Impact of drinking water salinity on children's education: Empirical evidence from coastal Bangladesh

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Impact of drinking water salinity on children's education: Empirical evidence from coastal Bangladesh

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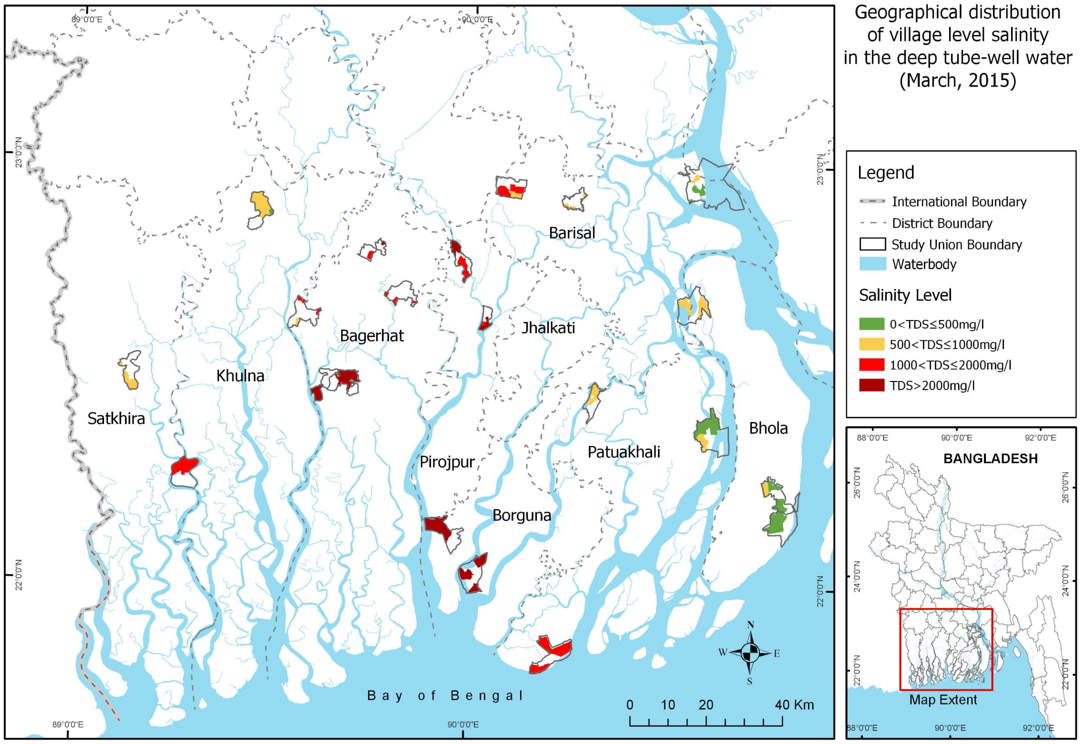
Highlights

- At least a third of southwestern coastal residents of Bangladesh are exposed to low to moderate drinking water salinity.
- Seasonal variation in deep groundwater salinity is very low to nonexistent.
- Exposure to drinking water salinity decreases 7−12 year old children's grade advancement likelihood by 6.7 percentage points.
- No significant effect of drinking water salinity on grade advancement of 13−18 age group is identified.
- No significant gender difference of the adverse effect of salinity on grade advancement is observed.

Graphical Abstract



Abstract

This study examines the impact of drinking water salinity on children's education using a unique and rich dataset collected from eight southwest coastal districts of Bangladesh. Salinity concentration in drinking water is measured at the household level using water samples from households' primary source of drinking water during the summer, wet and dry season of 20014−15. A third of the *deep* tube-well water samples was found to be slightly ($1{,}000 < TDS < 2{,}000$ mg/l) to moderately ($TDS \geq 2{,}000$ mg/l) saline. Linking the child-level data on educational outcome to water salinity (i.e. TDS level), the study reveals a statistically significant negative effect of excessive salinity on grade advancement for 7−12 year old children. More specifically, exposure to excessive drinking water salinity ($TDS > 1{,}000$ mg/l) decreases the grade advancement likelihood of 7−12 year old children by 6.7 percentage points. The results remain robust to alternative model and econometric specifications. The adverse effect of salinity on grade advancement does not vary significantly across the gender of the child while poverty, as expected, exacerbates the effect. Impaired cognitive development due to early childhood exposure appears to be the most plausible channel through which the negative effects of excessive sodium consumption permeate to young children' educational deficit. Additionally, poor health of the adults and elevated medical expenditure play a small yet significant mediating role.

Key words: Deep tube-well, education, grade advancement, drinking water salinity, coastal Bangladesh

1. Introduction

Groundwater salinity poses serious threats to water security in many parts of the world (MacDonald et al., 2016; WWAP, 2015). The threat is particularly pronounced for countries where water resource is already strained due to population pressure, climate change, agricultural extraction and industrial and environmental pollution (Russo & Lall, 2017). Bangladesh is one such country where the water security of its 100 million rural population has come under repeated threats due to multiple environmental and human-induced shocks. Deep groundwater is the most valuable water resource and is a source of arsenic-safe drinking water for nearly 90% of coastal population of Bangladesh (Abedin & Shaw, 2018). Salinity contamination in deep groundwater aquifer (>150 mbgl[1]) is identified as a serious problem in the coastal zone of Bangladesh by recent hydrochemical research (Rahman et al., 2011; Sakamoto, 2017; Zahid et al., 2018; Lapworth et al., 2018). *Deep* tube-well technology was widely promoted by the government and international agencies in early 2000s as a safe alternative of *shallow* tube-well since the discovery of dangerous level of arsenic (As) in shallow aquifer in late 1990s (World Bank, 2007). The *deep* tube-well technology was rapidly adopted as it was the easiest, cheapest and most acceptable form of arsenic-mitigation option available in the coastal region. As of 2015, 75% of the southwest coastal population rely on *deep* tube-well to fulfil their drinking water need (Adams et al., 2016).

Saline water contains high concentrations of dissolved salts—sodium chloride (NaCl). Although sodium is necessary for human health, excessive consumption of sodium has negative health effects (Farquhar et al., 2015). While the adverse health effects of high salt consumption on adults, children and pregnant women are well-documented (Khan et al., 2014; Nahian et al., 2018), little is known about the impacts of salinity on human capital formation. There are several direct and indirect pathways through which children may be adversely affected by

[1] Meters below ground level.

elevated salinity level in drinking water. The direct pathways are the negative health effects experienced due to excessive salinity exposure (Eide & Showalter, 2011). The health effects may occur due to contemporaneous as well as *in utero* and early childhood exposure. The contemporaneous exposure to saline water may increase the risk of hypertension (He et al., 2008), respiratory syndromes (Corbo et al., 2008), kidney stone disease (Yamakawa et al., 1992) and reduced bone mass (Matkovic et al., 1995). *In utero* and early childhood exposure cause long-term health consequences by impairing intrauterine growth, increasing the risk of pre-term birth and restricting infants' neuro-metabolism (Khan et al., 2014; Stocher et al., 2018). The indirect pathways are the spillover effects of the poor health of adults which is likely to strain household budget by rising medical expenditure (Das et al., 2019). Parents' ill health may reduce time spent on childcare and diminish parents' capacity to supervise children's learning at home.

