Improved water and child health in Egypt: impact of interrupted water supply and storage of household water on the prevalence of diarrhoea

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المياه المحسَّنة وصحة الأطفال في مصر: تأثير انقطاع إمدادات المياه وتخزين المياه في المنازل على انتشار الإسهال

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الخلاصة: تقترب مصر من إتاحة الحصول على إمدادات مياه محسَّنة للجميع، ولكن التفاوت في جودة المياه المحسَّنة قد يكون له أثر صحي ملموس. ولقد استقصينا أثر مختلف تدابير الحصول على مياه محسَّنة على انتشار الإسهال بين الأطفال الذين تقل أعمارهم عن 5 سنوات. وباستخدام بيانات من المسح السكاني والصحي لمصر لعام 2008 وتقنيات المطابقة بين درجات الميل المحرزة، قارنّا بين أطفال في أسر لديها إمدادات مياه محسنة بحسب احتمالية انقطاعات في الإمدادات، وتخزين المياه في المنزل. فوجدنا أن الحصول على مياه محسنة لا تتعرض إلى انقطاعات قد أسفر عن انخفاض ملحوظ في انتشار الإسهال قدره 2.6 (نسبة الانخفاض في المناطق الريفية 4.7)، وأن الحصول على مياه محسنة لا تخزَّن قبل الاستخدام أدى إلى انخفاض بنسبة 3.5٪. هناك حاجة إلى إجراء مزيد من البحوث للوصول إلى فهم أفضل لطبيعة وأسباب انقطاع مياه المنازل في مصر، بغية التصدي لتحديات البنية التحتية المحتملة التي تؤدي إلى نتائج صحية أسوأ.

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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Received: 24/05/15; accepted: 18/10/15

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.

Table 1 Prevalence of diarrhoea in the 2 weeks prior to the survey, by different definitions of improved water supply

Definition	No. of children	Prevalence of diarrhoea (%)[d]	*P*-value
JMP definition[a]			
Improved	9731	8.4	NS
Unimproved	261	6.9	
Total	9992	8.4	
Improved–uninterrupted definition[b]			
Improved–uninterrupted	5738	7.0	< 0.001
Improved-interrupted	3993	10.6	
Improved–unstored definition[c]			
Improved–unstored	7909	7.8	< 0.001[e]
Uninterrupted	5395	7.5	
Interrupted	2514	10.8	
Improved–stored	1822	11.2	
Uninterrupted	343	10.8	
Interrupted	1479	12.4	

[a]Water obtained from a piped source within the dwelling, a public tap, a tubewell, borehole or a protected well or spring; [b]Improved water supply with no interruption in water supply in the past 2 weeks; [c]Improved water supply and household does not store water before use.
[d]Calculations use Egypt Demographic and Health Survey sample weights.
[e]P-value for improved–unstored versus improved–stored.
JMP = WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation; NS = not significant.

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

Table 2 Estimates of the impact of different definitions of improved water supply on the prevalence of diarrhoea in children under 5 years old: comparison of propensity score matching (PSM), coarsened exact matching (CEM) and logistic regression analysis

