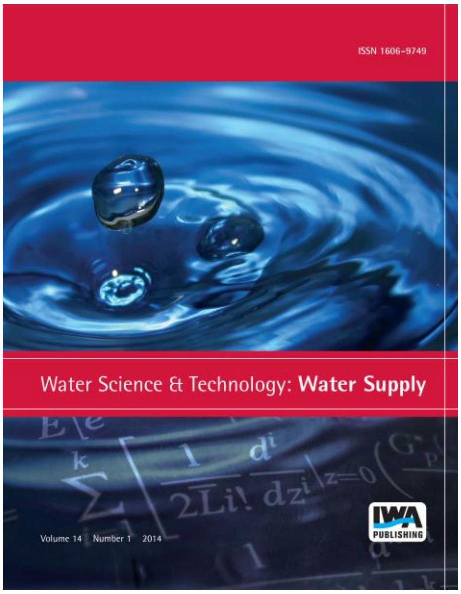

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Access to safe drinking water and human health: empirical evidence from rural Bhutan

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ABSTRACT

Provision of safe drinking water is essential for the promotion of human well-being. This paper makes an attempt to examine the patterns of access to drinking water, identify and analyze the factors that influence households access to safe drinking water sources, and analyze factors determining the extent of households travel to fetch drinking water, and assess the effects of access to safe drinking water on human health in Bhutan, using the data from the Bhutan Living Standard Survey 2012 (BLSS 2012). For this, various methodological tools have been adopted such as logistic regression model, censored least absolute deviation model, and the propensity score matching (PSM) approach. The logistic regression results show that households with educated, younger, and male members are more likely to have access to safe drinking water. Wealthier households also prefer safe drinking water than their poorer counterparts. The PSM results suggest that households having access to safe drinking water have fewer stomach disorders and skin diseases, and are likely to incur less expenditure on medicine. Keeping these findings in mind, the paper suggests that the Bhutanese government should invest in water infrastructure, which may lead to a significant reduction in water-borne diseases and health expenditure.

Key words | access, Bhutan, propensity score matching, safe drinking water, skin diseases, water-borne diseases

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INTRODUCTION

Safe drinking water is essential for the survival and maintenance of good health of people. Providing water security plays a major role in poverty reduction and livelihood improvement, and water scarcity and/or contamination has adverse effects on fertility and migration patterns (Falkenmark 1990) and human health (Dungumaro 2007). When provision and availability of drinking water become inadequate, people are forced to use contaminated and unsafe water sources, resulting in water-related diseases that cause loss of productive working hours and an increase in health expenditure. For instance, (Satterthwaite 2003) finds that inadequacies in provision for piped water, sanitation and drainage result in problems with insect-borne diseases such as malaria, and other diseases related to lack of water and use of poor-quality water. Poverty alleviation and access to safe and sufficient water are positively related, because provision of adequate water resources helps in achieving food security and improving human development indicators, including human health. Poor households frequently do not have access to quality water both in terms of sources of water and methods of water treatment, which makes them vulnerable to a variety of water-borne diseases, thereby adversely reducing their bare-minimum earnings and increasing their expenditure on medicines (Wang *et al.* 2005).

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In poor countries, lack of availability of convenient and easily accessible water resources forces households to travel long distances and often means that children are employed to collect water, adversely affecting productive activities of adults and education of children (Mehta 2014). In addition, poorer households may use water from open sources, often contaminated, which makes these people more vulnerable to water-borne diseases. According to WHO (2010), by the end of 2010 about 89% of the world's population (6.1 billion people) used improved drinking water sources, a figure which is even higher by 1% than the Millennium Development Goals (MDG) target of 88%. However, this means that approximately 11% of the world's population (783 million people) still does not have access to safe drinking water. Hence the expansion of access to safe and reliable drinking water sources, especially in the continents of Africa and Asia, is one of the priorities of the Millennium Development Goals program.

Studies show that when households do gain access to a safe drinking water system, their well-being, both economic and health outcomes, can improve dramatically (Zhang 2012; Mehta 2014). For example, Isham & Kahkonen (2002) found that access to a piped water system among households in Indonesia increased the probability of improved health by 0.29 probability points. Improved water quality has been observed to play an important role in reducing diarrhoea and mortality in various countries (Zhang 2012; Jessoe 2013). However, despite this compelling evidence of the positive effect of clean and sufficient water on human health and productivity, it has been observed that most households in developing countries, both in rural and urban areas, lack access to safe and sufficient water services. Several reasons are found to be responsible, for instance low economic status, and socio-cultural or other demographic conditions that prevent households from having access to water services. Under such circumstances, provision of adequate water to households may not be a sufficient condition for their overall well-being, as this also depends on the quality of the water. Hence, household adoption of effective water treatment is the key determinant of health outcomes (Rahut *et al.* 2015). This depends largely on household socioeconomic condition. For instance, in cities and towns, wealthy people generally use various water-treatment processes that can ensure the quality of drinking water, while poor people often use water that is untreated, resulting in an increase in illnesses and other health-related problems. In addition to income, levels of education and awareness play an important role in gaining access to effectively-treated water. World Bank (1993) find that in rural areas of developing countries, willingness to pay for the basic water services varies widely, and is affected by level of income and the characteristics of the existing supplies.

