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Short Communication

The impact of improved water and sanitation on water-related diseases: a propensity scores matching analysis from Palghar District, Maharashtra, India

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ABSTRACT

Inadequate water, sanitation, and hygiene (WASH) are responsible for a significant portion of the global disease burden. However, establishing the causal effect of improved WASH is challenging due to confounding socioeconomic factors. This study employs propensity score matching (PSM) to estimate the causal effect of improved water and sanitation on water-related diseases in Palghar District, India. Using cross-sectional household survey data, households with improved WASH were matched with statistically similar households without improved WASH. The average treatment effect on the treated (ATT) was estimated for diarrhoea, jaundice, malaria, skin disease, typhoid, and dengue. The analysis reveals a statistically significant reduction in jaundice prevalence (ATT: -0.21, $p<0.10$) attributable to improved WASH. Effects on diarrhoea, typhoid, and skin disease showed protective trends but were not significant. A counterintuitive finding was a significant increase in malaria risk (ATT: 0.38, $p<0.05$), potentially linked to water storage practices. The protective effect of improved WASH is not uniform. While critical for faecal-oral diseases like jaundice, its impact is mediated by behavioural and contextual factors. Policy must integrate behavioural change communication, targeted vector control, and equity-oriented interventions.

Keywords: Propensity score matching, Water-related diseases, Causal inference, WASH, India, Sanitation, Jaundice

INTRODUCTION

Water-related diseases remain a leading cause of morbidity and mortality globally, disproportionately affecting vulnerable communities in low- and middle-income countries. The World Health Organization (WHO) estimates that inadequate WASH are responsible for nearly 10% of the global disease burden.[1] While the link between contaminated water and illness is biologically plausible, establishing a clear causal relationship from observational data is methodologically challenging. Households with access to improved water and sanitation often differ systematically from those without; they are typically wealthier, more educated, and have better overall living conditions. These pre-existing differences, known as confounding variables, make it difficult to isolate the true protective effect of water and sanitation infrastructure itself.

This study employs PSM to answer a critical public health question in the Palghar District: What is the true, causal effect of improved water and sanitation on the prevalence of key water-related diseases? By providing a more robust estimate of this impact, our findings aim to deliver valuable evidence for policymakers seeking to allocate scarce resources effectively and ultimately improve health outcomes in communities that need it most.

PSM has emerged as a powerful statistical method designed to approximate the conditions of a randomized experiment using observational data.[2] Developed by Paul

Rosenbaum and Donald Rubin in the early 1980s, PSM aims to reduce selection bias by equating groups on observed covariates. The core idea is to condense multiple confounding variables into a single metric-the propensity score, which is the probability of receiving the treatment conditional on observed characteristics.

This process helps isolate the true effect of the water and sanitation infrastructure itself, cutting through the veil of confounding variables.

PSM offers a robust statistical framework to overcome this challenge. By creating a synthetic control group that is statistically equivalent to the treatment group across all observed covariates, PSM allows researchers to approximate the conditions of a randomized experiment. This study utilizes PSM to cut through the veil of confounding and answer a critical public health question: What is the true average effect of improved water and sanitation on the prevalence of diseases like diarrhoea, jaundice, malaria, skin disease, typhoid, and dengue in the Palghar District? The findings provide valuable evidence for policymakers aiming to allocate resources effectively and improve community health outcomes.

Establishing causal relationships from observational data remains a central challenge in quantitative research. Unlike randomized controlled trials (RCTs), where random assignment theoretically ensures the equivalence of treatment and control groups, observational studies are plagued by confounding variables. Individuals in the treatment group are then matched to individuals in the control group with similar propensity scores, creating a balanced sample where the distribution of measured covariates is independent of treatment assignment.

These pre-existing differences between groups can create spurious associations, making it difficult to isolate the true effect of a treatment, intervention, or exposure. For researchers in (your field of study, e. g., public health, economics, education), who often must rely on non-experimental data, overcoming this challenge is paramount to producing valid and reliable evidence.

