Drinking water salinity and raised blood pressure: evidence from a cohort study in coastal Bangladesh

Pauline F.D. Scheelbeek* a,b,c, Muhammad A.H. Chowdhuryd, Andy Hainesc,e, Dewan S. Alamd, Mohammad A. Hoquef, Adrian P. Butlerf, Aneire E. Khanag, Sontosh K. Mojumderh, Marta A.G. Blangiardoa,b, Paul Elliotta,b and Paolo Vineisa,b,g

a. Department of Epidemiology and Biostatistics, Imperial College London, London, UK
b. MRC-PHE Centre for Environment and Health, London, London, UK
c. Department of Population Health, London School of Hygiene and Tropical Medicine, London, UK
d. Initiative for Non-communicable Diseases, Health Systems and Population Studies, icddr.b Dhaka, Bangladesh
e. Department of Social and Environmental Health Research London School of Hygiene and Tropical Medicine
f. Department of Civil and Environmental Engineering, Imperial College London, London, UK
g. Grantham Institute for Climate Change, London, UK
h. Dacope Upazilla Health Complex, Khulna, Bangladesh

* Corresponding author: Dr Pauline Scheelbeek, Department of Epidemiology and Biostatistics, School of Public Health, St Mary’s Campus; Norfolk Place, London, W2 1PG, UK; +442075942773; pauline.scheelbeek@imperial.ac.uk

Running Title:
Drinking water salinity and raised blood pressure

Acknowledgements:
This study was funded by the Leverhulme Trust. PS was additionally supported by the MRC-PHE Centre for Environment and Health and, along with MH, the Wellcome Trust Institutional Strategic Support Fund (ISSF). PE is supported by the National Institute for Health Research (NIHR) Imperial College Healthcare NHS Trust (ICHNT) and Imperial College Biomedical Research Centre (BRC), the MRC-PHE Centre for Environment and Health, and the NIHR Health Protection Research Unit on Health Impact of Environmental Hazards; he is an NIHR Senior Investigator. For this research, PV was supported by the MRC-PHE Centre for Environment and Health and Imperial College Healthcare NHS Trust (ICHNT).

The authors would like to thank Dr Ali Tanweer for his contributions to the study design and questionnaires; Mr Khaled Hasan for his help with data management; Dr Muhammad Aziz Hasan for conducting the urine analyses; Professor Kazi Matin Ahmed and Professor Muhammad Akhtaruzzaman at Dhaka University for their great help in getting all water and food samples analysed; Mr Shafique Hossein and Mr Abul Hossein for the outstanding management of the field teams; all data collectors for the excellent work in and around Dacope.

Competing Financial Interests:
The authors declare that they have no competing financial interests that might have influenced the performance or presentation of the work described in this manuscript.
Abstract

Background – Millions of coastal inhabitants in South-east Asia have been experiencing increasing sodium concentrations in their drinking-water sources, likely to be partially due to climate change. High (dietary) sodium intake has convincingly been proven to increase risk of hypertension; it remains unknown, however, whether consumption of sodium in drinking water could have similar effects on health.

Objectives – We here present the results of a cohort-study in which we assessed the effects of drinking water sodium (DWS) on blood pressure (BP) in coastal populations in Bangladesh.

Methods – DWS, BP and information on personal, lifestyle and environmental factors were collected from 581 participants. We used generalised linear latent and mixed-methods to model effects of DWS on BP and assessed the associations between changes in DWS and BP when participants experienced changing water sodium levels and/or switched from “conventional” ponds or tube-wells to alternatives (Managed aquifer recharge [MAR] and rainwater harvesting) that aimed to reduce sodium levels.

Results – DWS-concentrations were highly associated with BP after adjustments for confounding factors. Furthermore, per 100mg/l lower sodium in drinking water, systolic/diastolic BP was lower on average by 0.95/0.57 mmHg and odds of hypertension lower by 14%. However, MAR did not consistently lower sodium levels.