Hence, provision of safe drinking water, adequate sanitation and personal hygiene are vital for reducing the incidence of diarrhoea, malaria, trachoma, hepatitis A and B and morbidity levels. Not having access to water and sanitation is a form of deprivation that threatens human life, destroys economic and livelihood opportunity and undermines human dignity. Thus, investing in the provision of safe water supply and adequate sanitation is not only a development oriented strategy in itself, it can also yield other socioeconomic benefits in terms of improved health status, quality of labour force and reduced burden-of-disease. In developing countries like Bhutan, the vast majority of people live in rural areas, which are often remote with limited or no access to markets. Lack of access to markets is also often linked to low education and income levels. Given these constraints, households tend to adopt a variety of strategies for securing adequate clean water.

In this context, issues of household socioeconomic conditions as they relate to water availability are not very well covered in water literature, particularly in the context of Bhutan. In Bhutan, about 69% of the country's population lives in rural areas, where most of the water-borne and water-related diseases such as diarrhoea, typhoid, skin infections, conjunctivitis, dengue and malaria are prevalent. These diseases are among the leading causes, of infant and child deaths in the country. In most cases, research tends to focus on factors leading to an inadequate supply of water, and not on exploring factors which hinder or enable households' access to water. It is argued that in certain instances, failure to obtain water from a safe source is caused by the inability to pay for it. Understanding household socioeconomic conditions offers a way of linking availability of water and ability of households to obtain water from a safe source. In this context, analysis of household-level determinants of access to drinking water sources is an important tool for gaining a comprehensive understanding of the behaviour that shapes a household's use of safe drinking water.

In order to contribute to this body of knowledge, the present study makes an attempt to examine the patterns of access to water, and to identify and analyze the factors that influence households' access safe drinking water sources, analyze factors determining the extent of households' travel to fetch drinking water, and assess the effects of access to safe drinking water to human health in Bhutan, using the data from the Bhutan Living Standard Survey 2012. The paper is organized as follows. The second section presents the propensity score matching (PSM) approach as a conceptual framework for assessing the effects of safe access to water on human health. Data, methods and variable description are presented in the third section. The fourth section presents the empirical results and discussions. Finally, the conclusion and policy implication are presented in the fifth section.

THE PSM APPROACH: A CONCEPTUAL FRAMEWORK FOR LINKING HOUSEHOLD ACCESS TO DRINKING WATER AND HUMAN HEALTH

In this section, the PSM approach is described as a simple conceptual framework for linking the effects of drinking water with human health. It is assumed that there are two categories of rural households in Bhutan, i.e. households having access to safe drinking water and the households having no access to safe drinking water, and the households having access to safe drinking water have higher utility levels as compared to households having no access to safe drinking water, as presented in Equation (1).

$$\mathrm{U(Wa)} > \mathrm{U(Wn)} \tag{1}$$

The rural households' access to safe drinking water is influenced by number of socioeconomic (φ), demographic (Ω), institutional (ξ) household and farm level (θ) factors as represented in Equation (2).

$$\mathrm{U(Wa)}(\phi, \Omega, \xi, \theta) > \mathrm{U(Wn)}(\phi, \Omega, \xi, \theta) \tag{2}$$

On the contrary, if it is assumed that the characteristics of these two sets of households, with and without access to safe drinking water, are similar, then it would be incorrect, as in the real world the socioeconomic and other characteristics of beneficiary and non-beneficiary households tend to be quite different from each other in many aspects. If the households are quite different from each other than the comparison and estimates may produce misleading results. In order to correct this sample selection bias, PSM approach has been employed. Matching involves pairing treatment and comparison units that are similar in terms of their observable characteristics. When the relevant differences between any two units are captured in the observable covariates, which occurs when outcomes are independent of assignment to treatment conditional on pretreatment covariates, matching methods can yield unbiased estimates of the treatment impact (Dehejia & Wahba 2002).

