Research Paper

Prevalence of water-borne diseases in western India: dependency on the quality of potable water and personal hygiene practices

Koustubh Karande, Shalini Tandon, Ritesh Vijay, Sunali Khanna, Tuhin Banerji and Yeshwant Sontakke

ABSTRACT

Unlike urban and semi-urban settlements where the potable water is supplied through a water treatment plant and a distribution network, in rural low-income settings, the provision of the water treatment plant for all villages is not feasible for a developing country like India. The most affordable and reliable way to provide clean drinking water is treatment at the consumer end. This research is aimed to assess occurrence of water-borne diseases based on personal hygiene and quality of drinking water source. Of the households, 4,237 in 15 selected villages were surveyed for personal hygiene using a questionnaire. Water samples were collected from all major water sources in the villages and analyzed for chemical and bacteriological properties. For water and personal hygiene, quality indices were calculated, and a mathematical model was developed using multiple linear regression analysis. The regression concluded that personal hygiene has a more significant effect on the occurrence of water-borne diseases than the quality of water source in the study area. Personal hygiene is one of the health factors neglected by the people specifically in rural India. Therefore, India needs to run campaigns like *Swachh Bharat Abhiyaan* (Clean India Mission), which mainly aimed to reduce open defecation, to promote personal hygiene and to reduce the prevalence of water-borne diseases.

Key words | personal hygiene, regression, water-borne diseases, water quality

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HIGHLIGHTS

- We studied the quality of potable water, hygiene practices by villagers and cases of water-borne diseases in the study area.
- A mathematical model developed using data collected from field survey to identify priority regions for the occurrence of water-borne diseases using water quality and hygiene.
- A mathematical model developed using water quality and personal hygiene index to identify priority regions for occurrence of water-borne diseases.

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INTRODUCTION

The importance of water, sanitation and hygiene (WASH) has been proved to be a crucial factor in the control of water-borne diseases (Maduka 2004; Bartram & Cairncross 2010; Freeman *et al.* 2013; Garriga & Foguet 2013; Patil *et al.* 2014; JMP 2019). An estimate by Joint Monitoring Programme (JMP) suggests that from 2000 to 2017, 10% of the total world population gained safely managed water services, yet 3 out of 10 people lack it. Also, in the same period a quarter of the total population in the world got access to basic sanitation services. It was estimated that in 2017, 60% of the world's population had access to basic handwashing facilities available at home (JMP 2019). India's *Swachh Bharat Abhiyaan*, launched in 2014, helped 500 million people, which represent 25% of the total world population, to gain access to basic sanitation. Even though more than 690 million people got access to toilets where India represents more than 50% of this population, 670 million people still practice open defecation in the world (JMP 2019). Total WASH-related disability-adjusted life years (DALYs) for India were estimated to be 28,213.3, which is one of the highest in the world (Prüss-Üstün *et al.* 2008). But JMP, due to the lack of affordable methods to test water quality directly, collects data from national surveys to investigate improvement in water source, which makes the data less reliable (Wang *et al.* 2017). Even though JMP conducts various workshops in order to regulate the assessment of indicators by national authorities, which can help in preparing more accurate estimates, but these indicators may lack region-specific desegregation. The government officials and policymakers need to have reliable microscale data with interpretation to develop region-specific plans to improve basic services and tackle disease burden.

In this project, data were collected from Solapur district in the state of Maharashtra located in western India. With low average rainfall ranging from 350 to 680 mm/year, and the study area belongs to one of the dry districts in western India (Yadav *et al.* 2018). Ujani Dam constructed on the Bhima River located near Indapur is a major source of freshwater to the Solapur district with an effective storage capacity of 1,517.2 MCM (NRLD 2018). The Maharashtra Pollution Control Board approached CSIR-NEERI to assess the prevalence of water-borne diseases due to water pollution in the region. Due to the lack of sources of water and poor economic status, the region is threatened with the prevalence of water-borne diseases like typhoid and cholera. This research aims to understand the dependency of water quality and personal hygiene on the occurrence of water-borne diseases and prepare a model to predict the occurrences of water-borne diseases in the study area. Regression analysis is used to understand the relationship between the variables and to develop a mathematical model (Watson 1964; Jolliffe 1986; Rawlings *et al.* 1998; Schaalje & Rencher 2007; Draper & Smith 1998).