This study presents the results of a natural experiment that examines the impacts of drinking water salinity on children's education drawing on a rich and unique dataset from eight southwest and southcentral coastal districts of Bangladesh (Adams et al., 2016). Exploiting the random variation in the spatial distribution of salinity concentration in deep aquifer (Ayers et al., 2016; Naus et al., 2019), the study aims to establish a causal relationship between salinity and educational outcome by comparing the grade advancement status of the enrolled children. This study offers three contributions to the literature. First, it presents the first empirical evidence of the nexus between salinity and children's educational outcome. Second, this is the first study that uses a household level measure of drinking water salinity and accounts for its seasonal variation. Third, the study explores two indirect pathways through which salinity exposure translates into decelerated progress in school. They are, adult household members' health and households' healthcare expenditure. This is an important contribution to the literature because only a handful of previous studies provide evidence of causal pathways.

2. Literature Review

The significance of safe water for human capital formation is underscored by many empirical studies. There is widespread evidence in the literature to show that water pollution has detrimental effect on children's cognitive ability and performance at school. Bouchard et al. (2011) use a cross-sectional study in southern Quebec (Canada) and find that manganese exposure in drinking water impairs 6–13 year old children's IQ. Using a sample of 6–10 year old school children in Mexico, Rocha-Amador et al. (2007) show that the children who are exposed to either fluoride or As experience an increased risk of reduced IQ. Asadullah and Chaudhury (2011) use a sample of nationally representative secondary school children from rural Bangladesh to test the impact of As exposure on mathematics test scores. They observe a statistically significant negative correlation between mathematics test scores and As-contaminated tube-wells at home.

Another strand of the literature documents evidence of positive link between access to clean and safe water and human capital formation. Zhang and Xu (2016) present evidence of the long-run effects of exposure to treated water on the educational benefit to rural youth (i.e. 18−25 year old individuals) in China. They find that early life exposure to a major water treatment program in rural China has increased educational attainment of youth by 1.1 years. Ortiz-Correa et al. (2016) find that access to water and sanitation increases around 0.8 school years or 160 school days for children aged 6–18. Chen et al. (2017) find that one additional year of exposure to tap water in early life increases cognitive test score at ages 10−15 by 0.132 standard deviations.

Most of these studies cited above do not provide evidence of transmission path. The human capital benefits (or costs) are largely understood to have been accrued from the underlying health benefits (or costs) enjoyed (or suffered) by the affected population. Chen et al. (2017)

show that the improved cognitive ability gain of access to tap water in China may have been derived from mothers' time saving on water collection which is spent on childcare or may have enhanced mothers' wellbeing. Asadullah and Chaudhury (2011) hypothesize that exposure to As may hamper learning at school through social channels. Children with visible signs of arsenicosis (i.e. skin lesions caused by long-term exposure to As) may be ostracized at school which may lead to demoralization, discontent and eventually underperformance.

3. Study Context

Bangladesh is a low income country with low overall quality of human capital. The World Economic Forum's (WEF) Human Capital Report 2017 ranks Bangladesh 111 among 130 countries of the world (World Economic Forum, 2017). Improving its human capital through investment in quality education is a top priority for the Government of Bangladesh. The context of the study is the southwestern coastal region of Bangladesh. This region is home to around 14 million people which accounts for about ten per cent of the country's total population (Szabo et al., 2018). The study region comprises of eight out of the nineteen coastal districts of Bangladesh. The average poverty rate in the study districts is 39% which is higher than the national average poverty rate (31.5%) (World Bank, 2016). The study districts are highly vulnerable to rapid onset of natural disasters like cyclones, storm surges and river flooding. Several major cyclones in the past fifteen years have inflicted significant damage to the school infrastructure, deteriorated basic school amenities and increased the dropout rate (Mallick et al., 2011).

In the recent decade, Bangladesh has made considerable progress in education in terms of primary and secondary school enrolment rates. The gross (net) enrolment rate in primary school increased from 107.7% (94.8%) in 2010 to 114.23% (97.85%) in 2018 (BANBEIS, 2018). Although the enrolment rate for secondary school is less impressive, the progress made over the last nine years is admirable. The gross (net) enrolment rate in secondary school has increased from 50.03% (46.17%) in 2010 to 61.23% (53.10%) in 2018 (BANBEIS, 2018). Dropout rate is considerably higher in the secondary school (37.62%) compared to the primary school (18.60%) (BANBEIS, 2018). The dropout rate is driven by a multitude of factors such as higher cost of education, high opportunity cost of education for boys (i.e. wage income opportunities), high propensity of child marriage for girls, and so on (Sabates et al., 2013). Additionally, failure to advance grade is an important reason for dropout (BBS and ILO, 2015). Grade repetition rate in primary school is highest in Grade I (6.7%) and lowest in Grade V (2.3%), and on average, 5.4% for all grades (BANBEIS, 2018). Girls are less likely to repeat grades compared to boys in all grades (BANBEIS, 2018).

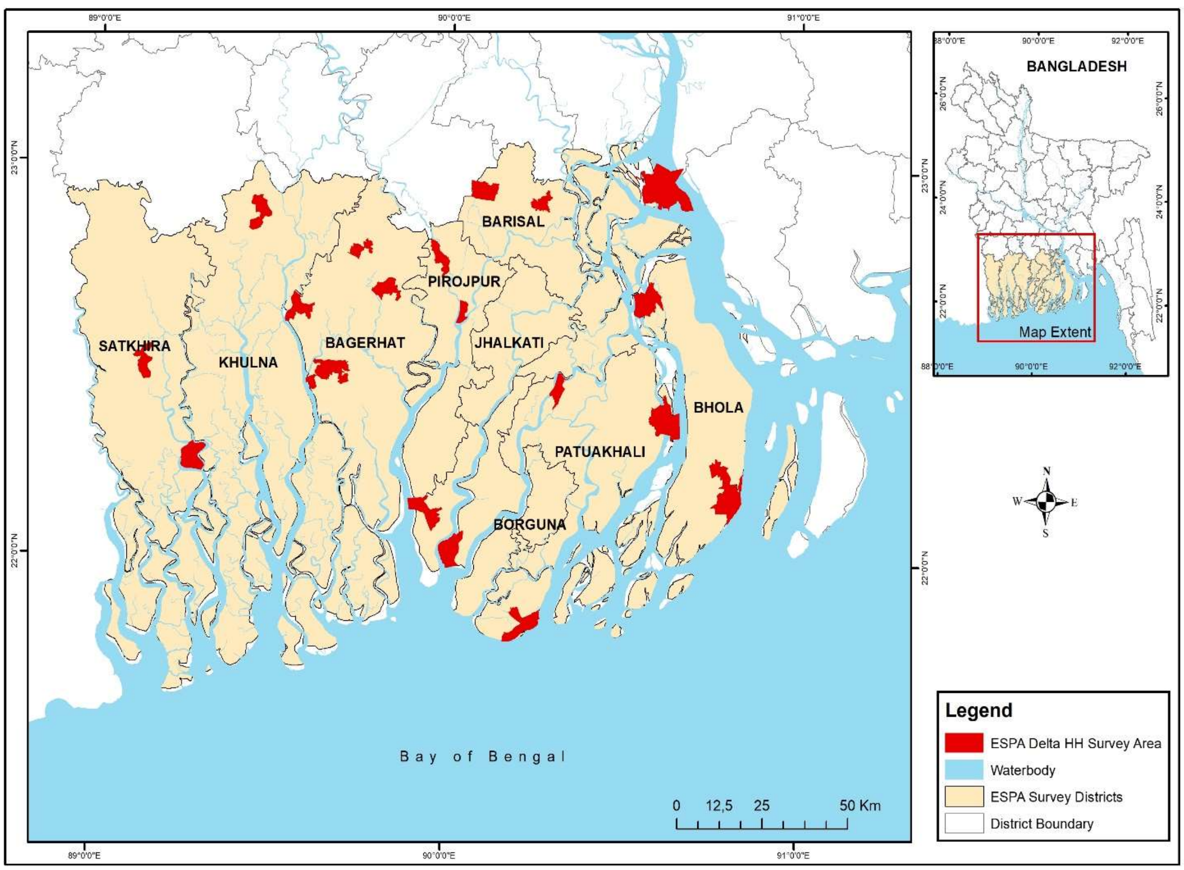
Despite the impressive progress in enrolment rate, quality of education in Bangladesh remains low. Children need to stay in school beyond the primary school years to learn basic numeracy skills that they should master in primary school (Asadullah and Chaudhury, 2015). The National Student Assessments conducted by the Government of Bangladesh also reveal poor literacy and numeracy skills among secondary school students (Ministry of Primary and Mass Education, 2016). The low quality of school education is pervasive and it prevails in all forms of school (religious and secular) (Asadullah et al., 2007). However, the schools in the poorer regions (including the coastal administrative divisions) and the children from the poorer households are significantly more likely to secure low scores in the education quality assessment tests (Ministry of Primary and Mass Education, 2016).