PSM follows that the expected treatment effect for the treated population is of primary significance. This effect may be given as:

$$\tau|_{I=1} = E(\tau|I=1) = E(R_1|I=1) - E(R_0|I=1) \tag{3}$$

where τ is the average treatment effect for the treated (ATT), R_1 denotes the value of the outcome for adopters of the new technology, in our case households with access to safe drinking water and R_0 is the value of same variable for non-adopters, in our case households without safe drinking water. As noted above, a major problem is that we do not observe $E(R_0|I=1)$. Although the difference $[\tau^e = E(R_1|I=1) - E(R_0|I=0]$ can be estimated, it is potentially a biased estimator.

In the absence of experimental data, the propensity score-matching model (PSM) can be employed to account for this sample selection bias (Dehejia & Wahba 2002). The PSM is defined as the conditional probability that a household has access to safe drinking water, given pre-access characteristics (Rosenbaum & Rubin 1983). To create the condition of a randomized experiment, the PSM employs the unconfoundedness assumption, also known as conditional independence assumption (CIA), which implies that once Z is controlled for, technology adoption is random and uncorrelated with the outcome variables. The PSM can be expressed as:

$$p(Z) = \Pr\{I=1|Z\} = E\{I|Z\} \tag{4}$$

where I is the indicator for access to safe drinking water and Z is the vector of pre-access characteristics. The conditional distribution of Z, given p(Z) is similar in both groups of households having access to safe drinking water and those that do not have access to safe drinking water.

After estimating the propensity scores, the average treatment effect for the treated (ATT) can then be estimated as:

$$\tau = E\{R_1 - R_0 | I = 1\} = E\{E\{R_1 - R_0 | I = 1, p(Z)\}\} \\ = E\{E\{R_1 | I = 1, p(Z)\} - E\{R_0 | I = 0, p(Z)\} | I = 0\} \quad (5)$$

PSM rests on two strong assumptions, i.e. CIA and the common support condition. The CIA states that once the observable factors are controlled for, access to safe drinking water is random and uncorrelated with the outcome variables. The common support condition states that matching can only be performed over the region of the common support. There are a number of matching algorithms which can be employed to estimate the PSM, i.e. nearest neighbour matching (NNM), kernel based matching (KBM), radius matching (RM) and mahalanobis metric matching (MMM). As the main purpose of the PSM is to balance the covariates before and after matching, a number of balancing tests have been employed in the current analysis such as a reduction in the median absolute bias before and after matching, the value of R^2 before and after matching and the *p*-value of joint significance of covariates before and after matching.

DATA, METHODS AND VARIABLE DESCRIPTIONS

This paper uses data collected by the National Statistical Bureau for the Bhutan Living Standard Survey for the years 2003, 2007 and 2012 (BLSS 2003, BLSS 2007, and BLSS 2012). This is a nationally representative and comprehensive survey which covers the whole of the country. The National Statistical Bureau of Bhutan collected and compiled BLSS 2003, 2007 and 2012 by using multi-stage stratified random-sampling techniques, covering about 4,007 households in 2003; 9,798 households in 2007; and 9,998 households in 2012. The BLSS 2003, 2007, 2012 collected information on demographic, consumption expenditure, housing, employment, health status, fertility, education, access to public facilities and services, price of commodities and assets ownership, etc. In this study, we have used the data related to household access to drinking water and their health status. Sources of water for domestic uses are classified into four groups. They are: (1) tap in dwelling, (2) public and neighbour water tap, (3) well, and (4) the natural sources such as river, spring, pond, etc. 'Tap in dwelling' as a source of drinking water means that the household has a tap in the house and is a clean, safe and convenient source of water compared open sources. 'Public and neighborhood' water sources indicate that the household uses the tap water from outside their own dwelling but in close vicinity and it is a source of safe drinking water. 'Natural and open' sources of drinking water are not safe, as it is exposed and not protected or treated. Like any other developing countries, households in rural Bhutan rarely use bottled water and hence are not included in the current analysis. The percentage of households having access to these sources of water for domestic uses, for both rural and urban areas, and for three data sets, BLSS 2003, 2007, 2012, is presented in Table 1. The comparative analysis indicates that, over the years, the access to tap water has improved in Bhutan. As now, nearly 73% of the households have a tap in their dwelling. About 23% of the rural population have access to water from public sources and neighbours. The rest have access from wells and natural sources.