METHODOLOGY

Primary survey and site selection

A primary survey was carried out to identify all the rural villages located near the bank of the river Bhima starting from the Ujani Dam to Pandharpur in Solapur district. Throughout the patch of the river (178 km), the sources of water supply were earmarked, and demographic information of each village was collected. Initially, 26 villages were identified with more than 500 households, and a water source located near the river. Out of these, 14 villages were selected randomly and an additional village which is distant from the river, as illustrated in Figure 1. Since the village distant from the river uses groundwater as a major source of freshwater, it is considered as a control village to evaluate the impact of personal hygiene on the prevalence of water-borne diseases.

After the primary survey, the study was divided into three activities:

1. Identification of sources of drinking water, water quality assessment and calculation of overall water quality index (OWQI).
2. Household survey to study the hygiene practices, occurrence of water-borne diseases and calculation of personal hygiene index (PHI), as well as identification of possible sources of freshwater contamination.

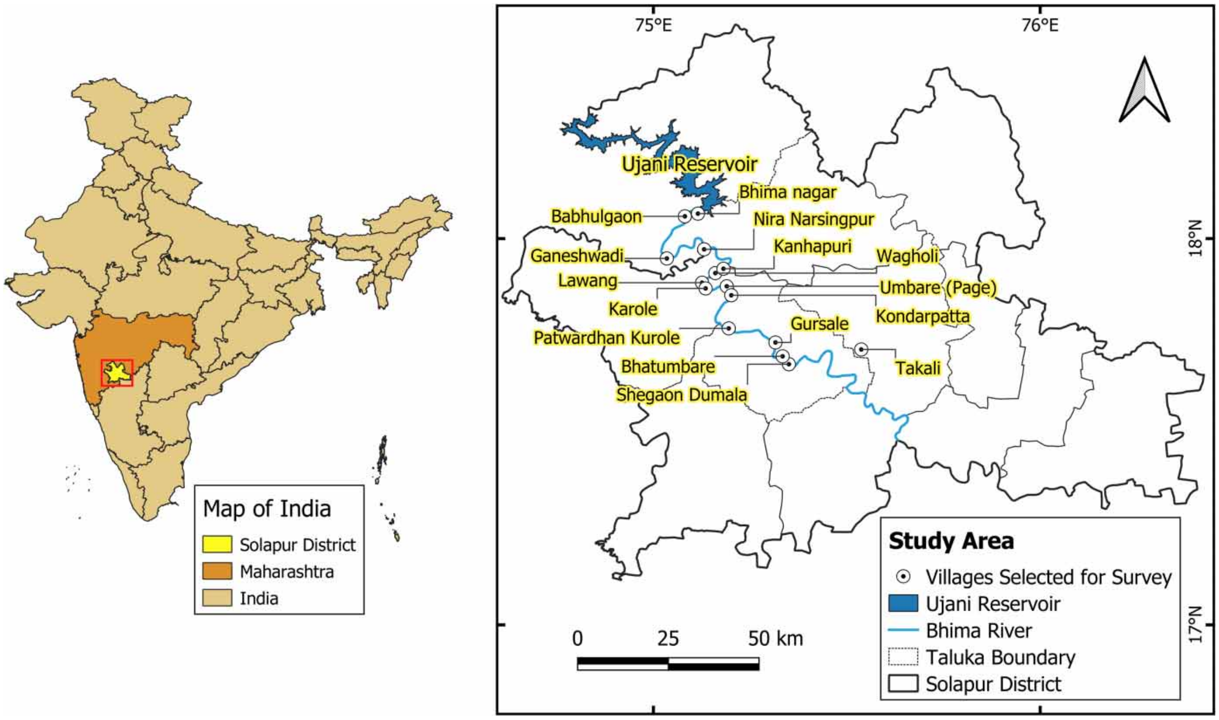

Figure 1 | Study area.

3. Regression analysis to understand the dependency of occurrence of diseases on PHI and OWQI.

Survey of sources of freshwater, water sampling, analysis and calculation of OWQI

The selected villages in the study area were remotely located with bad road connectivity; therefore, the preservation and storage of samples before transport to a laboratory was not feasible. Hence, two main parameters were selected, chemical oxygen demand (COD) and fecal coliform (FC), and analyzed at a temporary laboratory setup as per standard methods of analysis (APHA 1999). During the primary survey, all the major sources of water for the villagers were identified, and samples were collected for analysis.