4. Materials and Methods

4.1 Data

The study uses an open access dataset hosted at the UK Data Service ReShare repository (Adams et al., 2016). The dataset was collected as part of a large-scale, multi-disciplinary research project entitled *Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation in Populous Deltas*. The data collection effort was led by the International Centre for Diarrhea Disease Research, Bangladesh (icddr,b), and the survey instrument and sampling strategy was co-designed by the icddr,b, the University of Exeter and the University of Southampton (Adams et al., 2016). The study area covered sixty villages from eight districts of southwest coastal zone of Bangladesh (Figure 1). Sample selection was performed following a multi-stage random sampling strategy to ensure representativeness of the population of the study area (Adams et al., 2016).

Figure 1: Map of the study area.



Source: Adams et al. (2016)

Three waves of household survey were conducted with the same households (and in most cases with the same respondents) during 2014−2015. Wave 1 was administered during Jun−July

2014 (Spring/ Summer 2014); Wave 2 was administered during October−November 2014 (Wet Season 2014) and Wave 3 was conducted during March 2015 (Dry Season/Winter 2015). In each wave, the sample included roughly 1,586 households and 7,993 individuals (attrition rate=4.30%). The questionnaire included a wide variety of questions including education, income, land and non-land assets, food and non-food consumption, livelihood options, migration, credit, savings and negative and positive shocks. Additionally, the survey collected blood pressure readings, height and weight of one adult male and female members. Informed consent was collected from all respondents. The survey protocol was approved by the Research Review Committee and the Ethical Review Committee at the icddr,b (Adams et al., 2016).

Water samples were collected from all types of drinking water sources (except bottled water and rainwater) following standard protocol (Nahian et al., 2018). Water samples were tested for salinity concentration in the laboratory with an Electric Conductivity meter (HACH sensION5) (Nahian et al., 2015). Salinity measures are reported in Electrical Conductivity (EC) in microsiemens per centimeter (μS/cm), salinity (ppm) and Total Dissolved Solids (TDS) in milligram per liter (mg/l).

4.2 Analysis sample

The analysis sample of this study is restricted to households who collected drinking water from *deep* tube-well in all three waves. This constitutes 70% of the full sample (Table 1). *Deep* tube-well is defined as water sources that draw water from >150 mbgl (Nahian et al., 2018; Lapworth et al., 2018). *Shallow* tube-wells (<150mbgl) and surface water sources are excluded to rule out negative health effects occurring from other pollutants, particularly As and microbial contamination. Hydrochemical research reveals that the groundwater aquifer situated at >150 mbgl in the coastal regions of Bangladesh is thousand years old and generally resilient to ingress of shallow contaminated groundwater (Lapworth et al., 2018). Hydrochemical analysis also confirms the absence of high concentrations of As at >150 mbgl (Rahman et al., 2011; Lapworth et al., 2018).

Table 1 Distribution of drinking water sources of the sampled households (% of households)

Sources of Drinking Water	Wave 1 (June−July 2014)	Wave 2 (Oct−Nov 2014)	Wave 3 (March 2015)
Deep tube-well	72.03	70.58	73.00
Shallow tube-well	8.62	8.45	8.72
Surface water (River/Dam/Lake/pond/stream)	16.10	4.06	12.04
Rainwater	1.89	15.56	3.79
Other (tap/bottled water/piped water)	1.36	1.35	2.44
Total	100.0	100.0	100.0

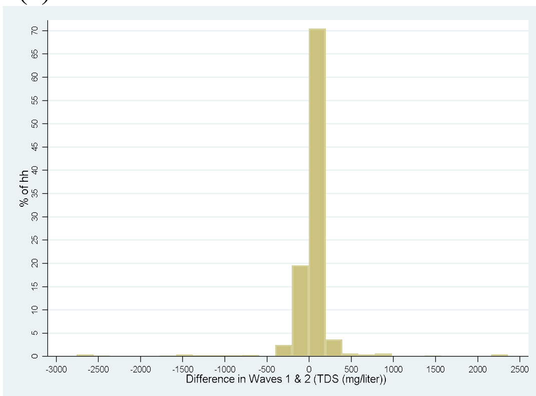
Source: Author's calculation based on Adams et al. (2016)

Only currently enrolled children and children who were born in the same sub-district[2] where the households were interviewed are included in the analysis sample. The latter criterion of sample selection is applied to eliminate unobserved heterogeneity arising from residency history between the exposed and unexposed children. Ninety-seven percent of the children of age 7–18 were ever enrolled in school. Eighty-five percent of the 7–18 year old children were enrolled in school during the survey. The average dropout rate for 7−12 age group in 2015 is 6%. The dropout rate almost doubles at the age of 13 (16%) from the dropout rate at the age of 12 (8%). The average dropout of 13−18 age group in 2015 in the analysis sample is 32%.

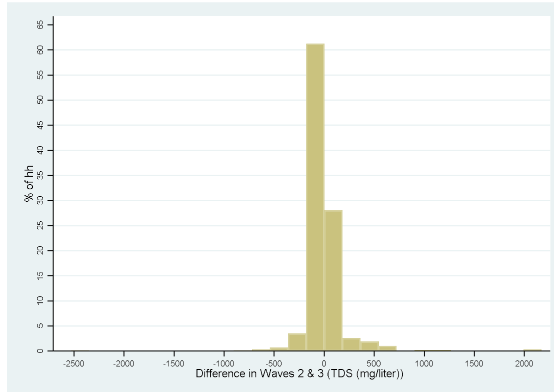
Figure 2: Within household difference in salinity (TDS (mg/l)) in water samples. Figure 2(a): Difference in salinity between Waves 1 & 2. Figure 2(b): Difference in salinity between Waves 2 & 3.

[2] This excludes 2% (n=26) children aged 7−18.

2(a)



2(b)



Note: Sample includes households who collect water from *deep* tube-well (>150mbgl) in Waves 1, 2 & 3.

Salinity measure used for the analysis is TDS mg/l. Figure 2 presents the distribution of intra-household difference in salinity level between Waves 1 & 2 and Waves 2 & 3 for the analysis sample. The intra-household seasonal variation in deep aquifer salinity is not significantly different than zero for a majority (over 80%) of the analysis sample. This finding is consistent with the theory that the deep aquifer water chemistry is unaffected by seasonal stressors such as rainfall and temperature that typically alter the chemical composition of the shallow aquifer (Lapworth et al., 2018).