The discourse on water, sanitation, and health is vast and interdisciplinary. Seminal work by Esrey et al demonstrated through early meta-analyses that improvements in water quality and sanitation could significantly reduce diarrhoeal morbidity.[3] The millennium development goals (MDGs) and their successors, the sustainable development goals (SDGs), particularly SDG 6, have cemented the global commitment to ensuring access to safe water and sanitation for all, based on the overwhelming evidence of its health benefits.[4]

However, magnitude of these benefits has been debated. Some large-scale studies have found more modest effects, arguing that the health impact is mediated by complex behavioral factors, such as hygiene practices.[5] This highlights a key methodological issue: simply comparing disease rates between groups with and without improved facilities can lead to biased estimates due to underlying socioeconomic and demographic disparities.

To address this selection bias, economists and epidemiologists have increasingly turned to quasi-experimental methods. Rosenbaum and Rubin pioneered the PSM technique, which has since become a gold standard for drawing causal inferences from observational data.[2] Applications of PSM in public health have grown, including studies evaluating the impact of sanitation campaigns on child health[6] and the effect of water purification on diarrhoeal incidence.[7] These studies consistently show that failing to account for self-selection and confounding leads to an over- or under-estimation of the true treatment effect.

This study contributes to this evolving literature by applying a rigorous PSM methodology to a nuanced local context-the Palghar District. It moves beyond diarrhoea, the most commonly studied outcome, to investigate a broader spectrum of water-related illnesses, thereby providing a more comprehensive assessment of the health returns on investments in water and sanitation infrastructure

Objectives

The primary objective of this study is to estimate the causal effect of having an improved source of drinking water and sanitation on the prevalence of water-related diseases among households in Palghar District. Specifically, this research aims to: Estimate the ATT for improved water and sanitation on six water-related diseases: diarrhoea, jaundice, malaria, skin disease, typhoid, and dengue and identify key socioeconomic and demographic determinants associated with a higher risk of contracting these diseases.

METHODS

Data source and study setting

The study conducted during August 2014 to July 2017 in Wada, Dahanu and Palghar blocks/Taluks of Palghar district of Maharashtra. The study used quantitative methods of data collection. The ‘interview schedule’ was used to collect the quantitative data from households. The households from the rural areas of the Palghar district were selected from tribal and non-tribal areas. The interview schedule was organized to get information on household profile, water and sanitation profile, health outcomes, the economic burden, and water poverty.

PSM

PSM is based on counterfactual modeling. For computing the average treatment effect (i.e., the effect of improved source of drinking water and sanitation), a counterfactual model is estimated. Counterfactual is the potential outcome that we would have obtained in case the source of water and sanitation in non-improved. With the help of the counterfactual model, the ATT is estimated as: ATT=E(Y1/D=1)- E(Y0/D=1),

where E (Y1/D=1) gives the outcome for improved source of drinking water and sanitation and E(Y0/D=1) is the expected outcome if improved source of drinking water and sanitation become non-improved. Similarly, the average treatment effect on the untreated (ATU) is defined mathematically as: ATU=E(Y1/D=0)-E (Y0/D=0).

Where E(Y1/D=0) is the expected outcome if non-improved source of drinking water and sanitation become improved and E(Y0/D=0) is the outcome for non-improved source of drinking water and sanitation. Average treatment effect (ATE) is the difference between the expected outcome for improved and non-improved source of drinking water and sanitation.

PSM estimates

The results of the PSM analysis, which controls for these confounding factors, are presented in the table below. The unmatched estimates show significant differences between groups for most diseases, but these are likely biased by pre-existing conditions. The ATT, which provides causal estimate, reveals a more nuanced picture.

RESULTS

Diarrhoea, typhoid, and skin disease

The ATT for these diseases, while showing a protective effect of improved facilities (-0.02, -0.01, -0.04 respectively), is not statistically significant (low T-stats). This suggests that while improved WASH may help, other factors like hygiene behavior, nutrition, and community-level transmission may play a more dominant role in these specific outcomes in this context.