A method formulated by Singh *et al.* (2015) was followed for the calculation of OWQI. This method was developed for the Indian subcontinent. COD and FC were classified based on the proposed range. For COD, the range is given as <2, 2–2.9, 3–7 and >7 and for FC, <50, 51–500, 501–5,000 and >5,000. Subindices were calculated using respective index functions provided by Singh *et al.* (2015).

$$\mathrm{OWQI} = \sum \frac{w_i \times s_i}{w} \tag{1}$$

where s_i is the subindex value for the parameter; w_i is the weightage given to each parameter, and w is the total weightage allotted to all parameters. OWQI was constructed by the aggregation of subindices with weightage to COD and FC as 2 and 4, respectively (Singh *et al.* 2015).

Wastewater collection and disposal systems

To understand the existing wastewater disposal system in all selected villages in the study area, site visits were conducted. Wastewater network and disposal system were studied. As most of the villages in the study area were observed to have gutter networks, they were mapped along with disposal sites and the water sources, which are located beside the network, were identified as the potential cross-contamination locations.

Ethics statement

Permissions were acquired from respective local and state administrative government bodies along with the department of health to conduct this survey. The team of surveyors collected data by voluntary enrollment of participants in the study area. To record the response, questionnaire survey sheets, duly signed by respondents after explaining the objectives of study, purpose of data collection, analysis of collected data and privacy rights, were collected. The methodology was approved by the Ethics Board.

Survey for health indicators and development of PHI

The main objective of the survey was to collect information on the hygiene practices and water-borne disease data from district hospitals and village primary health centers. The sample size for each village was calculated based on *the Cochran* formula with the level of precision ±5% and confidence level 95% (Glenn 1992). The study population included 4,237 households from 15 villages selected randomly. Household survey per village was carried out from December 2018 to February 2019 in the study area. A group of environmental experts, scientists, health specialist and government officials developed a questionnaire and guidelines for data collection.

The questionnaire was divided into four main sections. The first section was aimed to obtain data regarding sources of water and treatment methods used in individual households. The second section was designed to obtain information regarding water handling and storage practices. As main storage practices in the study area are clay utensils and plastic tanks, they are prone to sediment deposition and microbial growth. Therefore, questions regarding the frequency of cleaning the storage units and the frequency of refilling were included. The third section was more focused on the defecation practices including the availability of toilets, handwashing techniques and the provision of septic tanks. The last section was dedicated to collect information regarding the reported cases of water-borne diseases for year 2018–19. Diseases include typhoid, cholera, diarrhea and gastroenteritis.

For the development of PHIs of each village, a weightage is given to each of the parameters according to its possible impact on the health, and indices were developed.

$$I = \sum_{i}^{n} p_i \times w_i \tag{2}$$

where p_i is the parameter value for the village, and w_i is the weightage to parameter. For the whole village, according to their practices, each parameter was calculated in percentages, and the percentages were used as parameter values for the village.

Regression analysis

To understand the dependency of the prevalence of water-borne diseases on OWQI and PHI and to develop a model, multiple linear regression analysis was used.

$$y_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon \tag{3}$$

where y_i is the dependent variable (occurrences of water-borne diseases), x_1 and x_2 are independent variables OWQI and PHI, respectively, β_0, β_1 and β_2 are coefficients and ε is the error. A design matrix was used to calculate the coefficients. The *F*-test is used to test if a group of variables is significant jointly, and the following formula was used to calculate the *F*-value.

$$F = \frac{\mathrm{SSR}/k}{\mathrm{SSE}/(n-k-1)} \tag{4}$$

where SSR and SSE denote the regression sum of squares and the error sum of squares, respectively; n and k are the number of observations and the number of parameters, respectively. In addition to this, the *p*-value is also calculated. The *F*-value tests the significance of a group of variables, whereas the *p*-value calculates the significance of each parameter separately and it suggests the probability of a value exceeding the *F*-value (Schaalje & Rencher 2007). Therefore, the *p*-value is calculated to understand the significance of individual variable. For the *p*-test, the degree of error (α) is assumed to be 5%.