4.3. Estimation Strategy

To estimate the effects of drinking water salinity on children's education, the following equation is estimated:

$$Y_{ihv} = \alpha + \beta Salinity_{hvk} + \delta X_{ihvk} + \partial Z_{hvk} + \lambda V_{vk} + \theta_k + \varepsilon_{ihv} \qquad (1)$$

In equation 1, the subscript i indicates a child, h stands for household, v for village and k for union.

4.3.1. Outcome variable

Y_{ihv} is the grade advancement status in 2015 for children i. Y_{ihvk} is zero if a child stays in the same grade (or repeating the previous year's grade) in 2015 as in 2014 and equals 1 if a child moves to a higher grade in 2015[3] (i.e. not repeating a grade). The school enrolment age in Bangladesh is 6. Hence, the grade advancement effect can be observed from age seven or higher. Using the information on the highest grade achieved by each child in Wave 2 (October−November 2014) and Wave 3 (March 2015), the grade advancement status for each enrolled child between 7–18 year is computed. The school year starts on the 1st January and ends on the 31st December. If a child is reported being at a higher grade in Wave 3 compared to the grade he or she attended in Waves 1 and 2, the grade advancement status is coded as 1 and otherwise as zero. The analysis sample thus consists of 1,052 cross-sectional observations and one observation per child between ages 7−18.

4.3.2. Treatment variable

$Salinity_{hv}$ is constructed by averaging salinity levels over three seasons. $Salinity_{hvk}$is included in the model as a dummy variable. This specification is considered most appropriate because salinity poses health risk only when consumption exceeds a threshold. No widely accepted or official salinity threshold is currently available for human health (MacDonald et al., 2016). Water is generally considered acceptable for drinking when the sodium content (TDS) is ≤ 1,000mg/l (USGS, 2016; NHMRC and NRMMC, 2011). According to the WHO guideline (WHO, 2003), drinking water becomes significantly unpalatable when TDS level exceeds 1,000mg/l.

Based on this measure, over a third of the analysis sample (37.70%) and full sample (35.33%) is exposed to saline water (TDS>1,000). Disaggregating the distribution further, a quarter of the analysis sample and full sample is exposed to slightly saline (1000<TDS <2,000 mg/l) and 12.20% of the analysis sample (10.61% of the full sample) is exposed to moderately saline

[3] Students advance from one grade to another (e.g. grade 2 to 3) if they secure the minimum satisfactory score, usually 33%, in all subjects.

(TDS≥ 2,000 mg/l) water. The dummy variable *salinity* is coded 1 if the seasonal average salinity level (TDS) exceeds 1,000mg/l and zero otherwise. The small sample size at the moderate salinity concentration (TDS≥ 2,000 mg/l) limits the opportunity to test for the non-liner effect of low versus moderate level salinity on grade advancement.

4.3.3. Exogeneity of the treatment variable

The hydrochemical literature on water salinity posits that the spatial variation of deep groundwater salinity is random (Ayers et al., 2016; Naus et al., 2019). The coastal deep groundwater chemistry is determined by complex geological mechanisms such as rock dissolution and ion exchange (Rahman et al., 2011) and varies even within a short distance. This implies that the deep aquifer salinity in this part of the world is determined purely by natural geochemical process and has not yet been influenced by modern-day sea level rise, river hydrology or any other contemporary environmental or human induced stressors (Oude Essink et al., 2010; Lapworth et al., 2018). The salinity level across the sampled households is thus purely randomly distributed. However, one can argue whether households self-select themselves into high versus low saline water sources. For instance, parents who are highly concerned about children's health and education may choose to collect water from low saline sources. Self-selection due to unobserved characteristics would be a valid concern if households know, even qualitatively, how saline their water sources are. One way to check this would be to compare households' perceptions of drinking water salinity with the observed salinity level in the water samples. Since data on the perceptions of water salinity were collected during the survey, this hypothesis can be empirically tested. Outmigration can lead to self-selection bias only when migration is driven purely by drinking water salinity. This is unlikely to be the case as migration decisions in the study area are predominantly determined by the (lack) availability of economic opportunities at the point of (origin) destination (Bernzen et al., 2019). Major environmental calamities such as cyclone, flooding and river bank erosion that invoke considerable economic damage act as secondary drivers of migration (Rakib et al., 2019; Bernzen et al., 2019). Although drinking water salinity is expected to increase population movement in the future (Rakib et al., 2019), no evidence of salinity driven migration is available as of now.

4.3.4. Control variables

X, Z and V are vectors representing child, household and village controls to account for observed heterogeneity that might confound the treatment and outcome variables. The first set of controls includes child characteristics namely, age, gender and the highest grade attained in 2014[4]. The second set of controls includes household characteristics. They are household income, wealth index, land size, size of homestead, weighted dietary diversity, annual dietary salt consumption, household size, religion, access to electricity, distance from the nearest school and minor river. The third set of control variables includes village characteristics, namely the proportion of adults ever-enrolled in school, the proportion of ever-enrolled adults completed primary school, the proportion of ever-enrolled adults completed secondary school and the historical (1981−2010) annual average rainfall in mm and rainfall square.

θ_k in equation 1 represents union (i.e. collection of villages) fixed effects, ε_i is the error term. Standard errors are clustered at the household level to safeguard against heteroskedasticity and autocorrelation. The Union Council is the lowest administrative unit which is responsible for administration and delivery of social services such as education, health, social welfare, or

[4] Parents' education data are available only for a subsample of children. Hence, they are not included in the main model to avoid loss of observations. Given that salinity level is randomly distributed across households, the omission of parents' education is not expected to bias the key parameter estimate of interest (β). Nevertheless, the main analysis is repeated for the subsample of children for whom parents' education data are available (see Appendix 3).

housing. Union fixed effects thus control for unobserved attributes that influence the supply side of education such as teacher quality, school amenities, infrastructure (i.e. roads, bridge, transportation), school funding, the quality of the political institutions and safety and security. Appendix 1 presents the descriptive statistics of the outcome, treatment and control variables for the analysis sample and full sample. Appendix 2 presents the correlation coefficient matrix of the key socio-economic characteristics of the households for the analysis sample and full sample.

5 Results

5.1. Main results

This section presents the key findings of the study in relation to the effect of drinking water salinity on enrolled children's grade advancement likelihood. Equation (1) is estimated for 7–18, 7–12 and 13–18 age groups using the Linear Probability Model (LPM)[5]. Table 2 presents the LPM regression results. In Table 2, Columns 1, 3 and 5 present the average treatment effects for the sample population under the strict exogenity assumption. These coefficients (in Columns 1, 3 and 5) are simply the difference in the average grade advancement likelihoods of the exposed and unexposed children in 2015. In Columns 1, 3 and 5, the coefficients of *Salinity* are negative but the coefficient is significant at the ten percent level in Column 2 (p=0.05). This implies that, in 2015, the salinity exposed children in 7–12 age group were 6.7 percentage points less likely to advance grade compared to the unexposed children of the same age group. Columns 2, 4 and 6 present results of a model with the full set of control variables and union fixed effects. The coefficients of *salinity* in Columns 2, 4 and 6 are conditional average treatment effects. The coefficients of *salinity* in Columns 2 and 4 are negative and statistically

[5] Equation (1) is re-estimated using Probit model for robustness check. The results are available in Appendix 4.

significant at less than five and one percent levels, respectively. The coefficient value in Column 2 implies that, on average and all else constant, the 7−18 year old children who were exposed to TDS> 1,000 mg/l were 12.2 percentage points less likely to advance grade in 2015 than those who were exposed to TDS ≤ 1,000mg/l. Consistent with the results presented in Column 3, the coefficient of *salinity* in Column 4 reveals that the adverse effect of salinity exposure on grade advancement is significant only for age group 7−12. Consistent with the coefficient of *salinity* in Column 5, the coefficient of *salinity* in Column 6 is negative but not statistically significant at the ten percent level.