The objectives of the paper are to identify and analyze the factors that influence a household's ability and/or inability to access safe drinking water sources, and analyze factors determining household travel to fetch drinking water. To identify and analyze the factors that determine a household's ability to access safe drinking water, a logistic regression model has been employed, whereas for analyzing

Table 1 | Percentage of householdS by sources of water during 2012, 2007 and 2003

	Rural			Urban		
Water sources	2012	2007	2004	2012	2007	2004
Tap in dwelling	72.8	44.8	43.66	87.2	82.9	78.14
Public & neighbour	23.2	40.9	31.81	11.8	16.5	20.66
Well	1.1	1.7	4.27	0.4	0.2	0.17
Natural sources	2.8	12.6	20.26	0.5	0.5	1.03
Total	4.350	6.856	1.688	4.619	2.942	2.319

Source: Compiled from BLSS 2003, 2007 and 2012.

factors affecting household travel to collect drinking water, the censored least absolute deviation (CLAD) model has been applied. Based on the available literature on factors influencing household access to drinking water and our own understanding of the local household behaviour, it is assumed that various household socioeconomic and demographic characteristics may also influence household access to drinking water in Bhutan. These factors include age and gender of the household head, household size, years of schooling, landholding size, wealth of household, access to markets and others. Table 2 presents the descriptions and summery statistics of the variables used in the models mentioned above.

As can be seen from Table 2, the average age of the households was 49 years. About 66% of the surveyed households are headed by male member. The average number of children (<15 years of age) is about 1.5 children per household and the mean number of elderly people in the family are 0.34 people per household. The average family size of the sampled households is about 4.8 people. The average years of schooling of the household are 1.8 years. The average distance to the market was more than 0.8 h. About 73% of the households have access to a drinking water facility. The average operational land holding with the farmer was 1.3 acres. The mean distance to the safe water was about 9 min. The average number of livestock owned by households was about 1.9. About 91% of the households have access to a mobile facility and vice versa. About 5% of the households have access to internet facility. The average monthly per capita income of the household is about 2,319 ngultrum. About 81% of the households have access to toilet facilities and vice versa. The mean distance to the road is about 8 km. The average monthly per capita household food expenditure is about 1,399 ngultrum.

Table 3 presents the differences of the key characteristics of the households that are having access and not having access to safe drinking water. As can be seen from Table 3, most of the variables are having significant differences with a theoretically consistent direction between households with and without access to safe drinking water. The difference in age of the households is negative and significant at 5%, indicating that the households that

Table 2 | Variable descriptions and summery statistics

Variable	Description	Mean	Std dev.
Age of household head	Age of the farmer in number of years	49.13	15.33
Gender of household head	1 if the gender of the household head is male and 0 for female	0.66	0.37
Number of children under 15 years	Children under the age of 15 in the household	1.48	1.35
Elderly member in the households	Total adult in the household over the age of 65	0.34	0.62
Family size (household size)	Total number of family members living in the household	4.8	2.2
Education of household head	Number of years of schooling of the household head	1.83	3.94
Distance to food market/shop	Distance to the nearest food market/shop in h	1.61	5.7
Distance to road	Distance to main road in h	0.77	5.33
Distance to water source	Distance of the safe water in min	9.36	21.64
Water access	1 if the household have access to safe drinking water and 0 otherwise	0.73	0.39
Operational land	Total operational land in acres	1.28	2.08
Livestock assets	Livestock assets owned by the household	1.87	1.05
Mobile owned	1 if the household have mobile facility and 0 otherwise	0.91	0.08
Internet owned	1 if the household have access to internet facility and 0 otherwise	0.05	0.09
Toilet facility	1 if the household have improved toilet facility and 0 otherwise	0.81	0.03
Mean per-capita monthly income	Mean per-capita monthly household income in ngultrum	2.319	1.562
Mean per-capita expenditure	Mean per-capita monthly household food expenditure in ngultrum	1.399	1.142
Number of observations	4,173		

Household, income and expenditure are expressed in Bhutanese ngultrum or nu (exchange rate: 1 US$ = 53.44 nu at time of study; purchasing power parity rate: 1 US$ = 18.203 nu).

Table 3 | Differences in the key characteristics of the households having access and having no-access to safe drinking water

Variable	Water access	No water access	Difference	t-values
Age of household head	45.30	51.79	−6.49**	−2.15
Gender of household head	0.72	0.61	0.11***	2.94
Number of children under 15 years	1.40	1.56	−0.16	−1.27
Old age member in the households	0.37	0.32	0.05	0.80
Family size (household size)	4.27	5.32	−0.61*	−1.82
Education of household head	1.97	1.65	1.32**	2.07
Distance to food market/shop	1.73	1.51	−0.222***	−2.75
Distance to road	0.71	0.84	−0.07*	−1.86
Distance to water source	10.82	6.20	−4.62*	−1.66
Water access	0.72	0.61	0.11*	1.90
Operational land	1.52	1.00	0.52**	2.24
Livestock	1.87	1.62	0.25*	1.82
Mobile	0.93	0.85	0.08*	1.85
Internet	0.07	0.03	0.4*	1.74
Improved toilet facility	0.88	0.78	0.10**	1.83
Mean per-capita monthly income	2.519	2.013	−506**	−2.35
Mean per-capita expenditure	1.575	1.205	−370*	1.80