Definition/analysis method	No. of treated	No. of controls	Estimate (% point change)[a]	SE of % point change	95% CI of % point change	*P*-value
Main definitions						
Improved–uninterrupted definition: Improved–uninterrupted vs improved–interrupted						
PSM	5634	3877	−0.026	0.009	−0.043 to −0.009	< 0.01
CEM	3356	2501	−0.019	0.006	−0.029 to −0.007	< 0.001
Logistic regression	5738	3993	−0.031	0.005	−0.042 to−0.021	< 0.001
Improved–unstored definition: Improved–unstored vs improved–stored						
PSM	7764	1779	−0.035	0.012	−0.059 to−0.012	< 0.01
CEM	3289	1259	−0.027	0.007	−0.040 to−0.013	< 0.001
Logistic regression	7909	1822	−0.030	0.006	−0.044 to−0.016	< 0.001
Combined effects analysis						
Combined effects analysis 1: Improved–uninterrupted–unstored vs all other improved						
PSM	5302	4195	−0.027	0.009	−0.043 to−0.010	< 0.01
CEM	3232	2654	−0.020	0.006	−0.030 to−0.008	< 0.001
Logistic regression	5395	4336	−0.032	0.005	−0.042 to−0.022	< 0.001
Combined effects analysis 2: Improved–uninterrupted–unstored vs improved–interrupted–stored						
PSM	5302	1409	−0.050	0.015	−0.079 to−0.022	< 0.001
CEM	1996	868	−0.030	0.008	−0.045 to−0.015	< 0.001
Logistic regression	5395	1479	−0.047	0.006	−0.064 to−0.029	< 0.001
Combined effects analysis 3: Improved–uninterrupted–unstored vs improved–interrupted–unstored						
PSM	5302	2443	−0.028	0.009	−0.046 to−0.010	< 0.01
CEM	2721	1574	−0.013	0.006	−0.025 to−0.001	< 0.05
Logistic regression	5395	2514	−0.028	0.005	−0.040 to−0.015	< 0.001
Rural-urban analysis						
Improved–uninterrupted vs improved–interrupted: children residing in rural households only						
PSM	3372	2684	−0.047	0.010	−0.068 to−0.027	< 0.001
CEM	2130	1818	−0.025	0.009	−0.043 to−0.007	< 0.01
Logistic regression	3442	2748	−0.036	0.006	−0.049 to−0.023	< 0.001
Improved–uninterrupted vs improved–interrupted: children residing in urban households only						
PSM	2260	1186	−0.017	0.014	−0.045 to 0.011	
CEM	1286	730	−0.008	0.011	−0.030 to 0.013	
Logistic regression	2296	1245	−0.022	0.009	−0.041 to−0.004	< 0.05

[a]Estimates for the CEM and logit models are marginal effects
SE = standard error; CI = confidence interval.

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 7). The estimate under CEM, however, was smaller, indicating a 1.3 percentage point reduction (95% CI: –0.1% to –2.5%) ($P < 0.05$).

Rural–urban differences

Having an interrupted water supply was more common in rural areas than in urban ones; 46% of rural children compared with 32% of urban children lived in a household where the water had been cut off at least once in the past 2 weeks. The third panel of Table 2 shows that, as expected, rural areas accounted for a greater part of the effect seen with the improved–uninterrupted definition. Access to this type of water resulted in a 4.7 percentage point reduction (95% CI: –2.7% to –6.8%) in diarrhoea prevalence among children in rural areas under the PSM specification (balance statistics in Table 8) compared with only a 1.7 percentage point reduction for those in urban areas. This result was again robust to CEM, although with a smaller estimated reduction of 2.5 percentage points (95% CI: –0.7% to –4.3%). The estimate under the logistic regression model showed a 3.6 percentage point reduction. Among children in urban areas, the estimates for the impact of improved–uninterrupted water, while negative, were not significant under either PSM or CEM (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

Table 3 **Balance statistics for the effect of the improved–uninterrupted definition of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis**

