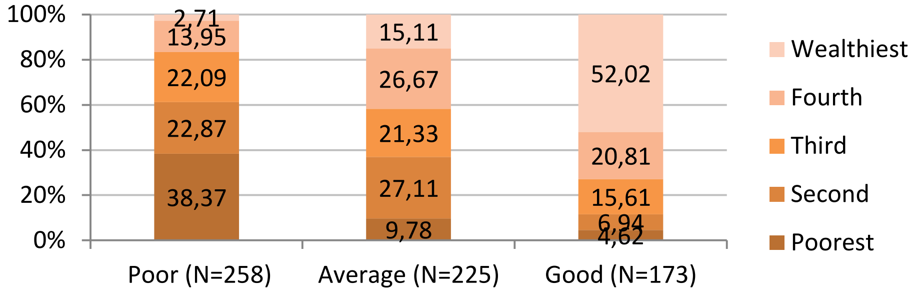

Figure 3 b Household with Hygiene score by wealth quintile

The households using tube well water for irrigation were richer (38.3%) than those using wastewater (14.07 %) and canal water (15.38%) in general (Figure 3a). Similarly, households with poor hygiene score tended to be poorer than those with average or good hygiene score. Hence, household wealth quintile is an important control variable in all our regression models.

Our survey results showed that 99% of the sample households had access to improved drinking water (mostly tap water) and 42% of the households had an improved toilet facility as defined by the JMP. In terms of sanitation behavior, 47% of the households reported practicing open defecation. All these figures are in line with the country-wide estimates published in the recent JMP 2015 report (95%, 40% and 44% respectively). Therefore, we can deduce that our sample is representative of the Indian population in terms of drinking water source, sanitation infrastructure and behaviour (JMP 2015).

We found that the microbiological water quality was generally not good. Some water samples showed with very high levels of E. coli contamination (an average of 85 MPN/100 ml and a maximum of 1700 MPN/100 ml). According to WHO standards, 80% of the household had storage water that was non-potable. The WHO drinking water quality guideline stipulates that the E. coli count in drinking water (MPN/100 ml) should be zero for it to be considered potable. The risk of waterborne infection increases with higher E. coli levels in water. Based on the the WHO risk categories Table 2, reports the distribution of household storage E.coli. Notably, contamination at POS was also high, with 73% of the households getting contaminated water (i.e., one or more E. coli MPN/100 ml water sample) from their POS. The numbers are comparable to those from another study conducted in a poor urban setting in Delhi, which showed a clear relationship between POS faecal contamination (45%) and POU faecal contamination (65%) (Satapathy 2014).

Table 2 E. coli in storage drinking water (WHO risk category classification)

E coli (MPN/100 ml)	Households (n)	%
No risk-0 Ecoli	124	19.47
Low risk- 1-10 Ecoli	187	29.36
Intermediate risk-11-100 Ecoli	226	35.48
High risk-101-1000 Ecoli	88	13.81
Very High risk- 1001-1800 Ecoli	12	1.88
Total	637	100

The next set of determinants of POU water quality was used to assess household-level hygiene behavior and status. We applied a subjective method (conducting spot checks) to compute a hygiene score for each household (Webb et al. 2006). The hygiene score comprised of five components: environment, sanitation, water, food and personal hygiene. The key components of the category environment include visible faecal contamination, waste piles, flies, roaming animals and stagnant water in the domestic and visible peri-domestic surroundings of a household. The category sanitation primarily considers the availability of toilet facilities, the cleanliness of toilet facilities and the availability of handwashing facilities near to or at the toilet. The category water considers water availability, cleanliness of a household’s water source and water storage. The category food assesses the adequacy of food storage in a household. The category personal hygiene covers the visible cleanliness of hands and nails of a household’s female head, who also answered the WATSAN module of the questionnaire. A score between one and three was given to a household for every category (environment, sanitation, water, food and personnel hygiene) based on the enumerator’s observation. Table 3 shows the percentage of households that had drinking water with E. coli MPN count of more than one (i.e., non-potable water) among the different categories of hygiene score. In every category, the poor score had the highest percentage of households with contaminated water. Chi-square (Fisher's exact) estimations showed there was a statistically significant difference between at least two groups in each category. Appendix 1 describes how these criteria were applied to each category.