Conclusions - DWS is an important source of daily sodium intake in salinity-affected areas, and a risk factor for hypertension. Considering the likely increasing trend in coastal salinity, prompt action is required. As MAR showed variable effects, alternative technologies for providing reliable, safe, low-sodium fresh-water should be developed alongside improvements in MAR and evaluated in ‘real-life’ salinity-affected settings.
Introduction

Low-lying deltas, such as Bangladesh, have been experiencing increasing numbers of storm surges over recent decades, inundating densely populated coastal areas (Singh et al. 2000). This trend is believed to be associated with climate change and, in combination with sea level rise, may result in contamination of unprotected drinking water sources, such as ponds and shallow tube wells, with saline water (Hoque et al. 2016; IWM 2014). Changes in river flow from an upstream barrage, faulty management of polders, shrimp farming and ground water extraction may all contribute further to salinization (Mahmuduzzaman et al. 2014). Previously, we found a mean sodium concentration in drinking water of approximately 700 mg/l (with extremes exceeding 1500mg/l) (Khan et al. 2014) in coastal areas: this contributes substantially to daily sodium intake of coastal populations (Scheelbeek 2015). As a consequence the WHO-recommended daily maximum sodium intake of 2000 mg can easily be exceeded in the area solely by drinking 2-3 litres of water (World Health Organization 2012b). Climate change predictions, including further sea level rise (Hijioka et al. 2014) suggest further exacerbation of salinity problems in the future.

High dietary salt intake from food is a major risk factor for raised blood pressure (BP) worldwide (Aburto et al. 2013; Elliott et al. 1996; Elliott and Stamler 2002; Elliott et al. 2007; Pietinen et al. 1988). It remains unknown, however, what effect long-term consumption of substantial amounts of sodium through drinking water has on population health.

In this study, we explored the relationship between drinking water salinity and BP in a coastal population in Bangladesh. We looked at the relationship between BP and drinking water sodium concentrations of individuals whose sodium intake fluctuated during the study period. Differences in sodium concentrations occurred because users consumed drinking water from different sources (pond, tube well, Managed Aquifer Recharge [MAR] system (Figure 1) or rainwater) or due to seasonal fluctuation of drinking water sodium concentrations in a single
source (i.e. pond). Furthermore, some participants changed their drinking water source during the study period. It was expected that consumers switching from ponds and tube wells to MAR-sources would experience a significant decrease in their drinking water salinity and the study assessed whether this occurred.

Methods

For this study ethical clearance was obtained from the National Research Ethics Committee of the Bangladesh Medical Research Council.

Three sub-districts in South-western Bangladesh – Dacope, Batiaghata and Paikghaccha (Supplemental Material, Figure S1) were selected for this study because of high salinity levels in drinking water and an ongoing MAR-construction project in the area (Netherlands Embassy in Bangladesh 2014; Sultana et al. 2014; UNICEF 2014) (Figure 1).

Based on access and hydrological conditions, 25 villages were found to be suitable for MAR-construction (Hasan 2012): six were prioritised based on water shortages. MAR-systems in these villages were scheduled to become operational during the study period; however, some participants started drinking MAR water prior to the planned starting day of the scheme. All 303 families in the six MAR-locations were invited to participate in the study. In addition, six other villages were randomly selected from the remaining 19 villages on the “waiting list”. All households in these villages (or a randomly selected maximum of 60 households in villages with more than 60 households), comprising an additional 321 families, were invited (Supplemental Material, Figures S2 and S3).

Each adult within the selected households was numbered following the Kish-grid method (Kish 1949): one adult household member was then invited for participation in the study. Invitees
were excluded if not able to meet the data collector within 7 days following the first visit and were then replaced by a household member of the same sex (if possible) and closest in age. During the initial recruitment visit, data collectors explained the aim of the study, reasons for selection, future use of proposed data collection, as well as the procedures and timeframe for participation. After answering questions of the potential participants, written informed consent was obtained. Participants were followed up for 15 months during which three measurement rounds were performed. Participants were not paid, but were offered a free health consultation from local health assistants. Blinding for source was not possible, but data collectors and participants were unaware of sodium concentrations measured during the study. A total of 624 participants were invited to the study of which 581 (93%) took part.