Table 2 Linear probability model (LPM) results of the impact of salinity exposure on grade advancement in 2015

	If advanced grade in 2015 (1=Yes; 0=No)					
	Age group: 7–18 years		Age group: 7–12 years		Age group: 13–18 years	
	(1)	(2)	(3)	(4)	(5)	(6)
Salinity	-0.042	-0.122**	-0.067*	-0.196***	-0.013	-0.050
(TDS)>1,000 mg/l	(0.028)	(0.061)	(0.034)	(0.072)	(0.052)	(0.086)
Child controls	N	Y	N	Y	N	Y
Household controls	N	Y	N	Y	N	Y
Village controls	N	Y	N	Y	N	Y
Union fixed effects	N	Y	N	Y	N	Y
Observations	1,052	1,035	658	648	394	387
R-squared	0.002	0.179	0.007	0.114	0.0002	0.432

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from *deep* tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors are clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1) Child controls: age, gender, highest grade attained in 2014; (2) Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980−2010).

In Table 3 & Panel A, the gender disaggregated results for the full model are presented. The main effects of *salinity* on grade advancement are consistent with the main results (Table 2). The coefficients of *Boys* are negative and statistically significant in Columns 1, 2 and 3 (Table 3 & Panel A) implying that, on average and all else constant, boys were significantly less likely to advance grade in 2015 compared to girls. This finding is consistent with the national grade repetition statistics for the primary school going children of Bangladesh which shows that boys are more likely to repeat grades in primary school than girls (BANBEIS, 2018). The coefficients of the interaction of *Boys* and *Salinity* are positive but not statistically significant at the ten percent level in any of the three models presented in Table 3 (p=0.14 in Column 1). The positive value of the coefficient imply that the human capital cost of water salinity is borne disproportionately by girls. This phenomenon can be explained by the gender gap in education expenditure in Bangladesh. Girls receive a significantly smaller proportion of the household education budget (Xu et al., 2019). The allocation is likely to get further skewed against girls when household experience economic hardship in the wake of a negative shock. The gender discrepancy in the human capital cost of salinity can also be caused by the gender difference in the biological capacity to cope with the health consequences invoked by salinity exposure. Since girls suffer more from malnutrition than boys (due to gender gap in intra-household food and resource allocation) (Raj et al., 2015), girls are more likely to be vulnerable to salinity induced poor health outcomes compared to boys.

In Panels B & C of Table 3, the negative effects of salinity is disaggregated across households' poverty and land ownership status. In Panel B (Table 3), the main effects of *salinity* remains consistent with the results presented in Table 2. The coefficients of the interaction of *salinity* and *Non-Poor* are positive and statistically significant at the ten percent level in Column 1 (p= 0.06) and Column 2 (p= 0.09). This implies that the salinity exposed children from the non-poor households were significantly more likely to advance grade in 2015 than that of the poor households.

Table 3 Linear probability model (LPM) results of heterogeneous effects of salinity exposure on grade advancement in 2015

	If advanced grade in 2015 (1=Yes; 0=No)		
Panel A: Gender	(1) 7–18 years	(2) 7–12 years	(3) 13–18 years
Salinity (TDS)>1,000 mg/l	-0.162**	-0.232***	-0.098
	(0.067)	(0.079)	(0.099)
Boys	-0.106***	-0.0705*	-0.102**
	(0.031)	(0.036)	(0.052)
[Salinity (TDS)>1,000 mg/l]*Boys	0.079	0.070	0.096
	(0.054)	(0.062)	(0.093)
Observations	1,035	648	387
R-squared	0.211	0.116	0.434
Panel B: Poverty			
Salinity (TDS)>1,000 mg/l	-0.213***	-0.279***	-0.103
	(0.071)	(0.083)	(0.135)
Non-poor[a]	-0.053	-0.045	-0.103
	(0.038)	(0.042)	(0.135)
[Salinity (TDS)>1,000 mg/l]*Non-poor[a]	0.116*	0.119*	0.040
	(0.062)	(0.071)	(0.124)
Observations	1,024	643	381
R-squared	0.210	0.105	0.429
Panel C: Agricultural land ownership			
Salinity (TDS)>1,000 mg/l	-0.191***	-0.249***	-0.057
	(0.071)	(0.085)	(0.121)
Functionally landless[b]	-0.002	-0.023	0.041
	(0.038)	(0.0434)	(0.064)
Marginal landowners[b]	-0.102**	-0.122**	-0.046
	(0.047)	(0.056)	(0.072)
Small, medium & large landowners[b]	0.00116	0.0370	0.109
	(0.075)	(0.107)	(0.098)
[Salinity (TDS)>1,000 mg/l]*	0.071	0.062	-0.034
Functionally landless[b]	(0.065)	(0.077)	(0.115)
[Salinity (TDS)>1,000 mg/l]* Marginal	0.138*	0.160	0.026
landowners[b]	(0.083)	(0.103)	(0.132)
[Salinity (TDS)>1,000 mg/l]* Small,	-0.014	-0.011	-0.142
medium & large landowners[b]	(0.132)	(0.178)	(0.182)
Observations	1,035	648	387
R-squared	0.212	0.110	0.429
Child controls	Y	Y	Y
Household controls[c]	Y	Y	Y
Village controls	Y	Y	Y
Union fixed effects	Y	Y	Y

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1)

Child controls: age, gender, highest grade attained in 2014; (2) Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980−2010). [a]Base category is poor. Poverty line income is defined as US$15 per person per month. This is equivalent to the World Bank's "PPP$1-a-day" standard of poverty income threshold. [b]Base category is landless (0 decimal land). Functionally landless group owns <50 decimal agricultural land. Marginal landowners own 50–149 decimal agricultural land and small, medium & large landowners own >150 decimal agricultural land. [c]Panel B and C excludes hh assets index, agricultural land size, size of the homestead and annual income from household controls.

In Panel C (Table 3), the heterogeneous effects of salinity exposure across land ownership status is explored. Most of the coefficients of the interaction effects between *salinity* and land ownership are statistically insignificant except for the coefficient of *salinity* and *marginal land owners*. The coefficient is positive and significant at the ten percent level in Column 1 implying that the salinity exposed children of the marginal land owners are significantly more likely to advance grade than that of the landless households.

5.2. Robustness checks

The first robustness test is conducted to check if the omission of parents' education is biasing the β estimate. Hence, equation 1 is re-estimated with mothers' and fathers' education. The findings are summarized in Appendix 3. The results are highly consistent with the main results presented in Table 2. The second robustness check is performed to test if the results are specific to the econometric framework (i.e. the LPM). Equation 1 is re-estimated for the analysis sample using a probit model. The results are reported in Appendix 4. In terms of signs and significance level and even magnitude, the coefficients (average marginal effects) estimated by the probit model are highly consistent with the LPM estimates presented in Table 2.