Note: The results (***, **, *) indicate significance at 1, 5 and 10 percent levels, respectively.

are having access to safe drinking water are younger (lower aged) as compared to farmers having no access to a safe drinking water facility. The difference in gender is positive and significant at 1% level, indicating that male headed households are having frequently more access to safe drinking water and vice versa. The child and elderly difference is not significant. The family size difference is negative and significant indicating that, in general, households having no access to safe drinking water have higher family size and vice versa. The education difference is positive and significant at 5% level, indicating that educated households have more access to drinking water than less educated households. The difference in market access distance is negative and significant at 1% level, meaning that the further the household is located from the market, the more it is away from access to drinking water. The difference in water access is positive and significant at 10% level of significance.

The difference in operational land holding is also positive and significant at 5% level of significance, meaning that landed households have access to safe drinking water. The water distance is negative and significant at 10% level of significance. The difference in livestock ownership is positive and significant at 10% level, which means households having more livestock holding are also having access to safe drinking water. The difference in access to mobile facility is positive and significant at 10% level. The income difference is positive and significant at 10% level, indicating that higher income households have access to safe drinking water. The road distance is negative and significant at 5% level of significance. The difference in expenditure is positive and significant at 10% level of significance, which suggest that households that expend more have access to safe drinking water.

EMPIRICAL RESULTS AND DISCUSSION

Factors affecting household access to safe drinking water

The results of the logistic regression model estimation on determinant factors affecting household access to safe drinking water are presented in Table 4. The dependent variable of

Table 4 | Determinant factors affecting household access to safe drinking water (logit estimates)

Variable	Coefficient	z-values
Age of household head	−0.12***	−2.73
Gender of household head[a,b]	0.11**	2.08
Family size (household size)	0.13***	4.10
Education of household head	0.12**	2.25
Distance to market (in min)	−0.13**	−2.14
Distance to road (in min)	−0.24**	−2.04
Distance to water source (in min)	−0.10***	−2.76
Operational land (in acres)	0.16**	1.98
Livestock assets (TLU)	0.12**	2.04
Mobile owned[a,c]	0.04	1.13
Internet owned[a,d]	0.08*	1.92
Improved toilet facility[a,e]	0.05	1.47`
Per capita monthly household income	0.09**	2.03
Monthly per capita food expenditure	0.11**	2.16
Constant	0.27**	2.25
LR χ^2	135.27	
Prob > χ^2	0.000	
Pseudo R^2	0.24	
Number of observations	4.170	

Note: The results (***, **, *) indicate significance at 1, 5 and 10% levels, respectively.
[a]Dummy variables.
[b]Excluded category: female head.
[c]Do not have mobile phone.
[d]Do not have internet.
[e]Do not have improved toilet.

the model is a dummy that takes 1 if the household is having access to safe drinking water and 0 otherwise. A host of socio-economic and demographic characteristics of households was included in the model as independent variables. The overall model is highly significant (Chi square is significant at 1% level) with pseudo R square of 24%, indicating the robustness of the variables included in the model. With regard to individual variables, almost all the variables have turned out significant with theoretically consistent signs. The age coefficient is negative and significant at 1% level, indicating that young farmers have better access to safe drinking water facility than the older farmers. The gender coefficient is positive and significant at 5% level, indicating that male headed households have easy access to safe drinking water as compared to female headed households. The results of age and gender of households indicate that younger and male member households are likely to have easy access to safe drinking water in Bhutan, which is to some extent true in the case of Bhutan where the geographical condition is such that people have to make an effort to reach the drinking water source.

The family size coefficient is positive and highly significant at 1% level of significance indicating that large family size households have easy access to safe drinking water. This could be due to the fact that a large family has more members to be employed for collecting drinking water from the safe source. The education coefficient is positive and significant at 5% level, indicating that educated farmers have access to safe drinking water compared to less educated or uneducated farmers. This is because of acute awareness about the importance of safe drinking water for healthy life on the part of educated people as well as the opportunity costs of not having safe drinking water. The coefficient of market distance is negative and significant at 5% level indicating that the greater the distance to the market, the lesser the access to safe drinking water and vice versa, which suggests that market access promotes access to safe drinking water via higher income and infrastructure developments. The operational land holding is positive and significant at 5% level of significance, indicating that farmers having higher land holding have easy access to safe drinking water and vice versa, which indicates that wealthier households tend to have better access to safe drinking water.