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*–value	Mean treated	Mean control	% bias	*t*-value	*P*–value
Region										
Urban Lower Egypt	0.091	0.076	5.4	2.62	0.009	0.092	0.092	0.2	0.1	0.922
Rural Lower Egypt	0.291	0.259	7.3	3.55	< 0.001	0.291	0.297	–1.3	–0.68	0.495
Urban Upper Egypt	0.133	0.105	8.6	4.14	< 0.001	0.133	0.138	–1.5	–0.77	0.441
Rural Upper Egypt	0.303	0.400	–20.4	–9.96	< 0.001	0.302	0.299	0.5	0.27	0.789
Frontier governorates	0.022	0.089	–29.7	–15.26	< 0.001	0.021	0.021	0.1	0.07	0.947
Wealth quintile										
Wealth quintile 2	0.191	0.209	–4.7	–2.27	0.023	0.191	0.190	0.2	0.12	0.905
Wealth quintile 3	0.198	0.196	0.5	0.24	0.808	0.199	0.199	–0.1	–0.05	0.962
Wealth quintile 4	0.227	0.162	16.3	7.76	< 0.001	0.226	0.246	–4.9	–2.4	0.017
Wealth quintile 5	0.235	0.160	18.8	8.93	< 0.001	0.235	0.227	1.9	0.96	0.336
Dwelling type										
House	0.415	0.524	–22.0	–10.70	< 0.001	0.412	0.395	3.4	1.84	0.065
Apartment	0.566	0.458	21.7	10.55	< 0.001	0.569	0.585	–3.1	–1.66	0.097
Parents' education										
Father's education	9.295	8.201	20.4	9.93	< 0.001	9.307	9.372	–1.2	–0.66	0.510
Mother's education	8.182	6.507	30.0	14.62	< 0.001	8.199	8.272	–1.3	–0.71	0.478
Age										
Mother's age (years)	28.491	28.472	0.3	0.16	0.872	28.494	28.372	2.1	1.12	0.261
Child's age (months)	28.212	28.116	0.6	0.27	0.788	28.205	27.729	2.7	1.48	0.140
Livestock										
Yes	0.242	0.395	–33.4	–16.43	< 0.001	0.241	0.244	–0.6	–0.33	0.742
Combined categories										
Upper Egypt rural poor	0.198	0.280	–19.2	–9.42	< 0.001	0.202	0.187	3.6	2.02	0.043

Table 4 **Balance statistics for the effect of the improved–unstored definition of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis**

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Urban Lower Egypt	0.095	0.042	21.2	7.38	< 0.001	0.094	0.105	1.3	–2.31	0.021
Rural Lower Egypt	0.288	0.235	12.0	4.54	< 0.001	0.287	0.283	1.0	0.62	0.533
Urban Upper Egypt	0.128	0.091	12.0	4.43	< 0.001	0.128	0.124	1.4	0.85	0.397
Rural Upper Egypt	0.325	0.417	–19.0	–7.45	< 0.001	0.326	0.322	0.8	0.48	0.631
Frontier governorates	0.030	0.132	–38.0	–18.48	< 0.001	0.030	0.030	0.0	0.00	1.000
Wealth quintile										
Wealth quintile 2	0.194	0.218	–6.0	–2.30	0.021	0.195	0.189	1.3	0.86	0.392
Wealth quintile 3	0.201	0.182	5.0	1.89	0.058	0.202	0.203	–0.4	–0.24	0.810
Wealth quintile 4	0.209	0.160	12.7	4.69	< 0.001	0.209	0.200	2.3	1.35	0.176
Wealth quintile 5	0.217	0.148	18.0	6.56	< 0.001	0.216	0.223	–1.8	–1.03	0.304
Dwelling type										
House	0.439	0.552	–22.8	–8.79	< 0.001	0.438	0.440	–0.5	–0.29	0.771
Apartment	0.542	0.433	21.9	8.43	< 0.001	0.544	0.539	1.0	0.60	0.551
Education										
Father's education	9.034	8.035	18.5	7.18	< 0.001	9.022	8.977	0.8	0.53	0.598
Mother's education	7.772	6.289	26.6	10.21	< 0.001	7.761	7.844	–1.5	–0.93	0.355
Age										
Mother's age (years)	28.509	28.371	2.3	0.90	0.369	28.499	28.591	–1.5	–0.96	0.336
Child's age (months)	28.152	28.262	–0.6	–0.24	0.807	28.157	27.656	2.9	1.79	0.074
Livestock										
Yes	0.278	0.421	–30.4	–12.09	< 0.001	0.278	0.279	–0.3	–0.20	0.844
Combined categories										
Upper Egypt rural poor	0.216	0.300	–19.3	–7.71	< 0.001	0.220	0.219	0.4	0.23	0.816
Lower Egypt rural poor	0.088	0.112	–7.8	–3.12	0.002	0.090	0.099	–3.1	–1.98	0.048