Table 3 Hygiene Variables (E coli>=1) in % by Households

Variable	N	Category	E coli>1(%)	Chi^2-P value
	156	1 Poor	90.4	0.000
	264	2 Average	83.3	
Hygiene Score	236	3 Good	71.6	
	255	1 Poor	85.9	0.001
	224	2 Average	82.1	
Environment Score	177	3 Good	71.8	
	46	1 Poor	87	0.043
	325	2 Average	83.7	
Sanitation Score	285	3 Good	76.5	
	218	1 Poor	89.4	0.000
	67	2 Average	85.1	
Water Score	371	3 Good	74.9	
	351	1 Poor	86.3	0.000
	20	2 Average	90	
Food Score	285	3 Good	73.3	
	222	1 Poor	89.6	0.000
	127	2 Average	81.9	
Personnel Score	307	3 Good	73.9	
Total	**657**		**80.8**	

Next we present an analysis of the simple correlation between our main independent variables, the household and village-level variables (i.e., agricultural, WATSAN and hygiene indicators), and the presence of E. coli in stored drinking water (POU). The bivariate analysis suggests that several of the determinants listed had a clear impact on the POU drinking water quality (Table 4). Households using wastewater or surface canal water for irrigation had poorer-quality stored drinking water than those using tube well or rainwater. Chi-square (Fisher's exact) tests showed that at least two categories under most independent variables were statistically different (at 0.01 or 0.05 confidence level). This was not the case, however, for caste, education level, soap use, handwashing after defecation, livestock ownership, and safe waste disposal.

Table 4 E. coli in stored water (%) – bivariate analysis

		Storage drinking water *E.coli*>=1		
Variable	**N**	**Category**	**Row %**	**Chi^2-P value**
Irrigation water	156	Canal	86.5	
	141	Tube well / Rain	68.1	
	327	Wastewater	84.4	
	33	No farm involvement	72.7	0.000
Wealth quintile	130	Poorest	87.7	
	132	Second	81.1	
	132	Third	83.3	
	132	Fourth	79.5	
	131	Wealthiest	72.5	0.033
Caste	592	ST/SC/SEBC	81.3	
	65	Other general	76.9	0.400
Education level of the household head	267	Illiterate	79.8	
	389	Educated P,S or T	81.5	0.584
RO water plant	606	No	82.8	
	51	Yes	56.9	0.000
Improved toilet	385	No	83.1	
	272	Yes	77.6	0.075
Soap use	404	No	82.2	
	253	Yes	78.7	0.264
Handwashing after defecation	50	No	86	
	607	Yes	80.4	0.333
Livestock	188	No	78.7	
	469	Yes	81.7	0.387
Waste Disposal safe	588	No	81.5	
	69	Yes	75.4	0.223
Garbage collected by Town Panchayat	297	No	87.9	
	360	Yes	75	0.000
Households with drain	450	0 <.80	83.3	
	207	1 >=.80	75.4	0.016
Open Defaecation	165	0 <=25%	73	
	492	1 >25%	84.6	0.000
Community drainage	210	Closed/ Open Pucca	72.4	
	447	Open Kuccha/No drainage	84.8	0.000
Total households with *E.coli*>=1	**657**		**80.8**	

Briefly summarizing on the health indicator variable on diarrhea among under 5 children we find that the areas exposed to wastewater had a mean longitudinal diarrhea incidence of 2 per person-years, which was higher than the areas using freshwater for irrigation; the mean longitudinal diarrhea incidence in the areas with tube well and fresh surface water were 1 per person-years and 1.2 per person-years respectively. A higher E. coli count in stored drinking water was associated with a higher diarrhea incidence; when E. coli count in stored drinking water was higher than 100 MPN/100 ml, the mean longitudinal diarrhea incidence was 1.8 per person-years. The overall mean longitudinal diarrhea incidence in the study sample was 1.5 per person-years. Diarrhea incidence decreased with lower E. coli count in stored drinking water; the mean longitudinal diarrhea incidence was 1.3 per person-years when stored drinking water had E. coli MPN count was zero. A broader systematic analysis of the health impacts of irrigation water types is the subject of an upcoming publication.