RESULTS

Sources of freshwater and wastewater collection and disposal systems

It was observed in most of the villages, wastewater collection and disposal system were inadequate. The villages with borewells as a main source, shown in Table 1, observed to have a distribution network for the supply of water but without any treatment. Some of the villages with borewell had partial connectivity, and unconnected households were observed to be taking water from the nearest dug well or handpump. In villages with no wastewater disposal system, households dispose wastewater into the open on roadsides which either make small streams and meet a gutter that carries wastewater outside the village, or it makes a small pond from which the water evaporates or percolates leaving a layer of sludge. Due to this sludge, a small wetland-like formation was observed at several locations. Villages, namely Babhulgaon, Ganeshwadi, Kanhapuri, Karole, Wagholi, Gursale, Bhatumbare and Umbare (Page), have constructed gutters or underground sewers which mostly dispose of the wastewater on the outskirts of the village or in farmlands for agricultural use. Only Bhatumbare has a complete wastewater collection system that disposes the collected wastewater into agricultural land or *nallahs*, which meets river. It was observed that the gutters/sewers were leaking due to either improper design or lack of maintenance.

Water quality analysis

The OWQI value from 0 to 24 suggests heavily polluted water, not suitable for any purpose; 25 to 49 has poor quality, but with special treatment can be used for domestic purposes; 50 to 74 considered to be of fair quality, and with filtration and disinfection is suitable for potable use; 75 to 94 defined as acceptable, whereas 95 to 100 suggests pristine quality water source (Singh *et al.* 2015). As Figure 2 represents, the average value of OWQI is 73 with a median of 74.5, which can be considered as fair quality. Out of 15 villages, 7 villages have the OWQI of acceptable quality, and the rest were observed to have fair quality. The lowest OWQI was recorded in Ganeshwadi (53.6), and the highest was Shegaon Dumala (89.5). First and third quartiles in the OWQI are 62.9 and 80.6, respectively. Figure 3 illustrates the calculated values of OWQI for each source of water in the villages (as numbered in Table 1).

Table 1 | Drinking water source and sewerage system

Sr. No.	Village	Drinking water source	Wastewater collection system
1	Bhimanagar	River and handpumps	Partial sewer and open roadside disposal
2	Babhulgaon (Pune)	Handpumps	Unconstructed gutters
3	Takali	Dug wells	Partial sewer and constructed gutters
4	Shegaon Dumala	Dug wells	Sewer
5	Bhatumbare	River	Sewer
6	Gursale	Dug well	Partial sewer and constructed gutter
7	Patwardhan Kurole	Bore well and handpump	Partial sewer and constructed gutter
8	Karole	Borewells	Constructed sewer
9	Nira Narsinghpur	Dug well	Constructed gutters and open roadside disposal
10	Ganeshwadi	Borewells	Partial sewers and unconstructed gutters
11	Lawang	Borewells	Constructed gutters
12	Wagholi	Borewells	Constructed gutters
13	Kondarpatta	Dug wells	Open roadside disposal
14	Umbare (page)	Dug wells	Partial sewer and constructed gutter
15	Kanhapuri	Handpumps and bore well	Partial sewer, constructed gutter and open disposal

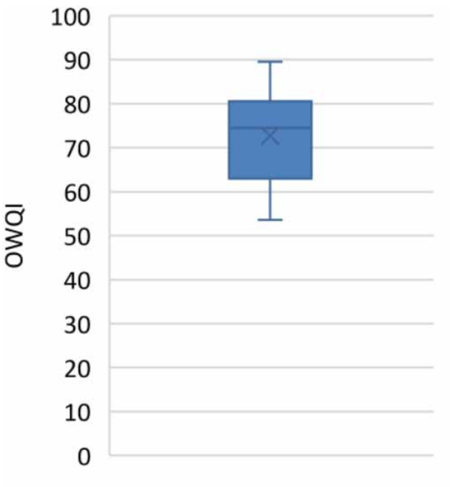

Figure 2 | Overall water quality index.