The coefficient of the variable water distance is negative and significant at 1% level, meaning that households that are located far away from water sources are not likely to have access to safe drinking water. The livestock ownership is positive and significant at 5% level, which again confirms that richer households have access to safe drinking water as they can afford to do so. The access to internet was also included as a dummy variable and the coefficient is positive and significant at 10% level of significance. This may be due to the easy access to information and market access. The income coefficient is positive and significant at 5% level of significance, which suggests that households with higher incomes are likely to have access to safe drinking water than their poorer counterparts. The coefficient of variable household expenditure is positive and significant at 5% level, which indicates that households having more expenditure are those who have more access to safe drinking water.

Factors affecting household travel to fetch drinking water

The CLAD model has been estimated for the distance travelled to fetch water. The CLAD model has been estimated instead of Tobit model because, in the face of heteroskedasticity or non-normality, the Tobit model produces biased estimates. In contrast to Tobit, since the CLAD estimator does not depend on distributional or homoscedasticity assumptions of the errors and is robust to censoring it produces consistent estimates even in the face of heteroskedasticity, non-normality and censoring. (The CLAD estimator is a generalization of the least absolute deviation (CLD) estimator. Unlike the standard estimators of the censored regression model such as Tobit or other maximum likelihood approaches, the CLAD estimator is robust to heteroskedasticity and is consistent and asymptotically normal for a wide class of error distribution.) The determinants of the distance travelled to have access to safe drinking water are presented in Table 5. The dependent variable is the number of kilometers travelled to have access to safe drinking water. A set of independent variables are included in the model. The age coefficient is negative and significant at 5% level of significance indicating that aged farmers are less likely to travel longer distances to fetch water and/or younger people can travel to long distance to ensure safe drinking water for their families. The gender of the household head was included as dummy variable and the coefficient is negative and significant at 10% level indicating that female headed households normally travel more distances to have access to safe drinking water.

Table 5 | Determinant factors affecting household travel to distance to access safe drinking water (Tobit estimates)

Variable	Coefficient	t-values
Age of household head	−0.07**	−2.32
Gender of the household head[a,b]	−0.06*	1.69
Family size (household size)	0.08**	2.19
Education of household head	0.10***	2.74
Distance to market	−0.12***	−3.16
Operational land	0.11***	2.71
Livestock asset	0.13**	2.12
Mobile[a,c]	0.14**	2.08
Internet[a,d]	0.15*	1.67
Improved toilet facility[a,e]	0.03	1.40
Mean per-capita monthly income	0.09**	2.16
Monthly per capita food expenditure	0.05**	1.99
Constant	0.175***	2.79
Pseudo R^2	0.39	
Sample size	4.170	
Uncensored sample	3.061	

Note: The results (***, **, *) indicate significance at 1, 5 and 10% levels, respectively.
[a]Dummy variables.
[b]Excluded category: female head.
[c]Do not have mobile phone.
[d]Do not have internet.
[e]Do not have improved toilet.

The family size coefficient is positive and significant at 5% level indicating that large families normally can travel longer distances to have access to safe drinking water. This may be because people in large family is having less opportunity costs and hence can spend time to travel longer distance to fetch water. The coefficient of the variable education is positive and significant at 1% level, which suggests that educated households can travel longer distances to have access to safe drinking water. In this case, the awareness about the importance of safe drinking water dominates the opportunity costs that the educated household may face. The distance to market coefficient is negative and significant at 1% level of significance, indicating that the greater the distance to market, the less the households have access to safe drinking water.

The operational land is positive and significant at 1% level of significance. Similarly livestock ownership is positive and significant at 5% level indicating that wealthier households have easy access to safe drinking water. The mobile ownership and internet access were included as development indicators and the coefficients are positive and significant, which suggest that overall development is likely to generate demand for safe drinking water. The households' income coefficient is positive and significant at 5% level, indicating that higher income households are likely to travel long distances to fetch safe drinking water. Here, also access to safe drinking water dominates.

Impact of safe drinking water on human health

The impact of safe drinking water on human health is estimated by employing the PSM. The matching method has been employed to correct for potential sample selection bias that may arise due to systematic differences between the households having access to safe drinking water and having no access to safe drinking water. The most important parameter of interest is ATT, i.e. difference in outcome of the treated and non-treated. In the current analysis, a number of different matching algorithms are employed, i.e. nearest neighbour matching (NNM), KBM, RM and MMM. The nearest neighbour matching matches with the nearest neighbour only, the KBM takes the weighted average of all the non-participants and then matches. In RM, each treated subject is matched with a corresponding control subject that is within a predefined interval of the treatment subject's propensity score. In MMM, the subjects are ordered randomly and then the distance between the treated and control subjects is calculated. The treatment and control are matched based on the smallest Mahalanobis distance. The process is repeated until each treatment subject is matched and then the unmatched control subjects are removed.