In the following section, we present a regression analysis aimed at finding out the sign and extent of these impacts by considering the variables altogether.

4. Theory and Empirical Strategy

The proximate determinants of an individual's health usually are decisions made by the individual or by the household in which he or she lives- given the assets, cost, time and community endowments. Therefore the starting point in the determination of individual health starts at the household level. In a static household production model (Becker 1965) the households are assumed to maximize their household utility function subject to constraints. According to the theory, households allocate resources to purchase different goods and combine them with time into a household production system to produce various commodities and services. These purchased goods and produced commodities directly enter into the household's utility function.

Utility is presumed to depend on the health of each of the household individuals, consumption of goods and leisure. The household preference function is maximized to constraints. One of the constraints is a production function of water for intake which depends upon the water infrastructure and quality at source, treatment process of water on storage in household, the time spent by the household member collecting water and is assumed to be a function of distance to the source of water, knowledge of good practices of handwashing with soap and hygiene in the household as they relate to water collection, storage and use. Besides the communities exposed to different types of water systems for irrigation are affected differently on their household storage water quality due to the interaction of irrigation water with sanitation and hygiene.

The communities exposed to different types of water systems for irrigation are affected differently on their household storage water quality due to the interaction of irrigation water with sanitation and hygiene. Household behaviour on hygiene and sanitation and their use of information regarding linkages between WATSAN to irrigation water affects household water quality.

The study analyzes the impact of irrigation water type on drinking water at the POU using a counterfactual framework approach in which each household has an outcome either with or without exposure to wastewater. We specified the following econometric model to estimate water quality:

$$Y = X\beta + \alpha W + \varepsilon$$

Where Y is the outcome variable, the quality of drinking water of each specific household, defined by the level of E. coli contamination. X is a vector of exogenous variables that are expected to affect the quality of drinking water. These variables can be measured at household or community level, and their impact was captured by the parameters vector β. W is the treatment variable, in this case the type of irrigation water. The effect of using wastewater was measured by the coefficient of the treatment parameter α. We hypothesized that this parameter has a positive and statistically significant effect on Y, indicating that households exposed to wastewater irrigation are significantly more likely to have poor drinking water quality than those exposed to freshwater irrigation. We used two different specifications of the outcome variable: a level variable expressed as the log of E. coli MPN count per 100 ml of drinking water, and a binary variable assuming the value of 0 if the water is not contaminated (zero E. coli per 100 ml of water) and one if it is contaminated (one or more E. coli per 100 ml of water). The WHO drinking water quality guideline stipulates that the number of E. coli bacteria per 100 ml should be zero for drinking water to be considered potable. On the other hand, the level variable should allow us to pick up incremental effects of the water treatment on household water quality; given that the vast majority of the households in the sample have poor-quality water, it could be difficult to correlate a binary outcome with the treatment or the set of characteristics in vector X. We fitted a simple ordinary least square (OLS) regression for the level variable and a logit model for the binary variable. Finally, ε is the usual error term, to which the standard assumptions apply.

5. Estimation Results

This section highlights the results from the multivariate regressions. Our main goal is to highlight the impact of the type of irrigation system on drinking water quality while controlling for a wide range of potential pathogen transmission pathways. We achieved this by analyzing covariates that reflected farm infrastructures, farm-related activities and behavior, drinking water sources, sanitation and hygiene. An OLS model was used to determine factors associated with the natural log of E. coli, a measure of water quality at the POU (stored water for drinking). And logit regression was used to estimate the risk of having contaminated stored water (i.e., water having one or more E. coli MPN/100 ml). For both types of regression analysis, different model specifications were estimated in stages to allow for inferences about potential confounders and to test the robustness of the estimated impacts.

The OLS regression results (Table 5, Model I) show that households using canal water and wastewater for irrigation had poorer drinking water quality (POU) than households using tube well or rain water for irrigation; the E. coli in storage water increases by 93% and 44% respectively (the latter result had a lower statistical significance). The households that used RO water treatment had better drinking water quality than the households without RO treatment facilities; E. coli in their water sample was 66% lower and the difference was statistically significant. This indicates that water treatment affected POU drinking water quality positively as expected but was insufficient for ensuring that a household had potable drinking water (i.e., less than one E. coli MPN/100 ml), as Table 4 shows. Larger drinking water storage capacity was associated with lower drinking water quality, although by a very small marginal effect (7.5%). Finally and unexpectedly, livestock ownership, and having an improved toilet or a clean toilet had no statistically significant impact on the water quality. As shown below, the results were robust across all specification (Models I-III).