Baseline data were collected in March 2013; first follow-up data in March 2014; and a second round of follow-up data in May 2014.

Data collection – at the participant’s house – included systolic and diastolic BP, sodium concentration of each drinking water source used and anthropometry. Interview data about lifestyle and environmental exposures were collected using an adapted version of the Non-Communicable Disease Risk Factor Survey Bangladesh (World Health Organization 2011b), which was pretested prior to data collection. Furthermore, participants were asked about (family) history of hypertension and cardiovascular disease (see Supplemental Material, “Confounders and effect modifiers” for full list of covariates). BP was measured in the left arm (resting, with palm up) using an arm-type fully automatic sphygmomanometer type H1209 with an Accumax arm-cuff. Data collectors were trained using the WHO STEPS-protocol (World Health Organization 2005). Participants were asked to refrain from eating, drinking and hukka/gul (smokeless tobacco) use during the interview. For religious reasons bare skin measurements were not always possible and alternatively performed on thin and non-constrictive clothing. If the first two BP measures differed by at least 10/6 mmHg...
systolic/diastolic BP, a third measurement was taken and the first discarded. A 3-minute break was observed between BP readings.

Samples of drinking water were collected after the interview. Each source consumed by the participants over the previous 2 weeks was sampled, using a 250ml plastic sampling bottle. Effects of changes in (drinking water) sodium intake on BP were expected to be measurable after a few days up to a few weeks (Law et al. 1991; Van Vliet and Montani 2008), hence participants were asked about the amount they had been drinking from each sampled source in the past two weeks, and on which specific days: based on this information a weighted average of sodium exposure could be calculated in the case that multiple sources were consumed in the “window-period”. In addition, cooking water sources (if different from drinking water sources) were sampled. The data collectors took care not to touch the bottle neck with their fingers. First, the bottle was rinsed with water from the source to be sampled. When a water sample had to be taken from an open water body, the data collector used the bucket/cup from the family or - if not available - a small sampling cup. This cup was then attached to a rope and immersed into the water source, pulled up and emptied into the sample bottle. All bottles were immediately sealed, labelled and placed in an icebox.

Spot urine samples were collected from all participants and 24h urine samples from a random subsample of participants (n=57). This enabled development of an algorithm to estimate 24h sodium excretion – usually regarded as a more accurate proxy for sodium consumption – from morning spot urine samples, based on earlier algorithms developed by Brown et al (Brown et al. 2013), taking into account age of the participant as well as potassium and chlorine concentrations in the spot sample (Scheelbeek, 2015). Response rate was 100%, but with two participants the 24h urine volume was less than 500ml and these collections were disregarded.
Drinking water sodium concentrations were measured by Atomic Absorption Flame Photometry method with Air-Acetylene flame (Supplemental Material, “Confounders and effect modifiers”) and multiplied by self-reported water volume intake in glasses per day; data collectors measured volume of presented glasses. Eighteen volunteers agreed to participate in a sub-study to assess the accuracy of self-reported drinking water volume; they poured a glass of water in a container for each glass drunk. No material differences were observed between reported and actual fluid intake. Sensitivity analysis was performed using average fluid intake in order to assess any significant differences in the models by comparing the use of these two methods of estimating fluid intake. Arsenic concentrations in tube well water - which plays an important role in water availability and water related burden of disease in other parts of Bangladesh (Chen et al. 2011; Smith et al. 2000) - is low in tube wells located in study villages. A nationwide survey (DPHE and BGS 2001) revealed that in the study area the arsenic levels of nearly all tube-wells fell within the WHO guideline of 10 µg/l (World Health Organization 2011a) and all within the national guideline of 50 µg/l (DPHE 2016) and was hence not measured in the samples collected for this study.

We estimated dietary sodium from questionnaire data combined with sodium measurements from 20 local dishes. However, since there was limited correlation between dietary sodium and spot urine sodium concentration (r=0.21), we also calculated the dietary component by subtracting estimated water sodium intake from estimated 24h urinary sodium excretion. Sensitivity analysis showed some significant differences between both methods: the latter method was more accurate and was used for further analysis.