Hygiene practices

Figures 4–7 summarize the hygiene habits in the study area. In total, 40% of the villagers in the study area use water for domestic purposes including drinking and cooking without any treatment. Among the villagers who treat water before use, 55% use cloth filter, 35% use RO + UV and the rest 10% use other methods. More than 90% of the villagers refill fresh water daily. In the villages facing water scarcity, it was observed that the villagers tend to store water for a longer period of time and without washing the storage utensils. But the proportion of villagers practicing this technique was found to be very low. Also, 85% of the villagers in the study area use toilets, and 96% use soap for handwashing.

Occurrence of water-borne diseases

Figure 8 illustrates reported cases of water-borne diseases, which were observed between 0.25 and 4.18% of the total population with an average of 1.7% in the study area. The most affected age group was kids of age less than 15 years followed by adults of age 30–50 years as shown in Figure 9. The least affected age group was elderly people more than 50 years of age.

Regression analysis

In this study, PHI and OWQI are considered as independent variables to understand their significance on the occurrence of water-borne diseases, which is the dependent variable. For the null hypothesis test, no significant relationship between variables was assumed for the following equation:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \tag{5}$$

Therefore, null hypothesis, μ_0: $\beta_1 = \beta_2 = 0$ and for alternate hypothesis, μ_1:$\beta_1 \neq 0$ and/or $\beta_2 \neq 0$.

In Table 2, ANOVA and *p*-value suggest no significant relationship between OWQI and the occurrence of water-borne diseases. In the case of PHI, ANOVA and *p*-value signify the relationship with the occurrence of water-borne diseases, and the coefficient of determination is 0.466 which indicates a moderate relationship as illustrated in Table 3.

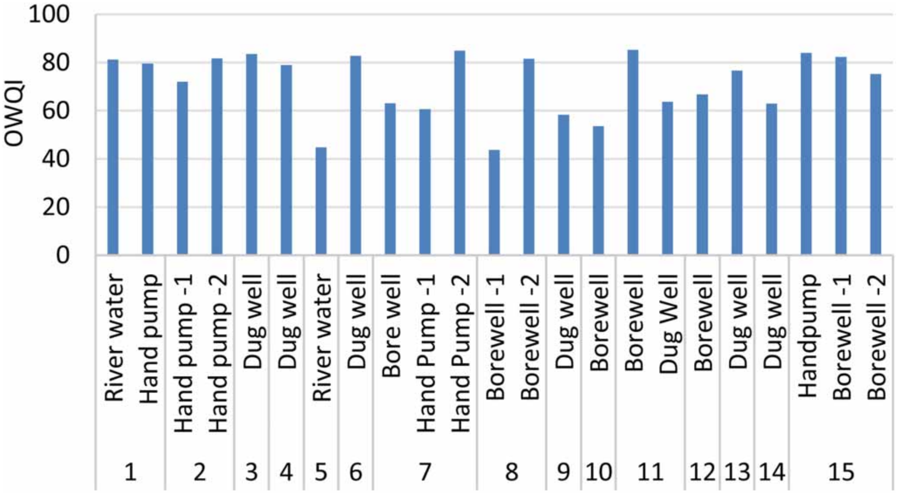

Figure 3 | OWQI for individual source of water in study area.

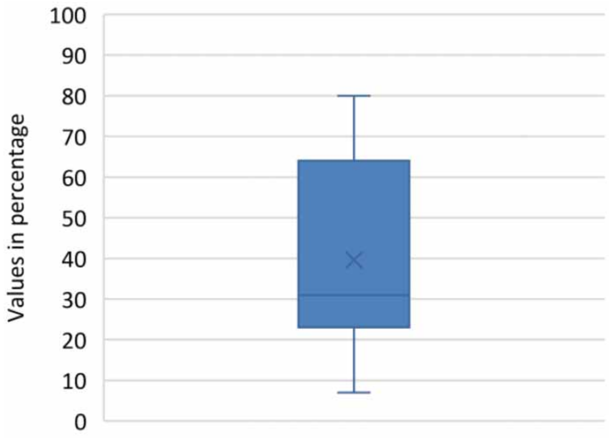

Figure 4 | Direct water consumption.