After controlling for household hygiene status and behavior (Table 5, Model II), we found that the households using canal water for irrigation still had poor-quality stored drinking water and that the coefficient was stable. However, the impact of using wastewater for irrigation on a stored drinking water quality became statistically insignificant. Using RO water treatment decreased the E. coli by 68%, so this result remained robust with the inclusion of the new covariates, as is the impact (coefficient) of higher drinking water storage capacity. The covariates that were not statistically significant in Model I remained so in Model II. Among the added hygiene variables, only the hygiene score appeared statistically significant 53% lower for the average score, 91% lower for the good score). The other hygiene and behavioral variables showed no significant impact. The hygiene score consisted of five components: environment, sanitation, water, food and personal hygiene score. A description of the five components and of the hygiene score are provided in the appendix. Each of these five components separately had little or no significant effect, but the combined hygiene score had a higher and statistically significant impact. This is due to the synergistic effect of the individual components, which together give a complete picture of household hygiene.

Finally, we added the community sanitation variables in Model III (Table 5). The percentage of people practicing open defection in a community and the village household density (calculated as the number of households per hectare of land) had little or no impact on the significance of the variables included in Models I and II. In particular, the use of RO water treatment, drinking water storage capacity and the hygiene score were still significant determinants of household drinking water quality. However, their impact (coefficient), along with their level of significance, decreased. On the other hand, communities in which more than 25% of the population practiced open defecation had significantly higher levels of E. coli contamination in their drinking water 76%). Also the village household density had a large impact on drinking water quality 105% E. coli count). We also investigated for any interaction between the household density and the prevalence open defecation in a community and found that there was no significant interaction between the two.

In the final part of the analysis, we also evaluated the impact of all regressors presented above on water quality as a binary outcome. A household was assigned a value of zero if the drinking water sample from the household was potable (zero E. coli MPN/100 mL), and one if the water was non-potable (one or more E. coli MPN/100 mL). The results (Table 6, Model I) showed a similar pattern as seen in the OLS regression; the households using canal water and wastewater for irrigation had poorer drinking water quality (POU) than the households using tube well or rainwater for irrigation, with a marginal effect of 12% and 10.6% higher respectively. Similarly, households using RO water treatment had better quality drinking water, with a statistically significant marginal effect of 14% lower. Higher drinking water storage capacity was associated with lower drinking water quality, although by a very marginal amount (1%). Having livestock, an improved toilet or a clean toilet had no statistically significant impact on drinking water quality, similar to the OLS regression results. After controlling for hygiene status and behavior (Table 6, Model II), we found that the households using canal water still had stored drinking water of poor quality and the effect was stable. However, the impact of using wastewater for irrigation became statistically insignificant. Similar to the OLS regression results, the logit model showed that the households using RO water treatment had improved drinking water quality by a marginal effect of 13% lower, contamination and the results were robust even with the inclusion of the new covariates, as was for higher drinking water storage capacity. The covariates that showed no statistical significance in Model I remained so in Model II. Among the added hygiene variables, only the good hygiene score had a slightly significant impact on the outcome, while the average hygiene score, which was significant in the OLS model had no impact in the logit model. The other hygiene and behavior variables show no significant impact. After the community sanitation variables had been added to Model III (Table 6), the results of the logit model showed that open defecation had no significant impact on household drinking water quality. However, a village's household density had a large impact on drinking water quality; a unit increase in household density resulted in a marginal increase of 27%. Due to multicollinearity problems, some of the community-level variables, such as garbage collection and the drainage type, were not included in the regression models owing to their correlation with other community-level variables, such as open defecation. Use of soap water, a self-reported behaviour showed no significant effect in the linear model but with a significant effect in the adjusted logit model mode (III, table 6). Although soap water use should ideally improve household water quality as also seen in the simple bivariate analysis the effect was opposite in the multivariate model logit model only.