Details on confounders, effect modifiers, sample collections and calculations of the intra-cluster correlation coefficient are given in the Supplemental Material, “Confounders and effect modifiers” and “Intra-Cluster Correlation Coefficient”.
We collected a complete set of baseline data, information on confounders and effect modifiers for 581 individuals: 93% of all people invited to the study. Of these, 521 (83%) took part in the first follow-up a year later, of whom 14 were interviewed away from their home, so no water sample could be collected; 507 participants (81%) were visited in the second follow-up (two months after the first follow-up) of whom 5 were interviewed away from the home. All data collected at each of the data points were used in the statistical models (up to three measurements per individual). Study design and a flow chart with recruitment data are shown in Supplemental Material, Figures S2-S4. A (pseudo) experimental design – with MAR as the intervention – was ruled out in the design stage of the study as drinking water sodium levels in MAR systems (measured in neighbouring areas) showed large variations and did not consistently offer a lower sodium alternative to pond or tube well water for the population.

The main outcomes in this study were systolic and diastolic BP (mmHg). Hypertension and was considered a secondary outcome. The latest definition of hypertension, developed by the Joint National Committee, was used (James et al. 2014): systolic/diastolic blood pressure >140/90 for people below the age of 60 and 150/90 for those 60 and older. The main exposure for BP related outcomes was drinking water sodium concentration.

We used Generalised Linear Latent And Mixed Models (GLLAMMs) to analyse association between blood pressure and drinking water salinity over the three measured time-points. As the study was conducted in field settings GLLAMMs were preferred to Generalised Linear Mixed Models (GLMM) as this would allow us to account for unmeasured heterogeneity: GLLAMMs allow latent variables to be both discrete or have a (multivariate) normal distribution. (Skrondal and Rabe-Hesketh 2003). We used three consecutive regression models: Model 1 adjusted for age and sex; Model 2, in addition, adjusted for physical activity, body mass index and smoking; Model 3 included Model 2 variables plus demographic factors, socio-economic status, environmental and weather exposures (such as temperature), underlying
diseases, education, religion, use of local stimulants, exposure to chemicals (such as pesticides) and estimated dietary salt intake. (Supplemental Material, “Confounders and effect modifiers”).

One random effect per participant was used, and the models also accounted for the geographical location of the participants, assigning one random effect per village and sub-region. Models were used to identify the average effect of each 100 mg/l decrease of water salinity over all participants and measurement periods. The linear predictor (υ) in the GLLAMM was specified as:

\[ \eta_{ij} = x_{ij} \beta + \sum_{d=d_0}^{d_h} \sum_{m=1}^{M} \eta_{ij}^{(d)} C_{mij} \]

where \( x' \) is the drinking water sodium concentration, \( \beta \) the fixed effect parameter and \( i,j,k \) represent the three model levels (individual, village and sub-region); \( d_0 \) corresponds to the baseline data collection round; while \( d_h \) is the last data collection round (follow-up 2); the second term of the linear predictor is a collection of random effects, where \( \eta \) is the vector of latent variables and \( C_m \) the confounders that were adjusted for in each model.

We used Mixed-effect Logistic Regression Models (MLRM) to analyse the odds of hypertension related to decreases in sodium concentration for all participants over the three measurement points. One random effect per person was used in both models as well as per village and sub-district.

In order to further explore the relationship between changes in drinking water salinity and BP, an additional analysis was performed to assess the differences in sodium concentrations and associated differences in blood pressure for each individual (comparing baseline to follow-up 1 and follow-up 1 to follow-up 2). Prior to data collection it was decided to allocate all
participants experiencing a decrease in their drinking water sodium of 200mg/l or more between two time points (approximately 500mg sodium intake through water per day, based on 2.5 litre estimation of intake) to a “sodium decrease” group (dNa). Those who experienced no or minor changes in sodium concentration (between -200 and +200 mg/l) were allocated to the “reference group” and those that experienced an increase in sodium more than 200mg/l were allocated to the “sodium increase” group (iNa). The three groups represented three hypothetical situations: A “do nothing scenario” (an expected increase in salinity in the future), a business-as-usual scenario (representing the current situation), and an “intervention scenario” (successful rollout of low-salinity drinking water options), respectively. For this within-person analysis we used GLMMs to analyse differences in BP with respect to changes in drinking water sodium scenarios, using the same three-step modelling approach as described above.