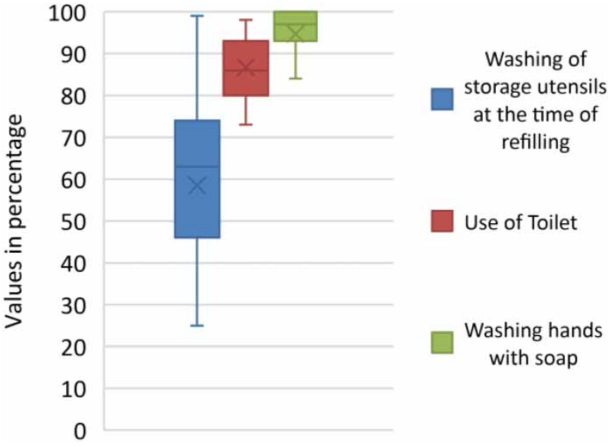

Figure 7 | Other hygiene practices.

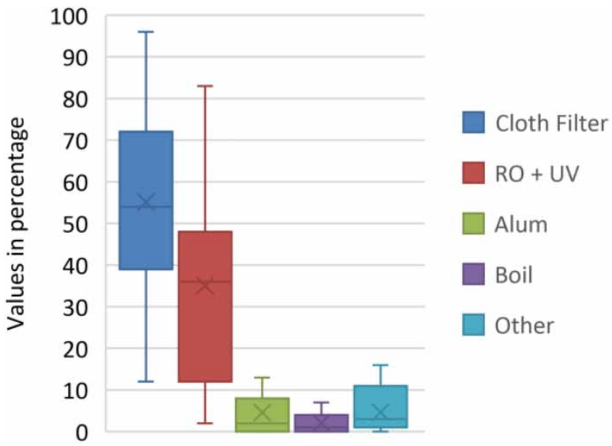

Figure 5 | Water purification techniques.

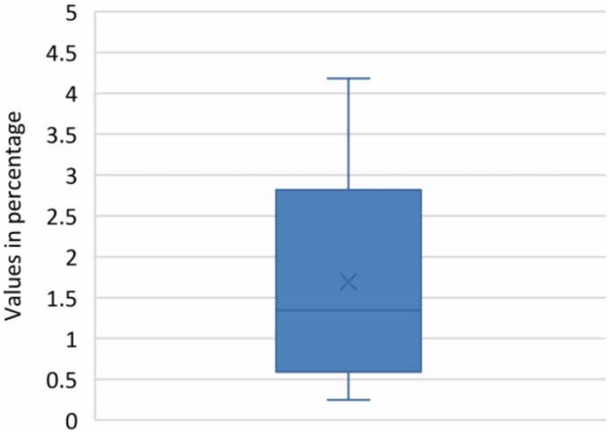

Figure 8 | Reported cases of water-borne diseases.

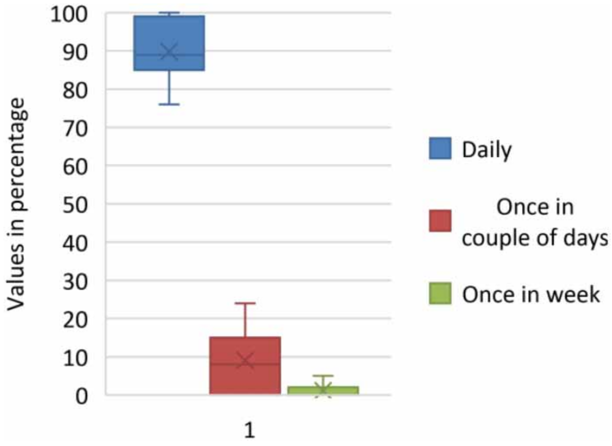

Figure 6 | Freshwater refilling frequency.

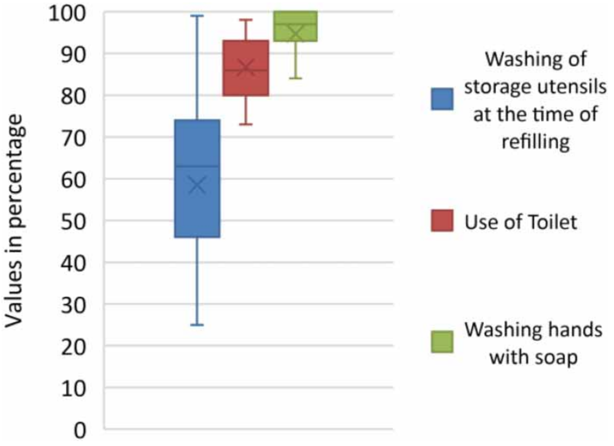

Figure 9 | Affected age groups among reported cases.