Table 5 Multivariate Regression model- Simple Linear with outcome-natural log of E coli

	Model I		Model II		Model III	
	logecoli		logecoli		logecoli	
Variable Categories	**coef**	**se**	**coef**	**se**	**coef**	**se**
Tube well / Rain	*Reference*					
Canal	0.932***	(0.261)	0.899***	(0.263)	0.517*	(0.289)
Wastewater	0.439**	(0.211)	0.137	(0.245)	-0.400	(0.325)
No farm involvement	0.368	(0.413)	0.461	(0.418)	0.387	(0.408)
Poorest	*Reference*					
Second	0.0902	(0.259)	0.283	(0.271)	0.160	(0.267)
Third	-0.00969	(0.258)	0.197	(0.257)	-0.0565	(0.255)
Fourth	-0.269	(0.275)	0.0590	(0.284)	-0.155	(0.285)
Wealthiest	-0.0844	(0.312)	0.360	(0.337)	0.0537	(0.335)
Education of Head of Household	0.0461	(0.171)	0.0202	(0.176)	0.0742	(0.175)
Caste	0.358	(0.346)	0.566*	(0.342)	0.592*	(0.329)
Adult female density in House	-0.231	(0.757)	-0.242	(0.775)	-0.407	(0.761)
Livestock	0.0284	(0.187)	-0.121	(0.193)	-0.111	(0.187)
Improved Toilet	-0.0574	(0.183)	0.0545	(0.207)	0.118	(0.203)
Closest drain distance	-0.0008	(0.0005)	-0.0008	(0.0005)	-0.0008	(0.0005)
Main water tank distance	0.0005	(0.0006)	0.0003	(0.0005)	0.0006	(0.0005)
RO water plant	-0.666**	(0.310)	-0.687**	(0.313)	-0.713**	(0.313)
Storage container size	0.0752***	(0.0214)	0.0727***	(0.0230)	0.0470**	(0.0237)
Use soap			-0.0451	(0.202)	0.138	(0.202)
Handwashing post def			-0.460	(0.323)	-0.269	(0.320)
Waste Disposal safe			-0.114	(0.270)	-0.143	(0.258)
NoToilet	*Reference*					
Clean Toilet-Poor			-0.126	(0.251)	-0.0476	(0.257)
Clean Toilet-Good			-0.114	(0.254)	-0.0629	(0.253)
Hygiene Score- Poor	*Reference*					
2 Average			-0.530**	(0.242)	-0.373	(0.241)
3 Good			-0.915***	(0.278)	-0.658**	(0.277)
Open Defaecation					0.765***	(0.273)
Village Household density					1.541***	(0.294)
Constant	1.198**	(0.466)	2.227***	(0.630)	0.757	(0.673)
Observations	639		639		639	
R-squared	0.093		0.113		0.148	

Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table 6 Multivariate Regression model- Logit Regression-Outcome E coli<1 or E coli>=1