As participants changed drinking water source at different periods during the study period, some crossed-over between sodium-change and/or control groups when comparing two consecutive years, and two measurements in the same dry season respectively. Sensitivity analysis was performed including and excluding participants with various combinations of crossover patterns.

Analyses were performed in STATA® version 13.1 (StataCorp. 2013) and R-Studio version 3.0.1 (RStudio 2012).

**Results**

Baseline characteristics for all study participants and stratified per baseline sodium concentration are shown in Table 1. Participants drinking water with low sodium concentrations were more often from a higher socio-economic class and on average more educated than participants drinking water with higher sodium concentrations; also a significant
difference was found in physical activity between low, intermediate and high sodium water drinkers. Those drinking low sodium water at baseline were more likely to be former smokers.

The sodium measurements showed high sodium concentrations in several drinking water sources including some of the MAR sources, however, with large variation within each type of source (Figure 1). We found a gradual concentration increase over the course of the dry season. Median sodium concentrations of pond and MAR sources were approximately 400 mg/l towards the end of the dry season, whereas median sodium concentrations in tube wells exceeded 800mg/l. Again, we found extremes above 1500mg/l (Figure 2). Some rainwater users mixed their rainwater with water from other sources to prolong the period of rainwater use: towards the end of the dry season only those with large storage space (and hence likely to consume unmixed rainwater) still reported rainwater as main drinking water source: this explains the high outliers in sodium concentrations in “rainwater” in the early dry season measurements.

Adjusted generalised linear and latent mixed models showed significantly lower systolic and diastolic blood pressures with decreasing drinking water sodium concentrations: after adjustments for several confounding factors the models showed that per 100mg/l lower sodium in drinking water, systolic BP was lower on average by 0.95 mmHg [0.71, 1.20] and diastolic blood pressure was lower on average by 0.57 mmHg [0.38, 0.76]. Small differences were observed between men and women (Table 2)

Mixed effect logistic regression models showed that per 100 g/ml lower sodium concentration in drinking water the odds of hypertension were lower by 13.8% (7.4, 20.6) (Table 3).

The results of the GLMMs analysing “sodium difference” groups showed – in the between-year comparison – a significant decrease in the dNa group and a significant increase in blood pressure in the iNa group compared to those that did not experience changes in sodium
concentration. Differences were smaller in the within-year comparison. Further details can be found in Supplemental Material, “Results Generalised Linear Mixed Models”, Tables S1 and S2, and Figure 5.

Discussion

Our study confirms that sodium concentrations in ponds, tube wells and some MAR systems are extremely high: a problem hypothesised to be partly related to climate change. We found evidence for a direct relationship between drinking water sodium and BP: moreover, the sodium group analysis suggests reversibility of BP response if an alternative lower salinity source of drinking water is used instead of a high-saline source. The results are in line with previous dietary sodium (reduction) studies, though the effect for water sodium found here is somewhat larger than has been reported for food sodium (Elliott et al. 1996; He et al. 2013; Pietinen et al. 1988; Sacks et al. 2001). This might be partly explained by the way imbibed sodium is absorbed in the body compared to sodium consumed through food (Lifshitz and Wapnin 1985). The absorption mechanisms from water have been investigated, for example in the context of optimizing rehydration for athletes, mostly in studies with small sample sizes and low study power. (e.g. (Shirreffs et al. 1996)). It has been hypothesised that sodium absorption mechanisms depend on its concentration in the rehydration solution (water) and differ from absorption mechanisms following rehydration through (sodium-rich) foods (Lifshitz and Wapnin 1985; Shirreffs et al. 1996). The greater between-year than within-year differences may indicate that the effects of high drinking water sodium on BP are relatively long lasting.

