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ABSTRACT Egypt is approaching universal access to improved water supply, but the variable quality of improved water may have a measureable health impact. We investigated the impact of different measures of improved water access on the prevalence of diarrhoea among children aged under 5 years. Using data from the 2008 Egypt Demographic and Health Survey and propensity score matching techniques we compared children in households with improved water supplies, with/without interruptions to supplies and with/without in-home storage of water. Access to improved water that was not subject to cuts resulted in a significant 2.6 percentage point reduction in the prevalence of diarrhoea (4.7% reduction in rural areas), and access to improved water that was not stored prior to use resulted in a 3.5% reduction. Further research is needed to better understand the nature and causes of piped water interruptions in Egypt, in order to address potential infrastructure challenges that are leading to poorer health outcomes.

Eau améliorée et santé de l’enfant en Égypte : impact de l’interruption de l’approvisionnement en eau et de la conservation de l’eau à usage domestique sur la prévalence de la diarrhée

RÉSUMÉ L'Égypte se rapproche de l'accès universel à l'approvisionnement en eau améliorée, cependant la qualité variable de l'eau améliorée peut avoir un impact sanitaire mesurable. Nous avons examiné l'impact de différentes mesures d'accès à l'eau améliorée sur la prévalence de la diarrhée chez des enfants de moins de cinq ans. A l'aide de données issues de l'Enquête démographie et sanitaire en Égypte de 2008, et de la méthode d'appariement par scores de propension, nous avons comparé des enfants vivant dans des foyers dotés d'un approvisionnement en eau améliorée, avec ou sans interruption d'approvisionnement et avec ou sans stockage de l'eau à domicile. L'accès à une eau améliorée qui n'avait pas fait l'objet de coupures entraînait une réduction importante de 2,6 points de pourcentage de la prévalence de la diarrhée (4,7 % de réduction dans les zones rurales), tandis que l'accès à une eau améliorée qui n'avait pas été stockée avant utilisation correspondait à une réduction de 3,5 points de pourcentage. Davantage de recherches sont nécessaires pour mieux comprendre la nature et les causes des coupures d'eau courante en Égypte, afin de lutter contre les problèmes d'infrastructure potentiels qui entraînent une dégradation des résultats sanitaires.

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Introduction

The Millennium Development Goal (MDG) of reducing by half the world's population that lives without sustainable access to safe drinking water has been met (1). However, as acknowledged by the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation (2), the current definition of improved water and means of measuring access are imperfect proxies for sustainable access, and leave many factors unexplored, such as water quality, continuity of supply and maintenance of facilities (3–5). As more countries, and regions within countries, approach universal access to improved water supply it is therefore increasingly important to re-evaluate what sustainable access to this basic service means. This issue has been part of the impetus for maintaining a dedicated water goal among the post-2015 Sustainable Development Goals (SDGs).

Egypt is one of the middle-income countries that has met the MDG water target, and in which

coverage of an improved water supply according to the current JMP definition is nearly universal, at 99%, with 96% of households having water that is piped onto the premises (1). However, the quality of delivery continues to serve as a barrier to sustainable access at the sub-national level (6,7). This makes Egypt an ideal context in which to examine the effect of access to improved water—using alternative definitions to those of the JMP—on child health.

A major motivation for the provision of improved water supply is the high disease burden associated with the consumption of contaminated water, much of which is attributable to diarrheal disease (8,9). In Egypt, the limited literature on the topic has suggested that contamination of drinking water is a concern due to the poor quality of the pipes that connect households to water treatment facilities (6,7). Leaking pipes allow contaminated groundwater to enter the drinking supply, as evidenced by higher bacterial counts at the point of water usage than at treatment sites (7). This problem may be exacerbated by breaks in water pumping, as more groundwater enters the pipe system when it is not pressurized (5,7). Public officials have also blamed several diarrhoeal outbreaks in recent years on water that was contaminated due to poor pipe quality (10,11). These arguments emphasize the need for a more nuanced examination of the quality of improved services.

A large number of studies have investigated the impact of water supply on child health worldwide. Systematic reviews and meta-analyses (3,12–14), as well as cross-national studies (15), have found that improvements in water quality and increased water supply are effective in reducing morbidity due to diarrhoea. Individual and multi-country studies, however, have highlighted important differences in quality among types of water supply that are classified as improved (4,16). In Egypt, to the best of our knowledge, the limited research on the impact of water supply on child health has found that access to better quality water is associated with reductions in child mortality (17,18). Findings regarding the association with child diarrhoea have been more mixed (19,20). The results are also sensitive to the method of estimation (18,20), suggesting that the statistical approach adopted in the study, as well as the definition used for improved water supply, may affect measures of the impact of improved water supply on child health.