	Model I		Model II		Model III	
Variable Categories	**marginal effects**	**se**	**marginal effects**	**se**	**marginal effects**	**se**
Tube well / Rain			*Reference*			
Canal	0.122**	(0.0539)	0.114**	(0.0545)	0.109*	(0.0633)
Wastewater	0.106**	(0.0516)	0.0829	(0.0582)	0.0632	(0.0789)
No farm involvement	0.0471	(0.0857)	0.0593	(0.0782)	0.0561	(0.0752)
Poorest			*Reference*			
Second	-0.0427	(0.0509)	-0.0227	(0.0564)	-0.0355	(0.0506)
Third	-0.0107	(0.0527)	0.00286	(0.0592)	-0.0271	(0.0552)
Fourth	-0.0781	(0.0612)	-0.0528	(0.0636)	-0.0865	(0.0603)
Wealthiest	-0.0842	(0.0639)	-0.0712	(0.0782)	-0.115	(0.0742)
Education of Head of Household	0.0304	(0.0360)	0.0195	(0.0374)	0.0277	(0.0366)
Caste	0.0762	(0.0613)	0.0874	(0.0654)	0.106*	(0.0609)
Adult female density in House	-0.138	(0.142)	-0.120	(0.139)	-0.132	(0.144)
Livestock	0.0270	(0.0407)	0.00977	(0.0429)	0.0135	(0.0416)
Improved Toilet	0.0228	(0.0401)	0.0422	(0.0426)	0.0541	(0.0427)
Closest drain distance	-0.0002**	(9.95e-05)	-0.0002**	(9.56e-05)	-0.0002**	(9.69e-05)
Main water tank distance	0.0002**	(0.0001)	0.0002**	(0.0001)	0.0002**	(0.0001)
RO water plant	-0.139***	(0.0514)	-0.130**	(0.0522)	-0.153***	(0.0522)
Storage container size	0.0103***	(0.00385)	0.0119***	(0.00429)	0.00783*	(0.00445)
Use soap			0.0655	(0.0431)	0.0950**	(0.0412)
Clean hands post def			-0.102	(0.0782)	-0.0569	(0.0771)
Waste Disposal safe			0.0112	(0.0601)	0.00620	(0.0578)
No Toilet			*Reference*			
Clean Toilet-Poor			-0.00964	(0.0599)	-0.00404	(0.0574)
Clean Toilet-Good			-0.0305	(0.0480)	-0.0300	(0.0477)
Hygiene Score- Poor			*Reference*			
2 Average			-0.0703	(0.0477)	-0.0544	(0.0494)
3 Good			-0.110*	(0.0645)	-0.0850	-0.0623
Open Defecation					0.0359	(0.0607)
Village Household density					0.271***	(0.0706)
Observations	**640**		**640**		**640**	
Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1						

6. Conclusions

In the study areas, 98% of the households had access to an improved water source. However, the water at both the POU and POS generally had poor microbiological quality and could not be considered potable. Most of the water samples showed very high levels of E. coli contamination. POS contamination among the sample households was high, with 73% of the POS water samples having one or more E. coli MPN/100 ml. And 80% of the POU water samples taken from the households had one or more E. coli MPN/100 ml.

One of our hypotheses is that irrigation water plays an important role in transmitting microbial contamination to domestic drinking water through human and animal interaction with irrigation water. Our study found that the households using wastewater for irrigation generally had poor-quality drinking water before controlling for hygiene and community characteristics The households using surface water for irrigation had poor drinking water quality even after controlling for hygiene, behavioral and community variables. Tube well irrigators have no impact on drinking water quality. The probable explanation to poor water quality among surface canal water irrigators in comparison to wastewater areas could be one due to regular chlorination of water tanks managed in the wastewater areas and second presence of more open drainage areas in many surface water irrigated communities. Due to collinearity issues chlorination variable and community variables as open drainage had to be dropped from the model.

Animals usually carry high levels of fecal coliform bacteria (Rajasooriyar et al. 2013), which may affect household water quality. In our study, however, we found that livestock ownership did not have any impact on household water quality.

Good hygiene practices improve the quality of household drinking water (Gwimbi 2011). And poor sanitation and a lack of awareness of personal hygiene is responsible for water quality deterioration (Suthar, Chhimpa, and Singh 2009).Our study found that the households with poor hygiene score were worse off than those with good or average hygiene score in terms of household drinking water quality. Hygiene score was based on observation on 5 hygiene components observed by an enumerator while the soap water use was a self- reported behavior. In comparison to hygiene score we see that the soap water use had an opposite effect in the multivariate logit model only however the effect is not consistent as well as significant in other models. This makes us conclude that soap use, a self-reported behavior did not have a consistent effect in our study and could possibly be a reporting bias by household member to paint a good picture of their cleanliness. The households using RO water treatment had better drinking water quality, and the effect is consistent even after controlling for other hygiene, behavioral and community variables. Other methods of water treatment are rarely carried out properly. For example, although almost 90% of the households reported using the straining method to treat their water before storage, many were observed to have used dirty strainers. Most of the areas surveyed have a bore operator who is supposed to clean water storage tanks on a regular basis and chlorinate water stored in the tanks. However, the bore operators do not usually clean the tanks on a regular basis, and water chlorination is not practiced consistently because the villagers dislike the taste of chlorinated water. Further, health workers go door-to-door to distribute chlorine tablets to the households, but this takes place too infrequently (once a week) and covers too few areas.