The current analysis is carried out by employing the four different matching algorithms, i.e. NNM, KBM, RM and MMM. The impact of access to safe drinking water is estimated on stomach disorder, dehydration, medicine expenditure, and skin diseases. The impact of safe drinking water on stomach disorders is negative and significant in the case of all the four different matching algorithms, i.e. NNM, KBM, RM and MMM, indicating that households having access to safe drinking water have less stomach disorder in the range of 0.10–0.13. The impact on dehydration is also negative in the case of all the four different matching algorithms, i.e. NNM, KBM, RM and MMM. The impact of access to safe drinking water on dehydration indicates that households having access to safe drinking water have less dehydration in the range of 0.10–0.16. The impact on skin diseases is also negative and significant in the range of 0.01–0.02 indicating that households having access to safe drinking water have fewer skin diseases. The impact on medicine is also negative and significant in the range of Bhutanese rupees 248–415, indicating that households having access to safe drinking water have less expenditure on the purchase of medicines. The results are in line with the previous studies such as Rice *et al.* (1992) and Blake *et al.* (1993) which indicated the access to safe drinking water reduced diarrhoeal illness. The results are also in line with the previous study of (Jalan & Ravallion 2003) which estimated that piped water in India can help to improve child health (see Table 6).

The main purpose of the PSM is to balance the covariates before and after matching. The results regarding

Table 6 | ATT results regarding access to safe drinking water (PSM estimates)

Matching algorithm	Outcome	ATT	t-value	Critical level of hidden bias	Number of treated (A)	Number of control (B)
NNM	Stomach disorder	−0.10*	−1.95	1.40–1.45	2.310	1.493
	Dehydration	−0.16***	−3.22	1.85–1.90	2.146	1.720
	Medicine expenditure	−248**	−1.98	1.10–1.15	2.035	1.627
	Skin diseases	−0.02*	−1.65	1.30–1.35	2.519	2.766
KBM	Stomach disorder	−0.09**	−2.05	1.20–1.25	2.416	1.572
	Dehydration	−0.15**	−2.34	1.35–1.40	2.239	1.725
	Medicine expenditure	−385**	−2.10	1.25–1.30	2.462	1.763
	Skin diseases	−0.05**	−2.07	1.30–1.35	2.031	1.467
RM	Stomach disorder	−0.12**	−1.97	1.35–1.40	2.217	1.584
	Dehydration	−0.13***	−2.56	1.95–2.00	2.138	1.369
	Medicine expenditure	−415***	−3.03	1.50–1.55	2.046	1.433
	Skin diseases	−0.01	−1.42	–	2.418	1.671
MMM	Stomach disorder	−0.13**	−2.18	1.45–1.50	2.064	1.329
	Dehydration	−0.10***	−3.27	1.10–1.15	2.316	1.472
	Medicine expenditure	−375***	−2.93	1.40–1.45	2.258	1.230
	Skin diseases	−0.03	−1.22	–	2.353	1.670

Note: ATT stands for the average treatment affect for the treated, the results (***, **, *) are significant at 1%, 5% and 10% levels, respectively, for the nearest-neighbor matching, the calipers are reported, while for the kernel-based matching, the band widths are reported, the numbers in each section of the column (A) and (B) are different because different calipers and bandwidths are used.

Table 7 | Indicators of covariates balancing before and after matching

Outcome	Median absolute bias before matching	Median absolute bias after matching	Percentage bias reduction	Value of R^2 before matching	Value of R^2 after matching	*p*-value of joint significance of covariates before matching	*p*-value of joint significance of the covariates after matching
Matching algorithm: NNM							
Stomach disorder	22.57	4.21	81.34	0.185	0.003	0.001	0.735
Dehydration	27.14	6.79	74.98	0.226	0.004	0.002	0.622
Medicine expenditure	18.52	5.36	71.05	0.132	0.005	0.003	0.713
Skin diseases	19.23	6.55	65.93	0.189	0.005	0.004	0.646
Matching algorithm: KBM							
Stomach disorder	18.55	6.29	66.09	0.113	0.005	0.004	0.724
Dehydration	19.34	4.57	76.37	0.251	0.006	0.001	0.512
Medicine expenditure	20.41	7.18	64.82	0.396	0.007	0.003	0.485
Skin diseases	17.69	5.26	70.26	0.241	0.003	0.004	0.373
Matching algorithm: RM							
Stomach disorder	17.39	5.12	70.55	0.209	0.003	0.006	0.576
Dehydration	15.28	6.34	58.50	0.326	0.004	0.003	0.468
Medicine expenditure	22.31	5.43	75.66	0.413	0.005	0.002	0.316
Skin diseases	24.10	6.35	73.65	0.510	0.006	0.004	0.637
Matching algorithm: MMM							
Stomach disorder	19.35	5.80	70.02	0.362	0.001	0.004	0.412
Dehydration	18.27	4.76	73.94	0.429	0.002	0.007	0.351
Medicine expenditure	19.44	5.29	72.78	0.310	0.004	0.005	0.520
Skin diseases	20.15	6.82	66.15	0.473	0.005	0.004	0.361