A problem that arises when attempting to quantify the effect of interventions aiming to improve water supply is that if we observe a household with improved drinking water, we will not be able to simultaneously observe the same household without access to improved services. This issue, which can be thought of as a missing data problem, biases the results of simple choice regressions and hazard models, since unobserved characteristics of households may be important determinants both of the household water source and the incidence of childhood diarrhoea (18). Propensity score matching (PSM) methods have been widely used in the impact evaluation literature on access to water supply and sanitation to correct for this self-selection or simultaneity problem (21–24). PSM matches subjects in the intervention (treated) group with

subjects in the control (untreated) group based on the likelihood of being in treatment status as a function of observed characteristics (25,26). Throughout the paper we use the term “treated” to refer to the intervention group with higher-quality water supply, by various definitions, and not treated in the sense of water treatment practices. PSM techniques therefore have the advantage over regression and hazard models of allowing the analyst to isolate a control group that best approximates the characteristics of the intervention group in order to estimate treatment effects, even when using observational data (26,27). Matching techniques, however, do not control for selection based on unobserved characteristics. To reduce the possibility of selection bias when using matching methods, researchers often control for a wide range of locality and household characteristics that might be correlated with

the treatment and the outcome variables (26). Following this literature, we use PSM methods to estimate the impact of improved water service quality on the prevalence of diarrhoea among children aged under 5 years in Egypt.

Methods

Study design and data source

Our analysis used data from the 2008 Egypt Demographic and Health Survey (EDHS), which successfully interviewed 18 968 households containing 10 581 children younger than 5 years old. The outcome of interest was diarrhoea prevalence, as measured by whether a child was reported by the mother to have experienced diarrhoea during the 2-week period preceding the survey. The primary analytical unit for this analysis was the 9992 children for whom data were available on diarrhoea occurrence in the past 2 weeks.

Definitions of improved water

Based on the WHO/UNICEF JMP definition for “improved” water (1), the 2008 EDHS defines improved sources of drinking water as water obtained from a piped source within the dwelling, a public tap, a tubewell, borehole or a protected well or spring (28). This definition will henceforth be referred to as the JMP definition. Access to improved water services according to the JMP definition is nearly universal in Egypt, at 98% of households in 2008. The JMP definition for improved water supply does not account for the quality of service delivery, yet a significant percentage of households in the EDHS experienced problems with service quality. According to the EDHS data, 29% of households with improved water supply experienced a cut in water availability during the 2 weeks prior to the survey, and 17% of households stored their water (authors’ calculations).

We exploited these indicators of service delivery from the EDHS to create 2 alternative indicators for water quality among households that had an improved water supply according to

the JMP definition. A household was defined as having: (1) “improved–uninterrupted” water supply if it had access to an improved source of drinking water with no interruption in water supply in the past 2 weeks, and (2) “improved–unstored” drinking water if it had access to an improved source of drinking water and did not store that water before use. Due to the small number of children living in households with an unimproved water supply according to the JMP definition (Table 1), these children were dropped from the analysis.

The definitions of improved–uninterrupted and improved–unstored water were not mutually exclusive; 55% of children had access to both types of water supply. We therefore also tested the impact of having both improved–uninterrupted and improved–unstored water by comparing children with improved–uninterrupted–unstored water with children in all other households with improved water; and with children in households with improved–interrupted–stored water. Finally, we tested the net effect of having uninterrupted water, controlling for storage practices, by comparing children in households with improved–uninterrupted–unstored water with children with improved–interrupted–unstored water.

Estimation techniques

Our primary estimation technique was one-to-one propensity score matching, in which each treated case was matched to the control case that had the closest propensity score (27). Throughout the paper, we defined treatment status as having access to improved water supply in the household of residence, but we used varying definitions of “improved”, as explained above. For all analyses, we estimated the average treatment effect on the treated, which estimates the effect of the intervention—in our case access to improved water—on treated (intervention) units only (26). Standard errors of the estimates of average treatment effect on the treated were adjusted to account for the fact that the propensity score was estimated using a logistic regression model prior to the match, rather than known a priori (27).