Having an improved toilet did not have any significant impact on household drinking water quality but lowers the open defecation prevalence in a community, which improved household drinking water quality. The results showed that areas with high prevalence of open defecation tended to have poor water quality. Studies have shown that high population density and open defaecation are perhaps the key to explain the unresolved puzzles of high prevalence of stunting among children in India (Chambers and Von Medeazza 2013). Our study also found that high village household density had a significantly negative impact on domestic water quality. Other community variables such as the type of drainage systems, drainage coverage in community, household density, and garbage collection service played a important role in determining domestic drinking water quality. Although all the community variables could not be included in the regression analysis due to collinearity issues but the bivariate analysis clearly shows a significant impact of the community variables. And since all the community variables have a synergistic effect a holistic approach should be applied when considering community interventions.

Studies have shown that in a rural setting, the proximity of latrines to a groundwater body is negatively related to the microbiological quality of the groundwater (Megha et al. 2015). Our study also found that the households located closer to an area with open drains were more likely to have poorer water quality, although the estimated effects were very small. Drinking water may be contaminated in distribution systems because of breaches in the integrity of the pipework and storage reservoirs (Sur et al. 2006). Our study also showed that the distance of a household to their main water supply tank is positively correlated to the household’s drinking water quality.

One of the ways a household benefit from improved water supply coverage is that it reduces the distance they have to travel for cleaning and washing. This increases the household’s washing and cleaning activities, which improves the overall household hygiene but it also generates a larger amount of sewage. Because the rural and peri-urban areas of India generally have poor drainage infrastructure, sewage is often released into the open or kuccha drainage systems. Eventually, the sewage may make its way into a village pond and turn the pond into a breeding ground for mosquitoes. Also, domestic sewage released into such open kuccha drainage systems may be further contaminated by human and animal feces. The sewage in an open kuccha drainage system could contaminate household drinking water through children who played around open drains coming into contact with drinking water, or even through sewage seeping into water pipelines through cracks.

7. Recommendations

Despite the fact that 98% of the households had access to an improved water source, water quality at the POU remained poor. We suggest adopting an enhanced monitoring strategy that includes measuring water quality along with indicators of sanitary protection.

Emphasis on water treatment methods along with good hygiene practices and sanitation are needed to improve the quality of household drinking water. Household water filters if used correctly, consistently, and continuously could serve as a useful tool in ensuring safe drinking water. We observe that though the household members in general consider their water quality as good they consider employing water treatment methods to improve water quality but lack knowledge on availability, cost and advantages of different water treatment methods. The households either use simple sieve/mesh filters or RO filters based on the affordability. Gravity non-electric filters were not commonly seen in our survey households due to poor availability. Almost 90% of the households in our study use the more conventional particle filter, such as sieve or cloth. These filters are low cost (Rs. 60 average) and have a widespread acceptance but are not very effective in removing harmful elements such as E.coli and total coliform. Also from our observation we see that households do not change these filters regularly and had organic matter deposits on it. In such circumstances these filters are not effective, rather would contaminate the water samples. We therefore recommend cloth filters with more folds and tighter weave in order to filter out harmful contaminants from drinking water as seen in one a study conducted in Bangladesh by (Colwell et al. 2003)

Reverse osmosis (RO) technique is very effective in reducing the protozoa, bacteria, viruses and also chemical contamination from water (Centers for Disease Control and Prevention). However these filters cost around 5000 Rs. and also requires electricity and regular filter cleaning which may not be affordable to all households. Instead we propose a village level RO filter of 250 Litres per hour capacity can be installed which will cost a family on an average 5 Rs. Per day at the rate of (0.10/ litre) (Government of India 2015).

Household toilet coverage needs to be scaled up to decrease the overall open defaecation prevalence in rural and peri-urban communities, which will decrease contamination in the community and improve water quality. Improvement in drainage infrastructure, sanitation services-garbage collection by town panchayat, access to water both quantity and quality, hygiene intervention – are all of significant intrinsic importance and need co-investments for better health outcomes. Hygiene score of the household has a significant effect on water quality. Interventions that promote household hygiene through IEC activities should be carried out on a regular basis. Community sanitation and drainage needs planning in parallel to deal with increased household sewage production to reduce cross contamination. Interventions on community sanitation to develop closed permanent drainage system and a self-sustained sewage treatment plant shared between two to three villages is needed, so that the sewage generated in communities is not disposed directly into the village pond which then becomes a breeding ground for mosquitoes. Also since peri-urban areas are expecting a growth in population and small-scale industrial activities, proper peri-urban planning is required to protect human health.