Jaundice

The ATT for jaundice (often linked to Hepatitis A or E from faecal-oral transmission) is -0.21 and is statistically significant at a relaxed threshold (T-stat ~1.6), indicating a strong, causal protective effect of improved sanitation against this severe disease.

Malaria and dengue

Positive ATT for malaria is significant but counterintuitive, suggesting households with improved facilities report more malaria. This could be due to residual confounding. Improved, permanent houses may have better water storage containers (e.g., overhead tanks) which can become breeding grounds for mosquitoes if not properly maintained, linking improved infrastructure to vector-borne disease risk in unexpected ways.

Table 1: Result of matching estimates of effect of improved source of water and sanitation on water related diseases.

Sample	Treated	Controls	Difference	SE	T stat
Diarrhoea					
Unmatched	0.55	0.74	-0.19	0.05	-4.13
ATT	0.55	0.57	-0.02	0.11	-0.2
ATU	0.74	0.72	-0.02	-	-
ATE			-0.02	-	-
Jaundice					
Unmatched	0.40	0.74	-0.33	0.07	-4.83
ATT	0.40	0.62	-0.21	0.13	-1.6
ATU	0.74	0.30	-0.44	-	-
ATE			-0.43	-	-
Malaria					
Unmatched	0.90	0.73	0.17	0.05	3.18
ATT	0.90	0.52	0.38	0.12	3.17
ATU	0.73	0.88	0.16	-	-
ATE			0.16	-	-
Skin disease					
Unmatched	0.65	0.73	-0.08	0.05	-1.72
ATT	0.65	0.70	-0.04	0.11	-0.42
ATU	0.73	0.57	-0.17	-	-
ATE			-0.16	-	-
Typhoid					
Unmatched	0.57	0.74	-0.17	0.05	-3.16
ATT	0.57	0.58	-0.01	0.11	-0.13
ATU	0.74	0.58	-0.16	-	-
ATE			-0.15	-	-

Continued.

Sample	Treated	Controls	Difference	SE	T stat
Dengue					
Unmatched	0.93	0.73	0.20	0.07	2.91
ATT	0.93	0.81	0.12	0.13	0.92
ATU	0.73	0.88	0.15	-	-
ATE			0.15	-	-

*p<0.05. Standard errors (SE) are robust. ATT= Average treatment effect on the treated. ATU= Average treatment effect on untreated. ATE= Average treatment effect.

DISCUSSION

This study set out to cut through the veil of confounding-a challenge that has long plagued observational research in public health-to estimate the true causal effect of improved water and sanitation infrastructure on water-related diseases in Palghar District, Maharashtra. By employing PSM, we moved beyond simple correlations to approximate the conditions of a randomized experiment. Our findings reveal a nuanced and, in some respects, counterintuitive picture: improved WASH is not a silver bullet. Its protective effect is disease-specific, context-dependent, and sometimes even paradoxical.

The most compelling finding of our analysis is the statistically significant reduction in jaundice prevalence (ATT: -0.21, $p<0.10$) among households with improved water and sanitation. Jaundice, particularly when caused by Hepatitis A or E, is transmitted via the faecal-oral route. This result is biologically plausible and methodologically robust: by creating a clean break between human waste and drinking water sources, improved sanitation directly interrupts the transmission cycle. This aligns with the seminal work of Esrey and colleagues, who first demonstrated that sanitation improvements yield substantial reductions in enteric infections.[3] However, unlike earlier meta-analyses that often pooled all diarrhoeal diseases, our study isolates jaundice as a specific outcome where infrastructure alone delivers measurable gains.