To reduce the possibility of selection bias when using matching methods, we used a range of child, parental and household characteristics that might be correlated with both treatment status and the outcome variable to predict the propensity score (26). The likelihood of children being in treatment status, i.e. to be living in a household with improved water supply, was estimated using a core set of variables that consisted of wealth quintile (ordinal variable), region of residence, mother’s and father’s education in years, mother’s age in years, child’s age in months, dummy variables for dwelling type (apartment, house or other) and whether the household had livestock. These variables were selected based on their theoretical importance in predicting child diarrhoea or their identification in previous studies as risk factors for diarrhoea infection in Egypt (29). Additional covariates were needed to achieve balance in some of the PSM matching analyses. These primarily consisted of dummy variables for different combinations of region and wealth, as urban residence and higher wealth quintile were the variables on which selection into treatment status consistently occurred. All PSM analyses were

run without replacement with a caliper of 0.03 (27) and standard errors were calculated using robust Abadie–Imbens standard errors (30).

To check the robustness of our results, for each analysis we compared the results produced by PSM with those produced by simple logistic regression and coarsened exact matching (CEM). CEM matches each treated case to all of the control cases with the same values on a range of coarsened covariates, approximating exact matching (31). For example, age in years is coarsened into age groups, and CEM then matches onto those groups. Compared with PSM, CEM tends to produce fewer matches but may improve balance (23). For consistency, we used the same set of covariates across all 3 methods—PSM, CEM and logistic regression—for each analysis.

Rural–urban differences

Based on the 2008 EDHS, 51.7% of households, containing 63.4% of the children aged under 5 years, resided in rural areas in Egypt, making this an important subpopulation for child health outcomes. Household-level connections to water systems are difficult to establish and maintain where populations are dispersed, and the rural water infrastructure in particular suffers from maintenance challenges in many low- and middle-income countries (8). In Egypt, many of the community-specific problems with pipe maintenance have been found in rural areas (6,7). We therefore hypothesized that the impact of having improved–uninterrupted water on child diarrhoea would be larger in rural areas, because poorer pipe maintenance in these areas may lead to greater risk of water contamination during breaks in pumping. To test this hypothesis, we conducted a separate analysis for the improved–uninterrupted treatment definition by residence.

Results

Effect of improved–uninterrupted and improved–unstored water access

Table 1 shows that 8.4% of children younger than 5 years of age were reported by their mothers to have experienced diarrhoea during the 2-week period preceding the survey. There was no significant difference in the percentage of children who experienced diarrhoea between those living in households with unimproved and improved water supply according to the JMP definition (P = 0.20).

In contrast, under both the improved–uninterrupted and improved–unstored definitions of water supply, children residing in households with poorer quality water supply (improved-interrupted or improved-stored, respectively) were significantly more likely to have suffered from diarrhoea (P < 0.001). Due to the small number of children living in households with an unimproved water supply according to the JMP definition (Table 1), adequate balance on key covariates could not be achieved and the PSM results were unreliable. We therefore present the multivariate results

for the other definitions only.

PSM matching results for the improved–uninterrupted definition are shown in the first panel of Table 2, comparing children in households with improved water supplies that were uninterrupted (intervention) with those for whom water supplies was interrupted (control). PSM resulted in improved covariate balance across the treatment and control groups on nearly all covariates (Table 3). The results indicate that having access to improved water supplies that were uninterrupted resulted in a 2.6 percentage point decline (95% CI: –0.9% to –4.3%) in the prevalence of diarrhoea in children under 5 years (Table 2), somewhat smaller than the estimate produced by the unmatched logit (the full logit models for all analyses are presented in Appendix 1, which is available in the on line version on the EMHJ website). As expected, CEM resulted in a substantially smaller analytic sample, as there were more unmatched (off common support) cases that were deleted from the sample than with PSM. The CEM analysis produced only a 1.9 percentage point reduction in diarrhoea prevalence (95% CI: –0.7% to –2.9%), but the result was still significant ($P < 0.001$). Access to improved water supplies that were unstored resulted in a 3.5 percentage point reduction (95% CI: –1.2% to –5.9%) in the prevalence of diarrhoea under PSM matching (Table 2; balance statistics in Table 4). The CEM and logit results again showed somewhat smaller percentage point reductions.

Combined effects analysis

Turning to the analyses of the combined effects of these 2 types of higher-quality improved water, the second panel of Table 2 compares children in households with the “best” improved water (i.e. uninterrupted and unstored) against children with all other forms of improved water, as well as against children with the “worst” improved water (i.e. interrupted and stored). For the first analysis, we obtained estimates of similar magnitude as the improved–uninterrupted definition, with a 2.7 percentage point reduction (95% CI: –1.0% to –4.3%) in diarrhoea prevalence under PSM (balance statistics in Table 5). However, in the second analysis, we obtained an estimate of a 5.0 percentage point reduction (95% CI: –2.2% to –7.9%) in diarrhoea prevalence. The CEM and logit estimates were also larger than in the earlier analyses. However, the balance statistics on several covariates was not optimal under this specification, likely due to the relatively small number of children in the control group (Table 6).