The observed decreases in BP in the dNa group are also in line with previously conducted food sodium studies: successful lowering of BP through decreased salt intake from foods has been extensively documented in several randomized controlled trials [e.g.(He et al. 2013)]. Animal
studies have looked at reversibility of BP changes through manipulation of sodium in drinking water and found similar results (Lenel et al. 1948; Sapirstein et al. 1950).

This is the first cohort study on drinking water sodium and blood pressure in (non-pregnant) adults in a salinity-affected coastal area. Although several other studies on drinking water sodium were carried out in in the last 3 decades of the 20th century - mainly analysing the salinizing effect of certain water softeners [e.g. (Calabrese and Tuthill 1985; Hofman et al. 1980; Luft et al. 1990; Schorr et al. 1996; Tuthill and Calabrese 1989)] – these studies evaluated much lower sodium concentrations. Furthermore, these studies looked at “man-made” drinking water salinity, whereas in this study we address a serious environmental health problem. The high drinking water sodium concentrations described here are of particular importance, as they affect millions of people living in poor coastal areas, in which often no or very limited alternative sources are available for consumption.

The strengths of our study include the ‘real world’ setting and the addition of a pseudo-experimental design to examine the effects on BP of a low-cost and practicable method to reduce salinity of drinking water. Although the study was done in South-West Bangladesh, findings may be more widely generalizable to other deltaic areas in South-East Asia (Hoque et al. 2016; Hoque and Butler 2015).

Previous studies in Bangladesh – where arsenic pollution plays an important role – have linked drinking water arsenic to cardiovascular diseases and mortality (Chen et al. 2011) but mixed results were found regarding the association between arsenic exposure and hypertension (Abhyankar et al. 2012; C-J Chen et al. 2007; Y Chen et al. 2007). In our study area, arsenic levels in drinking water were generally low and it was hence very unlikely that arsenic formed a confounder in the detected association between drinking water sodium and blood pressure. The implications of the results presented, however, are not limited to low-arsenic areas: in high-
arsenic coastal areas, the salinity problems as described above would complicate the search for safe drinking water alternatives if people want to change from a high-arsenic water sources to a safe, low-arsenic alternative.

Limitations of the study include the non-random selection of participants exposed to different concentrations of drinking water salinity and its open (unblinded) nature, which could have led to selection and other biases. Villages were selected on pragmatic grounds (see Methods), in locations with a broad range of (changing) drinking water salinity concentrations. Participants drinking from water sources with relatively low sodium concentrations were more likely to be better educated and have a higher socio-economic status and more likely to do less physical activity than participants drinking from high saline source, which could have confounded the relationship between drinking water salinity and blood pressure. However, all models were adjusted for these factors and results did not change significantly from the crude models. Diet is reasonably homogeneous in the study region and neither socio-economic status nor education or physical activity were associated with estimated food salt intake. Furthermore, we found an effect of water sodium changes in within-year analyses, which are not subject to the same potential biases (for example in physical activity) as comparisons between years. This study did not control for the concentration of specific anions attached to sodium, such as chloride or bicarbonate: certain sodium-anion combinations have been hypothesised to have a smaller effect on blood pressure than sodium-chloride (Hoque and Butler 2015); the bicarbonate anion has even been hypothesised to have a blood pressure lowering effect (Hildebrant et al. 1986; Luft et al. 1990; Morgan 1982; Santos et al. 2010). The concentrations of sodium bicarbonate was found to be higher in tube-wells as compared to ponds (Hoque and Butler 2015); the influence of anions should therefore be explored to more accurately quantify the association between the drinking water salinity and blood pressure in several different sources.
BP measurements were not always taken on the bare skin and could have affected the accuracy of the measurements, however several studies assessing this issue did not find a difference between bare skin or sleeved measurements [e.g. (Eder et al. 2008; Ma et al. 2008)]. Furthermore, it is unlikely that this have led to bias in the association between salinity and blood pressure, since non-bare skin measurements are not associated with drinking sources. Assessment of water intake was based on self-reporting and could have led to misclassification, but a cross-validation of self-reported and actual intake in a group of volunteers did not show important over- or under-reporting of volume intake (see Methods). Estimation of dietary sodium intake had limited accuracy, as it was based on 24h urinary levels imputed from spot urine samples using an algorithm developed in a subsample who had both spot and 24h urine measurements (see Methods). However, this is not likely to have led to differences between groups. Drinking water jars were commonly cleaned with potassium-rich wood ash: this lead to greatly varying potassium concentrations in stored drinking water depending on cleaning frequency. Since water samples were only measured once per measurement period, it was not possible to estimate individual daily potassium intake. However, it is unlikely that drinking water potassium would have played an important role in the study area as measurements in the area revealed median potassium levels of 30mg/l (Hoque and Butler 2015) This would form approximately 2% of the recommended daily intake of 3510 mg/day (World Health Organization 2012a), when consuming 2.5 litres of drinking water per day).