The third robustness test checks if the results presented in Table 2 are driven by sample selection bias. Equation 1 is re-estimated using the full sample to include households who collected water from *shallow* tube-well and surface water sources. The cross-sectional variation of salinity in the full sample is due to spatial variation of borehole depth (i.e. *deep* and *shallow* tube-well) and variation in water source (i.e. surface water vs groundwater). The results are presented in Appendix 5. The signs of the coefficients of salinity for age group 7−12 (see Appendix 5 (Columns 3 & 4)) are highly consistent with the main results (Table 2). The signs of the coefficients of *salinity* is negative for 13−18 year old children (Appendix 5 (Columns 5 & 6) implying the average effect of salinity on grade advancement to be negative. However, the coefficients are still not significant at the ten percent level.

The other robustness tests ran but not reported[6] are the following. First, to test whether the functional form of salinity is causing any bias, equation 1 is re-estimated using the natural log of salinity as a treatment variable. The coefficient of *ln of salinity* for 7–12 age group remains negative and statistically significant at the five percent level. Second, the children was grouped into primary and secondary education based on their current grade. The results remain consistent with the results presented in Table 2. The final robustness check tests if the results hold true for a different indicator of grade advancement, namely, *ever repeated a grade*. *Ever repeated a grade* measures whether a child repeated a grade over the entire period of schooling and not just in 2015. This indicator is prone to measurement error because it consists of a large number of missing and seemingly erroneous observations. Equation 1 is re-estimated using *ever repeated a grade* as the dependent variable. The coefficients of *salinity* are positive (i.e. higher the salinity higher the likelihood of grade repetition) and statistically significant at the five percent level for age group 7–12.

5.3. Test for exogeneity of deep groundwater salinity

In this section I test if households self-select themselves into higher versus lower sodium contaminated water sources. This hypothesis is tested by comparing households' (respondents') perceptions of salinity and actual salinity level observed in the water sample.

[6] These results can be obtained from the author upon request.

During the survey (in Waves 1, 2 and 3), respondents were asked about their perceptions of drinking water salinity in their village. Since respondents' perception of village level drinking water salinity is likely to be positively correlated with the perception of salinity in their own water sources, perception of village level drinking water salinity is used as a proxy and is compared with the actual salinity level observed in households' primary drinking water source. The cross tabulation results presented in Appendix 6 show no correlation between respondents' perceptions and actual salinity level in *deep* tube-well water. This finding suggests that self-selection is unlikely to cause endeogenity bias in the estimate.

5.4. Transmission paths

The dataset offers the opportunity to test two indirect transmission paths[7]. First, the survey collected data on blood pressure of one adult male (18–54 years) and female (15–49 years) household members. Using 140 mmHg as cut-off point for Systolic blood pressure (SBP) and 90 mmHg as cut-off point for the diastolic blood pressure (DBP) (WHO, 2015; Nahian et al., 2015), an individual is coded one if SBP $\geq$ 140 and/or DBP$\geq$ 90 in any of the three waves. Regressing the individual level incidence of hypertension against the salinity level in drinking water, the likelihood of hypertension incidence in relation to salinity is estimated.

Table 4 presents the regression results of the incidence of hypertension for the households who collected water from *deep* tube-well in Waves 1, 2 & 3. In addition to the previously mentioned household controls, three individual specific control variables are included in the model. They are age, gender and body mass index (BMI). The coefficient of *salinity* is, as expected, positive and statistically significant at the five percent level. This coefficient imply that, on average and

[7]The direct transmission paths (i.e. health effects of salinity exposure) could not be tested due to the absence of anthropometric and health data for the age group of interest.

all else constant, individuals who are exposed to TDS>1,000mg/l are about 4 percentage points more likely to be hypertensive than the unexposed individuals.

Table 4 Linear probability model (LPM) results of the effect of salinity exposure on incidence of hypertension among adults

	An adult household member is hypertensive (Yes=1, No=0)
Salinity (TDS) >1,000 mg/l	0.041**
	(0.021)
Age	0.003***
	(0.0007)
Gender (Female=0, Male=1)	-0.025**
	(0.011)
Body mass index (BMI)	0.010***
	(0.002)
Household controls	Y
Union fixed effects	Y
Observations	1,682
R-squared	0.069

Notes: Sample includes households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the school.

The next thread of the transmission pathway tested is health expenditure. It is hypothesized that hypertension leads to higher medical expenditure for the household. To test this hypothesis, households' annual medical expenditure (in log form) is regressed against the incidence of hypertension including the full set of household controls and union fixed effects. This analysis is conducted at the household level because healthcare expenditure is reported at the household level. The key independent variable is the intensity of hypertension which measures the number of times a hypertensive patient has been identified in a household over Waves 1, 2 and 3. The results are presented in Table 5. The coefficient of hypertension intensity is positive and statistically significant. The coefficient implies that, all else constant, a one unit increase in hypertension intensity, increases annual household medical expenditure, on average, by 7.8 percentage points.

Table 5 Ordinary least square (OLS) regression results of the effect of the incidence of hypertension on households' annual health expenditure

	Ln of households' annual health expenditure
Hypertension intensity[a]	0.078***
	(0.022)
Household controls	Y
Union fixed effects	Y
Observations	995
R-squared	0.110

Notes: [a]Hypertension intensity is the number of times a household is diagnosed with a hypertension patient during Waves 1, 2 & 3. Sample includes households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion.

Finally, to show that hypertension and health expenditures are two of the many potential indirect transmission paths, equation (1) is re-estimated by including these two variables. If these two variables mediate the impacts of salinity on grade advancement, then some of the negative effects of salinity would be absorbed by them. The re-estimation results are presented in Table 6. Columns 1 and 3 reproduce the main effects from Table 2 for comparison and Columns 2 and 4 show the coefficients after the inclusion of the additional control variables for age groups 7−12 and 13−18, respectively. As expected, in Column 2, the coefficient of hypertension intensity of adults is negative and statistically significant at the five percent level implying that a higher hypertension intensity in the household significantly decreases the grade advancement likelihood of 7−12 year old children. The coefficient of *ln of annual medical expenditure* in Column (2) is negative but not statistically significant at the ten percent level. The inclusion of *hypertension intensity* and *ln of annual medical expenditure* decreases the coefficient of *salinity* by 1.1 percentage points. They, therefore, absorb 5.6 percentage points of the negative effects of salinity for age group 7−12. These two variables have no effect on the grade advancement likelihood of age group 13−18.

Table 6 Hypertension and medical expenditure as mechanisms of grade advancement in 2015

	If advanced grade in 2015 (1=Yes; 0=No)			
	Age group: 7–12years		Age group: 13–18years	
	(1)	(2)	(3)	(4)
Salinity (TDS)>1,000 mg/l	-0.196***	-0.185**	-0.050	-0.052
	(0.072)	(0.072)	(0.086)	(0.095)
Hypertension intensity	–	-0.039**	–	0.008
		(0.016)		(0.016)
Ln of annual medical expenditure	–	-0.016	–	-0.011
		(0.016)		(0.022)
Child controls	Y	Y	Y	Y
Household controls	Y	Y	Y	Y
Village controls	Y	Y	Y	Y
Union fixed effects	Y	Y	Y	Y
Observations	648	645	387	382
R-squared	0.114	0.127	0.432	0.429

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1) Child controls: age, gender, highest grade attained in 2014; (2) Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980−2010).

5. Discussions

The findings of the study show conclusive evidence of drinking water salinity having adverse effect on grade advancement of 7−12 year old children. On average, salinity exposure contributes to 6.7 percentage point lower grade advancement rate for the exposed children of the sample population. To put this number in to perspective, the average sample grade advancement rate among 7−12 age group is 82%. Salinity exposure of TDS>1000 mg/l leads to 6.7 percentage points lower grade advancement likelihood for the exposed children. Although not significant, the coefficient of gender and salinity interaction among 7−12 age group is positive. This suggests that a larger share of the adverse human capital effect of salinity is borne by the girls.