Table 5 Balance statistics for the effect of the improved–uninterrupted–unstored versus all other definitions of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Urban Lower Egypt	0.094	0.073	7.4	3.63	< 0.001	0.095	0.095	0.1	0.03	0.974
Rural Lower Egypt	0.293	0.259	7.8	3.80	< 0.001	0.293	0.289	0.7	0.36	0.716
Urban Upper Egypt	0.133	0.108	7.7	3.76	< 0.001	0.133	0.139	–1.8	–0.88	0.380
Rural Upper Egypt	0.293	0.404	–23.4	–11.53	< 0.001	0.293	0.291	0.3	0.15	0.881
Frontier governorates	0.021	0.085	–28.9	–14.63	< 0.001	0.020	0.021	–0.3	–0.21	0.836
Wealth quintile										
Wealth quintile 2	0.190	0.208	–4.5	–2.20	0.028	0.191	0.183	2.0	1.07	0.284
Wealth quintile 3	0.197	0.198	–0.3	–0.14	0.888	0.197	0.197	0.1	0.07	0.942
Wealth quintile 4	0.228	0.166	15.6	7.54	< 0.001	0.228	0.246	–4.6	–2.19	0.028
Wealth quintile 5	0.241	0.158	20.9	10.07	< 0.001	0.241	0.236	1.3	0.62	0.538
Dwelling type										
House	0.407	0.525	–23.7	–11.64	< 0.001	0.405	0.405	0.1	0.04	0.968
Apartment	0.574	0.458	23.3	11.44	< 0.001	0.576	0.577	–0.3	–0.16	0.875
Parents' education										
Father's education	9.347	8.224	21.0	10.30	< 0.001	9.353	9.272	1.5	0.79	0.431
Mother's education	8.254	6.550	30.6	15.04	< 0.001	8.272	8.255	0.3	0.16	0.876
Age										
Mother's age (years)	28.494	28.470	0.4	0.20	0.838	28.500	28.594	–1.6	–0.82	0.413
Child's age (months)	28.202	28.137	0.4	0.18	0.854	28.198	27.975	1.3	0.67	0.506
Livestock										
Yes	0.228	0.401	–38.0	–18.79	< 0.001	0.228	0.230	–0.6	–0.32	0.746

Table 6 **Balance statistics for the effect of the improved–uninterrupted–unstored versus improved–interrupted–stored definitions of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis**

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Urban Lower Egypt	0.094	0.041	21.2	6.57	< 0.001	0.092	0.083	3.6	1.62	0.105
Rural Lower Egypt	0.293	0.229	14.6	4.87	< 0.001	0.290	0.282	1.8	0.91	0.364
Urban Upper Egypt	0.133	0.080	17.0	5.47	< 0.001	0.135	0.148	–4.4	–1.99	0.047
Rural Upper Egypt	0.293	0.408	–24.3	–8.47	< 0.001	0.296	0.300	–0.9	–0.49	0.623
Frontier governorates	0.021	0.155	–48.7	–21.73	< 0.001	0.020	0.020	0.0	0.00	1.000
Wealth quintile										
Wealth quintile 2	0.190	0.223	–8.1	–2.77	0.006	0.193	0.176	4.1	2.19	0.029
Wealth quintile 3	0.197	0.173	6.3	2.09	0.037	0.199	0.204	–1.4	–0.71	0.480
Wealth quintile 4	0.228	0.149	20.1	6.51	< 0.001	0.221	0.254	–8.7	–4.06	< 0.001
Wealth quintile 5	0.241	0.151	22.7	7.32	< 0.001	0.243	0.215	7.1	3.44	0.001
Dwelling type										
House	0.407	0.556	–30.1	–10.29	< 0.001	0.405	0.398	1.4	0.74	0.461
Apartment	0.574	0.429	29.2	9.95	< 0.001	0.577	0.586	–1.7	–0.89	0.373
Parents' education										
Father's education	9.347	7.929	26.2	9.07	< 0.001	9.294	9.332	–0.7	–0.37	0.709
Mother's education	8.254	6.114	38.8	13.27	< 0.001	8.206	8.162	0.8	0.41	0.681
Age										
Mother's age (years)	28.494	28.354	2.4	0.82	0.414	28.461	28.390	1.2	0.62	0.536
Child's age (months)	28.202	28.235	–0.2	–0.07	0.947	28.179	27.847	1.9	0.98	0.325
Livestock										
Yes	0.228	0.412	–40.2	–14.39	< 0.001	0.230	0.224	1.3	0.75	0.456
Combined categories										
Lower Egypt rural poor	0.082	0.117	–11.6	–4.15	< 0.001	0.084	0.083	0.4	0.25	0.805
Rural poor	0.275	0.453	–37.6	–13.25	< 0.001	0.283	0.273	2.1	1.11	0.266