To control for potential effects of improper storage practices, we then investigated the net effect of having an uninterrupted water source among households that did not store water (Table 2). Among children with improved–unstored water, the net effect of having an uninterrupted water supply was a 2.8 percentage point reduction (95% CI: –1.0% to –4.6%) in diarrhoea prevalence compared with those with interrupted supplies (balance statistics in Table 9).

Discussion

The results of this study support the growing body of evidence that there is a high degree of variability in the quality of improved water, including piped water, in low- and middle-income countries (4,16), and that these variations have measurable health impacts (5,16). We found that having access to an improved water supply that was not subject to cut-offs reduced the prevalence of diarrhoea in children under age 5 years in Egypt, as did access to improved water that was not stored prior to use. These results were robust both to the matching method used, and to different forms of overlap between improved–uninterrupted and improved–unstored water. These overall results were driven by treatment effects in rural areas, where access to an improved water supply that was uninterrupted led to substantial reductions in the prevalence of diarrhoea in under-5s. In contrast, no treatment effects were found in urban areas. This confirms our hypothesis that the effects of an improved–uninterrupted water supply would be greater in rural areas, where access to this type of water is also less common. Although we are not able to assess the quality of water at the source, these findings are consistent with arguments that the poor quality of pipes, potentially in combination with pauses in water pumping, is leading to water contamination.

We also found that treatment effects for children with the highest quality water as compared to those with the lowest quality were particularly large, suggesting that there is a compounding effect between poor quality water delivery and improper water storage practices. This agrees with previous studies that have found that improper water storage practices are a source of contamination even for water that may be clean at the source, and can lead to negative health impacts (32,33). However, given that a substantial percentage of households in Egypt do experience water cuts with some regularity, and there is an association between cuts and water storage, it is unrealistic to propose that in-home water storage be abandoned. Thus, in the absence of more continuous water supplies, interventions to promote proper water storage and water treatment practices would be expected to have a positive impact on child health (5). Water purification at home is currently very uncommon in Egypt, making this an area with substantial potential for impact while longer-term investments in the continuity of water delivery are undertaken.

On the other hand, our findings suggest that supply interruptions are driving the health impacts seen from the variations in water quality in this study. In other words, the direct health benefits of a continuous water supply may be greater than the benefits achieved by reducing the

likelihood that households will store their water. On a broader level, these findings also point to the importance of considering multiple dimensions of water quality in definitions of safe and sustainable water access. Although universal access to safe drinking water has been proposed as one of the SDG goals, the indicators to measure progress against this goal are still under discussion. Proposals include indicators for “safely managed” water, mentioning factors such as sufficient water supply and specific forms of contamination. The results of this study argue for including and ensuring the means to adequately measure a target indicator that captures sufficiency and consistency of water supply in particular.

A main limitation of this study was the lack of more detailed measures of the quality of water service delivery in the EDHS. Unfortunately, an analysis of the frequency, duration and causes of piped water interruptions in Egypt was not possible using the EDHS data, nor, to our knowledge, are such indicators available in alternative data sources. We were also unable to compare water quality at the source with water quality at point-of-use among households with piped water, which is needed in order to develop recommendations for investments in the water delivery system in Egypt. Although hygiene practices and access to sanitation facilities may also affect diarrhoea prevalence among children, we were not able to address these factors in this analysis. Access to improved sanitation according to the JMP definition is also near universal in Egypt, and we were unable to identify a robust alternative definition of sanitation access using the measures available in the EDHS. The EDHS also does not contain measures for hygiene practices such as hand-washing.

Another limitation of this study is that it was based on observational data; there may therefore be unobserved factors related to both water supply and child diarrhoea for which matching methods do not control. However, the fact that robustness checks using CEM showed highly consistent results with PSM suggests that, within the limitations of matching methods generally, our results are robust to the matching specification used.

Our findings therefore call for further investigation of the dimensions of improved water quality in rural and urban areas. Such studies are needed in order to better understand what investments in the water delivery infrastructure, and what changes in water handling practices, have the potential to reduce the negative health impacts of poorer quality piped water.

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