The results show no significant effect of salinity on grade advancement likelihood of 13−18 age group. This age group suffers from a higher rate of dropouts compared to the 7−12 age group. The discrepancy of dropout rates would be a cause of concern only if dropout is correlated with salinity level. No significant correlation between drinking water salinity and dropout is observed for either 7−12 or 13−18 year old children. Therefore, treatment specific attrition is unlikely to be driving the null results for 13−18 age group.

Consistent with the findings of the existing studies from the study region, the findings of the current study support the link among drinking water salinity, adverse health effect of adults and medical expenditure (Talukder et al., 2016; Nahian et al., 2018). As hypothesized, adult household members' poor health and households' medical expenditure partly explain young children's poor academic performance at school. However, they mediate only 5.6 percentage points of the negative effects and only relevant for the 7−12 age group. Since younger children require more care and supervision from adults, having sick adults in the household reduces the time spent on childcare and supervision of learning at home. However, the negative correlation between medical expenditure and grade advancement likelihood of 7−12 age group is somewhat perplexing given that primary education in Bangladesh is free of cost; therefore, educational outcome of the younger children is less sensitive to household poverty. Further, the positive correlation between salinity exposure and the hypertension likelihood of adults suggests that the 13−18 age group are also likely to be suffering from contemporaneous health effect due to elevated salinity in drinking water. Yet, the correlation between salinity and educational outcome for 13−18 age group does not reflect such tendency.

The largest segment of the negative effect of salinity on grade advancement appears to permeate through direct health effects in the form of impaired cognitive development in early childhood. Contemporaneous health effects such as blood pressure, kidney stone, bone mass etc. are less plausible pathways because both age groups would have been equally susceptible to these illnesses. Empirical studies document numerous evidence of early childhood and *in* *utero* exposure to polluted (clean) water impairing (augmenting) young children's cognitive development (Bouchard et al., 2011; Rocha-Amador et al., 2007; Chen et al., 2017). The public health and epidemiological literature also identifies several pathways through which early childhood and *in utero* exposure to salinity can imped young children's neurocognitive growth. For example, two recent studies report that maternal high-salt diet during pregnancy and lactation negatively effects neuro-metabolism, restricts intrauterine growth, increases the risks of fetal placental dysfunction and low birth weight (Stocher et al., 2018; Reynolds et al., 2015).

The absence of correlation between salinity and the grade advancement likelihood of the 13−18 age group offers further reason to believe that early childhood exposure is the most plausible transmission mechanism. Considering the history and timeline of *deep* tube-well installation and promotion in the coastal region of Bangladesh, it is likely that the 7−12 and 13−18 age groups were exposed to excessive drinking water salinity at different stages of their life cycles. The installation of *deep* tube-well by the Department of Public Health and Engineering[8] (DPHE) in association with the World Bank began around 2003 and a large part of the southwest coastal region was covered by 2006[9] (World Bank, 2007). A majority of the sampled children in the 7−12 age group were not borne in 2006 and some of them were 1−3 year old. Conversely, 13−18 year old children were 4–9 year in 2006. The 7−12 age group, therefore, have had an early life or *in utero* exposure while the 13−18 year old children were exposed at late childhood. Due to the absence of exposure history data, it is hard to establish this proposition with reasonable degree of confidence. However, in light of the emerging evidence of the high incidence of preeclampsia and infant mortality (Khan et al., 2014; Dasgupta et al.,

[8] The agency of the Bangladesh Government responsible for rural water supply.

[9] The intervention is ongoing. The DPHE monitors, maintains, extends and augments the rural water supply network on a regular basis.

2016) in the coastal districts of Bangladesh, the age of exposure appears to be the most likely driver of the heterogeneous impacts across 7−12 and 13−18 age groups.

6. Policy Implications and Future Research

The findings of the study suggest that salinity is slowing down young children's progress at school. This imply that the children exposed to excessive drinking water salinity would need longer time to complete primary school. The prolonged time required to complete primary education may lead to a series of cascading effects. First, it may potentially increase primary school dropout rate and decrease secondary school enrolment rate. Second, given the poor quality of primary school education and the longer time required to acquire basic literacy and numeracy skills, early dropouts and low secondary school enrolment would mean a massive loss of human capital for the study districts. Third, given that the schools in the poorer regions of Bangladesh and children from the poorer households are more likely to be deficient in basic education skills, deep groundwater salinity exposure has the potential to further exacerbate the skill gap between the poor and non-poor households and regions. Finally, considering the low level of economic development and high poverty in the coastal region of Bangladesh, the low human capital attainment by the poorer children will reinforce the poverty trap and impede social mobility in the long run.

The sample used for the study is representative of the southwest coastal region of Bangladesh. Future research should investigate if the similar correlation between salinity and education outcome prevails in the southeastern coastal districts of Bangladesh and in other countries of the world. Future research should also address the questions on transmission path that remained unanswered by this study. More specifically, it is important to gain a better understanding of the factors that drive the heterogeneous effect of salinity across age groups. Future research should test whether the age and length of salinity exposure drive the difference. The contemporaneous health effects of salinity and their implications for children's human capital formation needs research attention. Finally, the current study uses grade advancement as an indicator of human capital. Future research should test other indicators of human capital including indicators of cognitive ability such as IQ and proficiency gained at school (such as math, reading, writing test scores) and non-cognitive outcomes.

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Appendix 1 Descriptive statistics of the key variables for the analysis sample and full sample

	Analysis sample					Full sample				
Description	Obs	Mean	Std Dev	Min	Max	Obs	Mean	Std Dev	Min	Max
Average drinking water salinity (TDS) (mg/l)	1,129	1,069	815	342	6,152	1,545	982	813	34	6,152
If average drinking water salinity (TDS) >1000 mg/l	1,129	0.37	0.48	0.00	1.00	1,545	0.34	0.47	0.00	1.00
Child: If advanced a grade by 2015	1,052	0.74	0.44	0.00	1.00	1,433	0.73	0.45	0.00	1.00
Age of the child (7−18y)	1,129	11.57	3.15	7.00	18.00	1,546	11.60	3.18	7.00	18.00
Gender of the child (7−18y)	1,129	0.48	0.50	0.00	1.00	1,546	0.48	0.50	0.00	1.00
Highest grade attained by a child in 2014	1,052	4.21	3.14	0.00	12.00	1,433	4.27	3.13	0.00	12.00
Household head's highest grade attained	1,109	3.91	3.99	0.00	18.00	1,516	3.98	4.01	0.00	18.00
Household wealth index	1,129	41,709	49,953	517	468,867	1,546	43,663	55,064	517	520,433
Size of agricultural land owned by the household	1,129	43.02	89.62	0.00	1,136.67	1,546	48.21	139.06	0.00	2,727.33
Size of homestead land owned by the household	1,129	17.76	18.22	0.00	123.33	1,546	18.24	19.32	0.00	128.00
Annual household income (US$)	1,191	1743	1693	25	17,000	1,546	1755	2543	25	55250
Weighted Dietary Diversity Index	1,129	5.75	1.77	2.00	12.33	1,546	5.70	1.80	2.00	13.33
Annual dietary salt consumed (kg)	1,129	18.15	4.87	7.15	42.25	1,546	17.81	5.22	7.15	52.00
If had access to electricity grid	1,129	0.40	0.49	0.00	1.00	1,546	0.33	0.47	0.00	1.00
Household size	1,129	5.93	1.72	3.00	13.00	1,546	5.82	1.72	3.00	13.00
Religion - Muslim	1,129	0.82	0.38	0.00	1.00	1,546	0.81	0.39	0.00	1.00
Religion - Hindu	1,129	0.18	0.38	0.00	1.00	1,546	0.19	0.39	0.00	1.00
Religion - Christian	1,129	0.00	0.00	0.00	0.00	1,546	0.00	0.04	0.00	1.00
Religion - Buddhist	1,129	0.00	0.00	0.00	0.00	1,546	0.00	0.00	0.00	0.00
Distance from minor river (km)	1,129	2.67	2.39	0.02	8.67	1,546	2.57	2.29	0.02	8.67
Distance from nearest school (km)	1,129	0.47	0.34	0.00	2.22	1,546	0.50	0.37	0.00	2.22
Yearly average rainfall (1981−2010)	1,129	208	32	159	260	1,546	201	32	157	260