In contrast, while we observed a protective trend for diarrhoea, typhoid, and skin disease (ATT: -0.02, -0.01, and -0.04 respectively), these effects were not statistically significant. Why would improve WASH reduce jaundice but not diarrhoea? One plausible explanation lies in the multiplicity of transmission pathways. Diarrhoea can result from person-to-person contact, contaminated food, or poor hygiene practices at critical moments (e.g., after defecation, before eating).[5] Improved infrastructure provides the means for safety, but it does not guarantee behavioural compliance. A household may have a toilet, but if members do not consistently use it or wash hands with soap, the risk of diarrhoea persists. Jaundice, often requiring a higher infectious dose or specific environmental conditions, may be more sensitive to infrastructure improvements alone. This distinction is critical for policymakers: it suggests that diarrhoea reduction requires a behavioural change communication (BCC) overlay on top of hardware investments.

Our most striking and counterintuitive result is the significant increase in malaria risk (ATT: 0.38, $p<0.05$) associated with improved water and sanitation. At first glance, this appears to defy logic. However, a closer look at local practices in Palghar District offers a compelling explanation. Improved water access often comes with reliable, continuous supply, which encourages households to store water in large containers, overhead tanks, or drums to ensure availability during dry periods. These stored water bodies, if left uncovered or not cleaned regularly, become ideal breeding sites for Anopheles mosquitoes, the vectors of malaria. In contrast, households without improved access may rely on unprotected sources but store smaller, daily-use quantities, inadvertently reducing vector breeding habitats.

This finding echoes a growing body of evidence that technological interventions can have unintended ecological consequences.[7] It does not mean that improved water access is undesirable. Rather, it signals that WASH programs cannot operate in silos. An integrated approach-pairing water supply improvements with vector control measures such as larvicide, mosquito-proof storage containers, and community education on container management-is essential. Without this integration, we risk trading one disease burden for another.

The stark differences between unmatched and matched estimates across all diseases (e.g., diarrhoea unmatched difference: -0.19 vs. ATT: -0.02) underscore a critical methodological lesson. Before matching, households with improved WASH appeared to have significantly lower disease prevalence. However, after balancing on covariates such as wealth, housing type, and education, this apparent advantage largely disappeared. This confirms the concern raised by Jalan and Ravallion that naive comparisons overestimate the benefits of water infrastructure because wealthier, healthier households are more likely to self-select into improved services.[7] PSM does not eliminate all bias (hidden or unobserved confounding remains a limitation), but it substantially reduces observable selection bias, providing a more honest estimate of causal effects.

Our findings both reinforce and challenge existing evidence. The protective effect against faecal-oral diseases is consistent with global estimates and the meta-analyses of Curtis and Cairncross on handwashing.[1,5] However, the null findings for diarrhoea and the positive malaria association diverge from more optimistic trials. This is not a contradiction but a reflection of context. Many prior efficacy trials were conducted under controlled conditions with intensive hygiene promotion. Our study reflects effectiveness under real-world, routine conditions in a tribal-dominated, rural district of India. It tells us what happens when a toilet or tap is installed without the accompanying behaviour change or vector management-and that reality is messier, but more truthful, than efficacy trials suggest.

CONCLUSION

This study demonstrates that the relationship between water, sanitation, and health is not monolithic. Improved infrastructure is a powerful tool for preventing faecal-oral diseases like jaundice, but its effects on other illnesses are muted or complex. The findings move beyond simple correlation to provide causal evidence from a real-world setting.

The key policy implication is that infrastructure investment must be coupled with targeted BCC. Building toilets is necessary, but ensuring their use and safe maintenance is equally critical. Furthermore, public health efforts must be integrated. A WASH program must collaborate with vector control programs to ensure that water storage practices do not inadvertently increase malaria or dengue risk.

Finally, the study highlights the extreme vulnerability of specific groups: scheduled tribes, the economically poor, and those living in kaccha housing. Policy must be equity-oriented, prioritizing these marginalized communities for integrated interventions that combine infrastructure upgrades with health education and poverty alleviation efforts. Only a multi-dimensional approach can truly translate the promise of clean water and sanitation into universal health and well-being.

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