Table 2 | Regression analysis for OWQI

	Regression statistics					**ANOVA**		
Variable	***R***	***R^2***	**Adjusted *R***	**Standard error**	***n***	**df (total)**	***F*-value**	**F_{crit}**
	0.16	0.03	−0.06	10.92	15	14	0.31	4.67
OWQI	**Coefficients**		**Standard error**		***p*-value**			
	Constant	**OWQI**	**Constant**	**OWQI**	**Constant**	**OWQI**		
	74.35	−1.33	5.0243	2.4119	<0.001	0.5904		

Table 3 | Regression analysis for PHI

	Regression statistics					**ANOVA**		
Variable	***R***	***R^2***	**Adjusted *R***	**Standard error**	***n***	**df (total)**	***F*-value**	**F_{crit}**
	0.68	0.47	0.42	0.60	15	14	10.47	4.67
PHI	**Coefficients**		**Standard error**		***p*-value**			
	Constant	**PHI**	**Constant**	**PHI**	**Constant**	**PHI**		
7.999	−0.4312	0.2776	0.1333	<0.001	0.007			

To establish a model for the prediction of the occurrence of water-borne diseases based on PHI and OWQI using multiple linear regression analysis, ANOVA indicates that the relationship between a group of variables is significant and reduce the error generated due to less significant variable. Here, the *p*-value for PHI signifies the importance over OWQI. Using regression analysis in Table 4, the model can be represented as follows:

$$y = 12.33 - 0.318x_1 - 1.147x_2 \tag{6}$$

where y is the occurrence of water-borne diseases, x_1 is the OWQI and x_2 is the PHI.

Even though the study suggests the moderate correlation of PHI with occurrence of water-borne diseases as illustrated in Figure 11, which is a well-known phenomenon. However, it is important to highlight that study also indicates weak relationship with source water quality (Figure 10).

DISCUSSION

Results suggest that personal hygiene has significant importance over the quality of water source for the occurrence of water-borne diseases like typhoid and cholera. This study is

Table 4 | Regression analysis for OWQI and PHI

	Regression statistics					**ANOVA**		
Variables OWQI and PHI	***R***	***R^2***	**Adjusted *R***	**Standard error**	***n***	**df (total)**	***F*-value**	**F_{crit}**
	0.73	0.54	0.45	0.93	15	14	6.38	4.67
Coefficients			**Standard error**			***p*-value**		
Constant	**OWQI**	**PHI**	**Constant**	**OWQI**	**PHI**	**Constant**	**OWQI**	**PHI**
12.3299	−0.0318	−1.1468	3.1953	0.0245	0.3287	0.002	0.22	0.005

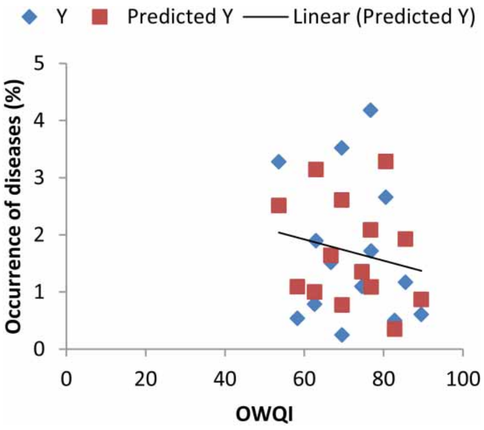

Figure 10 | Line fit plot for OWQI.