8. Strengths and Limitations

Studies in past on WATSAN effects on water quality and health have not included the irrigation component. Since ninety percentage of the water is being utilized for irrigation purposes it plays an important role in the hydrological cycle and hence affects drinking water quality. Our study included the effect of irrigation water type as an explanatory variable. Also our study had a more holistic approach including individual as well as community characteristics that can affect or confound the outcome variable in the study. Besides our study used the WHO recommended 'Most Probable Number' (MPN) technique to test the E coli in household water was performed in a laboratory setting.

The main limitation of this study is that it is difficult to establish causality using our empirical approach without a long-term longitudinal data set to test the causal relationships. Endogeneity can arise when there are unobserved covariates within the model that determine the treatment variable (the use of wastewater for irrigation), the WATSAN and hygiene characteristics, and the outcome variable (drinking water quality). In particular, the use of wastewater for irrigation may be an endogenous factor because of two factors: First, unobservable household heterogeneity may have driven both the treatment (the type of irrigation water) and outcome (drinking water quality) variables. Second, some omitted variables (variables that could not be captured in our data, such as cultural beliefs, historical reasons or migration) may be correlated with the outcome and explanatory variables (such as sanitation infrastructure and irrigation water use).

However, we noted that farmers who settled down along the downstream river have inherited their land generations ago and the downstream river water was not highly contaminated by wastewater in the past. Therefore, there was no self-selection bias. For example, poor farmers did not choose to farm in areas using wastewater for irrigation. Farmers did not select the type of water they use for irrigation, but rather it was determined by the location of the farm they inherited from their ancestors. Also, migration hardly takes place among these farmers due to cultural reasons and finding land elsewhere is very difficult. Leaving an area polluted by wastewater is therefore not a matter of choice that is driven by unobserved characteristics. Further, the survey areas were all within 15-20 km of the city and well connected through major highways and thus the areas are equally served in terms of monitoring, treatment and maintenance of water reservoirs and other government WATSAN interventions. Despite this, farmers using wastewater for irrigation were still poorer than those using tube well water for irrigation. However, they generally were not poorer than those using surface water for irrigation. Our arguments above nonetheless suggest that poverty did not drive a farmer's choice of location but is rather a consequence of it, and it has impacts on water quality.

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10. Appendix 1

Hygiene score:

In the environment category, a household was given a score of three if the enumerator found an insignificant number of flies and no sign of contamination in the household's peridomestic environment; a score of two if the enumerator found a significant number of flies, some waste, or restrained animals; and a score of one if the enumerator found a significant number of flies, fecal contamination, waste piles, stagnant water or free-roaming animals.

In the sanitation category, a household is given a score of three if the household has an improved sanitation facility with water access at home, a score of two if the household has an unimproved sanitation facility without water access for washing at home, and a score of one if the household had no sanitation facilities and practices open defecation.

In the water category, a household was given a score of three if they have access to improved water source and adequate water storage; a score of two if the water storage container had no cover or if the water withdrawal method was inadequate; and a score of one if the household uses an unimproved source for drinking water, if the water source or water storage container appeared visibly contaminated, or if no water was available from the source.

In the food category, a household was given a score of three if the household covered stored food and kept the food above ground, and if their dishes were clean; a score of two if they left stored food uncovered or on the ground, or if their dishes were dirty; a score of one if stored food was kept improperly, if there were a significant number of flies, or if their kitchen area was contaminated.

In the personal hygiene category, a household was given a score of three if the female head of a household had clean hands, clothes, and teeth and if she wore shoes; a score of two if her clothes were dirty or if she did not wear shoes; and a score of one if there were visible signs of dirt under her finger nail, if her hands were dirty, or if her teeth were severely discolored (black or red).

The final score of a household was obtained by summing the scores of all five categories and ranged from 5 to 13. The sample households were divided quintiles based on their final score.