Proportion of adults (> 18 years old) in a village ever enrolled in school	1,129	0.73	0.11	0.43	0.89	1,546	0.73	0.12	0.43	0.93
Proportion of ever-enrolled adults in a village completed primary education	1,129	0.68	0.12	0.25	0.95	1,546	0.68	0.12	0.25	0.95
Proportion of ever-enrolled adults in a village completed secondary education	1,129	0.18	0.11	0.00	0.57	1,546	0.18	0.11	0.00	0.57

Notes: Size of the analysis sample is 1052. Analysis sample includes households (1) who collect water from *deep* tube-well (>150mbgl) in Waves 1, 2 & 3; (2) have a currently enrolled child between 7−18 year; (3) have children born in the same upzilla (sub-district) where households were interviewed. Size of the full sample is 1432. Full sample includes households (1) who were surveyed in Waves 1, 2 & 3; (2) have a currently enrolled child between 7−18 year; (3) have children born in the same upzilla (sub-district) where households were interviewed.

Appendix 2 Correlation coefficients among key socio-economic variables for the analysis sample and full sample

	Education of the HH head	HH Wealth Index	Agricultural land size (in decimal)	Homestead land size (in decimal)	Annual household income (in Taka)	Weighted Dietary Diversity Index
Full sample						
Education of the HH head	1.000					
HH Wealth Index	0.300***	1.000				
Agricultural land size (in decimal)	0.330***	0.462***	1.000			
Homestead land size (in decimal)	0.320***	0.378***	0.419***	1.000		
Annual household income (in Taka)	0.170***	0.537***	0.664***	0.339***	1.000	
Weighted Dietary Diversity Index	0.346***	0.381***	0.346***	0.258***	0.314***	1.000
Analysis sample						
Education of the HH head	1.000					
HH Wealth Index	0.258***	1.000				
Agricultural land size (in decimal)	0.383***	0.406***	1.000			
Homestead land size (in decimal)	0.288***	0.361***	0.416***	1.000		
Annual household income (in Taka)	0.141***	0.510***	0.331***	0.348***	1.000	
Weighted Dietary Diversity Index	0.307***	0.357***	0.384***	0.250***	0.310***	1.00

Notes: The analysis sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. The full sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who were interviewed in Waves 1, 2 & 3. (*) p<0.1, (**) p<0.05, (***) p<0.001.

Appendix 3 Linear probability model (LPM) results of salinity exposure and grade advancement in 2015 controlling for parents' education

	If advanced grade in 2015 (1=Yes; 0=No)		
	Age group: 7–18years	Age group: 7–12years	Age group: 13–18years
	(1)	(2)	(3)
Salinity (TDS)>1,000 mg/l	-0.119**	-0.220***	0.014
	(0.061)	(0.074)	(0.094)
Mother's education (highest grade attained)	0.017***	0.021***	0.020**
	(0.006)	(0.007)	(0.010)
Father's education (highest grade attained)	-0.004	-0.006	-0.003
	(0.005)	(0.006)	(0.007)
Child controls	Y	Y	Y
Household controls	Y	Y	Y
Village controls	Y	Y	Y
Union fixed effects	Y	Y	Y
Observations	824	527	297
R-squared	0.229	0.163	0.447

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors are clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1) Child controls: age, gender, highest grade attained in 2014, mother's education, father's education; (2) Household controls: hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980–2010).

Appendix 4 Probit regression results (average marginal effect on P(Y)) of salinity exposure and grade advancement in 2015

	If advanced grade in 2015 (1=Yes; 0=No)					
	Age group: 7–18 years		Age group: 7–12 years		Age group: 13–18 years	
	(1)	(2)	(3)	(4)	(5)	(6)
Salinity (TDS) >1,000 mg/l	-0.042 (0.030)	-0.153** (0.0619)	-0.067** 0.034	-0.231*** (0.0726)	-0.013 (0.052)	-0.097 (0.086)
Child controls	N	Y	N	Y	N	Y
Household controls	N	Y	N	Y	N	Y
Village controls	N	Y	N	Y	N	Y
Union fixed effects	N	Y	N	Y	N	Y
Observations	1,052	1,035	658	648	394	387
Wald Chi^2	1.93 (p<0.20)	217 (p<0.0001)	4.07 (p<0.05)	88.61 (p<0.001)	0.07 (p<0.80)	163.10 (p<0.001)

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Robust standard errors clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1) Child controls: age, gender, highest grade attained in 2014; (2) Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980–2010).

Appendix 5 Linear probability model (LPM) results of salinity exposure and grade advancement in 2015 for the full sample

	If advanced grade in 2015 (1=Yes; 0=No)					
	Age group: 7–18years		Age group: 7–12years		Age group: 13–18years	
	(1)	(2)	(3)	(4)	(5)	(6)
Salinity (TDS) >1,000 mg/l	-0.066***	-0.093**	-0.093***	-0.165***	-0.026	-0.055
	(0.025)	(0.045)	(0.028)	(0.060)	(0.044)	(0.061)
Child controls	N	Y	N	Y	N	Y
Household controls	N	Y	N	Y	N	Y
Village controls	N	Y	N	Y	N	Y
Union fixed effects	N	Y	N	Y	N	Y
Observations	1,432	1,408	874	861	558	547
R-squared	0.005	0.197	0.13	0.109	0.006	0.382

Notes: Sample includes currently enrolled children, children who were born in the same sub-district where the survey was conducted, and households who appear in Waves 1, 2 & 3. Robust standard errors clustered at the household-level in parenthesis. (*) p<0.1, (**) p<0.05, (***) p<0.001. (1) Child controls: age, gender, highest grade attained in 2014; (2) Household controls: hh head's education, hh size, hh assets index, agricultural land size, size of the homestead, weighted dietary diversity index, annual salt consumption, annual income, access to electricity, religion, distance from the minor river, distance from the school; (3) Village controls: proportion of adults ever enrolled in school, proportion of adults completed primary education, proportion of adults completed secondary education; long-term mean annual rainfall (1980–2010).

Appendix 6 Cross-tabulation results of respondents' perception of village-level drinking water salinity and actual salinity level in their water sources (in %)

	Observed salinity level	
	TDS <=1,000 mg/l	TDS >1,000 mg/l
Perception of salinity		
Bad	6.02	3.28
Moderate	55.52	56.72
Good	38.46	40.00
Total	100.00	100.00
N	299	305
Chi^2 (p-value)	2.578 (p<0.300)	

Notes: Sample includes households where the same respondent answered the questions in Waves 1, 2 & 3 and ted, and households and households who collect water from deep tube-well (>150mbgl) in Waves 1, 2 & 3. Perception of salinity measures average perception of village-level drinking water salinity in across Waves 1, 2 & 3.