covariates balancing are presented in Table 7. A number of balancing tests like median absolute bias before and after matching, value of R-square before and after matching and the joint significance of covariates before and after matching are estimated. The median absolute bias is quite high before matching and is quite low after matching. Before matching, the bias is in the range of 15.28–27.14. The percentage bias reduction is in the range of 58–81%. The percentage bias reduction indicates that, after matching, the farmers with and without access to safe drinking water are very much similar to each other. The value R-square is quite high before matching and is quite low after matching, indicating that, after matching, there are no systematic differences between the participants and non-participants. The *p*-value of joint significance of covariates should always be rejected after matching, and should be accepted before matching, hence implying that, after matching, both the households with and without access to safe drinking water are very much similar to each other. The covariates matching results are in line with previous studies like Ali & Abdulai (2010) and Ali & Sharif (2011).

CONCLUSION AND POLICY IMPLICATIONS

This study examines the pattern of household use of drinking water sources, household access to safe drinking water, and the effects of safe drinking water on human health. It also makes an attempt to identify and analyze the factors affecting household access to safe drinking water sources in Bhutan. The descriptive statistics show that the percentage of both urban and rural households that use safe sources of water has increased during the years 2003–2012. The results also show that a much larger proportion of urban households have access to piped water in the dwelling or compound compared with rural households. Two important findings are clearly evident from the descriptive statistics: firstly, urban dwellers have better access to piped water in the dwelling or compound than rural households, possibly because piped water is considered to be the most reliable, safest and easiest source of drinking; secondly, access to safe drinking water increases with an increase in economic status.

The empirical analysis of the determinant factors affecting household access to safe drinking water suggests that level of education, gender, age, economic status, access to market, and location of the household are all factors that influence household access to safe drinking water in Bhutan. The results show that with an increase in the level of education, the likelihood of using safe drinking water increases, because educated households are expected to be more aware with regard to water safety, and also face a high opportunity cost of drinking unsafe water. Educated households often have paid employment in government or the private sector, and usually live in apartments or houses in urban and semi-urban areas which have piped water in the dwelling. Households with younger, male members, and of large size are more likely to have access to safe drinking water, as they can afford to travel the distance to ensure safe drinking water for their family. Economic status of the household such as landholding and livestock holding size are other key determinants of household access to safe drinking water.

The CLAD model estimates the determinants of household travel to fetch drinking water show that level of education, age of the household head, economic status of the household and location of the household are the key factors that influence household decisions to travel the distance to collect safe drinking water. It is found that households with higher levels of education and those with a younger household head are more likely to travel distance to fetch drinking water. Households with higher economic status (e.g. landholding and livestock holding size) are also likely to travel to ensure safe drinking water for their families. Since access to clean drinking water has numerous positive effects on the well-being of people, policies should be aimed at providing piped water in the compound/dwelling, as this is the safest, most reliable and easiest way of accessing water. In the context of provision of safe drinking water to rural households in Bhutan, it should be pointed out that although it may not be possible to connect each rural household with piped water, given the constraints they face in terms of economic disadvantages and location, an awareness must be created among households of the importance of adopting appropriate methods to treat their drinking water.

The results of the PSM approach show the impact of access to safe drinking water on four key indicators of water-borne human health such as stomach disorders, dehydration, medicine expenditure, and skin diseases. The results show negative and significant effects of safe drinking water on these four indicators, which indicates that households having access to safe drinking water are less likely to have stomach disorders, dehydration, skin diseases and fewer medicine expenses. These results are consistent with the findings of several other studies (Rice *et al.* 1992; Blake *et al.* 1993; Jalan & Ravallion 2003). From the analysis and discussion, it is clear that access to safe drinking water is available for only wealthier households in Bhutan and rural areas and poorer households often still rely on unsafe water sources. It is also found that households using unsafe drinking water are likely to suffer more from skin diseases, dehydration, stomach disorder, and are likely to incur more expenses on medicine, which can have cascading effects on their economic and physical well-being. Keeping these findings in mind, the paper suggests that the government should invest in water infrastructure in Bhutan. Such an investment in infrastructure for providing safe drinking water in the vicinity of the household would lead to a significant reduction in water-borne diseases and a consequent reduction in health expenditure. Access to drinking water in rural areas is complex, hence holistic and high investment in water infrastructure and sanitation is necessary. Given the very low level of access to improved toilet facilities, provision for access to improved toilet facilities is also very important to avoid the contamination of the water resources.

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