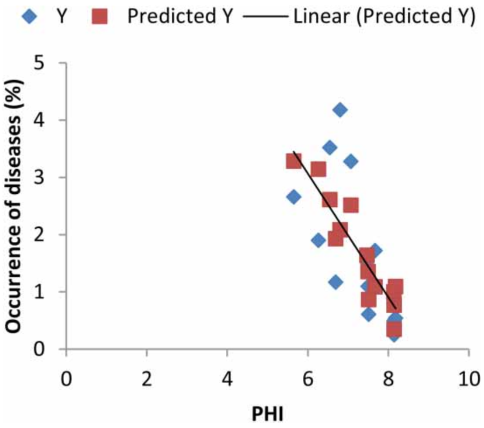

Figure 11 | Line fit plot for PHI.

focused on the quality of source water. The treatment of water at the household level is considered as a part of personal hygiene. The treatment of water coupled with periodic cleaning of storage utensils, use of toilets and good handwashing techniques are important for the control of diseases. India showed a 12% point reduction in open defecation per year over a 4-year period after the launch of *Swachh Bharat Abhiyan* (JMP 2019). More campaigns are required to change unsafe hygiene practices in the rural high-risk areas.

According to JMP's national hygiene estimates, only 49% of the rural population has access to basic sanitation services, whereas 80% of the urban population has basic sanitation services. It was reported in India, 56% of the rural population has safely managed water supply in 2017 compared to 20% in 2000 (JMP 2019). Along with infrastructure for safely managed water supply, it is important to manage the generated wastewater. This study shows that most of the villages lack wastewater treatment systems before disposal. Since the quantity of wastewater is low, it is generally disposed into *nallahs* which meets streams or rivers polluting one of the major sources of freshwater. Even in some villages, it was observed that these *nallahs* flow near wells, possibly leaching into the source, effectively degrading the quality. India treats only 30% of the total sewage generated, and most of the treatment plants are located in urban and semi-urban areas. In a developing country like India, the provision of water treatment plants in rural areas is not feasible due to financial constraints. Also, villagers tend to use river, dug wells or bore wells as a source of freshwater, since the treated water is supplied at a tariff which is not affordable to villagers, especially in low-income settings. Therefore, proper collection and disposal of wastewater is of major importance. Even though the quantity of water available to the villagers was not assessed in this study, it plays an important role in personal hygiene.

To improve personal hygiene, simple changes in handwashing techniques can reduce the risk of diseases in children (Nizame *et al.* 2013). As the results suggest that the most affected age group is kids less than 15 years of age, it is important to develop good hygiene practices in the childhood, especially in low-income rural settings. Handwashing is one of the important methods in childcare to curb the spread of diseases. Practices related to handwashing require patience to implement (Niffenegger 1997). Motivating people for washing hands has found successful in Ghana (Beth *et al.* 2008). A survey in Uganda suggested that a simple, hands-free handwashing facility, a tippy tap, has shown very promising results and revolutionized sanitation in schools (Kochar 2019). Made up of local materials, these facilities can reduce the cost substantially and the risk of contracting diarrhea by over 50% (Colley 2010).

The major focus of the governments has been the infrastructure development to improve the quality of water source rather than the hygiene conditions. Studies in the late 2000s indicate that improvement in water quality alone had very little health benefit. A systematic review by Cairncross (2003) concluded that improvement in handwashing techniques has resulted in the reduction of morbidity by 43%. Also, statistics during *Swachh Bharat Abhiyaan* suggest that the acute diarrheal disease outbreaks were recorded the lowest in 2017 and 2018 (Dandabathula *et al.* 2019). Therefore, even though source water quality is important, the overall development of personal hygiene should be prioritized. The *Swachh Bharat Abhiyaan*, in 6 years, has changed the basic sanitation practices in rural India. The main objective of this campaign was to make India open defecation-free country. The grants provided for the construction of toilets have been a crucial factor in achieving the objective. To significantly reduce DALYs due to water-borne diseases, government should now focus on the personal hygiene campaigns. Furthermore, studies are required for the development of sustainable model for the Indian subcontinent, which can be used to identify priority areas under the risk of water-borne diseases. To increase the reliability of the model, additional water quality and personal hygiene parameter can be incorporated. In addition to the quality of water, availability and accessibility of water should also be included.

CONCLUSION

Even though the relationship between personal hygiene and the occurrence of diseases is obvious, this study emphasizes the importance of it. Infrastructure development alone will have less influence on curbing diseases. A small improvement in personal hygiene can effectively reduce the cases of water-borne diseases. In particular, the study indicates that the household treatment of water combined with good handwashing practices contributed to controlling water-borne diseases. Systematic assessments using the risk-based approach will help identify region-specific health indicators. The intervention campaigns must be developed to address priority risks.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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