Table 7 Balance statistics for the effect of improved–uninterrupted–unstored versus improved–interrupted–unstored definitions of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Urban Lower Egypt	0.094	0.097	–0.8	–0.35	0.725	0.095	0.088	2.4	1.28	0.201
Rural Lower Egypt	0.293	0.276	3.9	1.61	0.108	0.293	0.304	–2.4	–1.23	0.218
Urban Upper Egypt	0.133	0.120	3.9	1.61	0.108	0.133	0.140	–1.9	–0.93	0.351
Rural Upper Egypt	0.293	0.395	–21.5	–9.02	< 0.001	0.293	0.290	0.6	0.34	0.732
Frontier governorates	0.021	0.050	–15.9	–7.14	< 0.001	0.020	0.017	1.6	1.15	0.249
Wealth quintile										
Wealth quintile 2	0.190	0.201	–2.8	–1.16	0.248	0.191	0.203	–2.9	–1.51	0.130
Wealth quintile 3	0.197	0.210	–3.3	–1.36	0.175	0.197	0.201	–1.0	–0.51	0.610
Wealth quintile 4	0.228	0.170	14.5	5.85	< 0.001	0.228	0.228	–0.2	–0.12	0.908
Wealth quintile 5	0.241	0.165	18.9	7.57	< 0.001	0.241	0.231	2.6	1.26	0.208
Dwelling type										
House	0.407	0.505	–19.8	–8.21	< 0.001	0.405	0.407	–0.3	–0.16	0.874
Apartment	0.574	0.476	19.7	8.18	< 0.001	0.576	0.577	–0.3	–0.16	0.875
Parents' education										
Father's education	9.347	8.362	18.4	7.68	< 0.001	9.353	9.312	0.8	0.40	0.689
Mother's education	8.254	6.739	27.1	11.30	< 0.001	8.272	8.303	–0.6	–0.29	0.770
Age										
Mother's age (years)	28.494	28.541	–0.8	–0.33	0.742	28.500	28.466	0.6	0.29	0.769
Child's age (months)	28.202	28.046	0.9	0.37	0.710	28.198	27.989	1.2	0.62	0.533
Livestock										
Yes	0.228	0.386	–34.8	–14.84	< 0.001	0.228	0.237	–2.1	–1.15	0.250

Table 8 Balance statistics for the effect of the improved–uninterrupted definition of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis: children in rural households only

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Rural Lower Egypt	0.486	0.376	22.3	8.71	< 0.001	0.485	0.489	−0.8	−0.32	0.751
Rural Upper Egypt	0.505	0.581	−15.3	−5.99	< 0.001	0.506	0.502	0.8	0.32	0.751
Frontier governorates	0.010	0.043	−21.1	−8.56	< 0.001	0.010	0.010	0.0	0.00	1.000
Wealth quintile										
Wealth quintile 2	0.258	0.253	1.2	0.48	0.631	0.260	0.260	−0.1	−0.03	0.978
Wealth quintile 3	0.228	0.215	3.2	1.22	0.222	0.228	0.197	7.4	3.07	0.002
Wealth quintile 4	0.196	0.126	19.3	7.39	< 0.001	0.194	0.212	−4.9	−1.82	0.069
Wealth quintile 5	0.096	0.057	14.9	5.70	< 0.001	0.097	0.101	−1.8	−0.65	0.514
Dwelling type										
House	0.580	0.644	−13.2	−5.15	< 0.001	0.576	0.563	2.5	1.01	0.313
Apartment	0.400	0.335	13.6	5.29	< 0.001	0.405	0.418	−2.8	−1.14	0.254
Parents' education										
Father's education	8.456	7.417	19.4	7.60	< 0.001	8.465	8.443	0.4	0.16	0.869
Mother's education	6.974	5.336	30.2	11.81	< 0.001	6.967	6.908	1.1	0.44	0.660
Age										
Mother's age (years)	27.892	28.197	−5.1	−2.00	0.046	27.877	27.831	0.8	0.32	0.749
Child's age (months)	28.275	28.583	−1.8	−0.70	0.486	28.243	27.754	2.8	1.15	0.250
Livestock										
Yes	0.363	0.519	−31.9	−12.49	< 0.001	0.363	0.359	0.8	0.33	0.741
Combined categories										
Lower Egypt rural poor	0.138	0.156	−5.2	−2.03	0.042	0.140	0.149	−2.5	−1.04	0.299

Table 9 **Balance statistics for the effect of the improved-uninterrupted definition of improved water supplies on the prevalence of diarrhoea in children, using propensity score matching (PSM) analysis: children in urban households only**

Variable	Unmatched sample					PSM matched sample				
	Mean treated	Mean control	% bias	*t*-value	*P*-value	Mean treated	Mean control	% bias	*t*-value	*P*-value
Region										
Urban governorates	0.401	0.230	37.3	10.37	< 0.001	0.400	0.372	6.1	1.93	0.054
Urban Lower Egypt	0.228	0.244	-3.8	-1.08	0.279	0.230	0.239	-2.1	-0.70	0.483
Urban Upper Egypt	0.332	0.337	-1.0	-0.28	0.780	0.332	0.351	-4.0	-1.35	0.178
Wealth quintile										
Wealth quintile 2	0.090	0.113	-7.7	-2.20	0.028	0.090	0.085	1.9	0.68	0.494
Wealth quintile 3	0.155	0.156	-0.4	-0.11	0.916	0.155	0.165	-2.8	-0.93	0.351
Wealth quintile 4	0.272	0.243	6.5	1.83	0.067	0.271	0.279	-1.8	-0.60	0.549
Wealth quintile 5	0.441	0.389	10.5	2.94	0.003	0.440	0.432	1.6	0.54	0.589
Dwelling type										
House	0.168	0.259	-22.5	-6.56	< 0.001	0.167	0.164	0.8	0.28	0.779
Apartment	0.815	0.731	20.3	5.88	< 0.001	0.817	0.814	0.6	0.23	0.818
Parents' education										
Father's education	10.553	9.928	12.3	3.52	< 0.001	10.538	10.365	3.4	1.17	0.242
Mother's education	9.998	9.087	17.5	5.01	< 0.001	10.004	10.050	-0.9	-0.31	0.755
Age										
Mother's age (years)	29.391	29.078	5.4	1.54	0.123	29.392	29.342	0.9	0.29	0.770
Child's age (months)	28.118	27.086	6.0	1.70	0.088	28.116	28.114	0.0	0.00	0.997

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.

Acknowledgements

We would like to thank Ali Rashed and Colette Salemi for research assistance.

Funding: This study was funded by a grant from the International Initiative for Impact Evaluation (3ie).

Competing interests: None declared.

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