The three comparison groups represent plausible scenarios of what may happen in coastal areas affected by climate change in the future. The group with stable sodium concentrations reflect the current situation. The other two groups show possible future scenarios: first, that of intervening and providing saline-low drinking water alternatives (dNa), and second (iNa) a “do-nothing” scenario, in which people will experience increases in drinking water sodium levels over time. Based on future predictions (Hijioka et al. 2014; Singh et al. 2000), small
scale modelling (Hoque et al. 2016) indicated that salinity levels in Khulna and similar coastal areas in South-East Asia are likely to continue to increase, though the size of this increase is difficult to quantify.

According to Cook et al., an increase of 1.9 g of dietary salt is associated with a 32% increase in stroke risk (Cook et al. 2007; Cook et al. 2014). An increase in drinking water sodium in Bangladesh of 250 mg/l (0.6 g/l salt) – due to exacerbation of salinity problems – would lead to this additional 1.9 g of salt intake, solely through drinking water. A systematic review (Aburto et al. 2013) indicated that reduction of dietary sodium intake below 2 g/d would lead to a fall in systolic/diastolic BP of 3.47/1.81 mmHg, associated with a 19% reduction in stroke risk, a 39% decrease in stroke mortality and a 42% decrease in coronary heart disease mortality.

As we found a stronger effect on BP for sodium consumed through water than through food, this may translate into a larger sodium-related morbidity and mortality in salinity affected areas than would be predicted from the above.

We also documented the limitations of currently available approaches to reducing drinking water salinity. The MAR sites used in this study had variable effects across locations (Figure 2), in some cases resulting in higher sodium levels. This reflected the fact that in many instances pond water, in addition to rainwater, was used to recharge the aquifer. The higher salinities of the pond water, in turn, affected the performance of the MAR: MAR could therefore not be considered as a reliable low-saline alternative to conventional sources. Assessment of salinity mechanisms in MAR-systems and improvement of the construction - currently carried out by several research groups in Bangladesh - will guide further improvements of MAR for future implementation and use.
All measured private and communal rainwater harvesting sources were low in salinity, however the effectiveness of rainwater harvesting as an adaptation strategy is limited by the capacity to safely store sufficient freshwater until the end of the dry season.

Conclusions
Drinking water sodium is an important source of daily sodium intake, and therefore a risk factor for increased BP in salinity prone coastal areas. This adds to the cardiovascular health risks associated with food sodium intake in Southeast Asian populations: in Bangladesh, 20% of all stroke deaths are attributable to high sodium diets (Institute for Health Metrics and Evaluation (IHME) 2015). Current predictions estimate an increase of salinity concentrations in drinking water in these areas for the future, and prompt action is required. Low-saline alternative drinking water sources could effectively help prevent high BP and hypertension-related morbidity and mortality in these coastal populations: new technologies for the supply of such alternative sources, including safeguarding the microbial quality, should be further studied.

References


StataCorp. 2013. Stata statistical software: Release 13., (Station C, ed). TX:StataCorp LP.


Table 1: Baseline characteristics of all study participants and stratified by drinking water sodium concentrations

<table>
<thead>
<tr>
<th>Drinking water sodium concentration at baseline</th>
<th>&lt;200mg/l (n=210)</th>
<th>200-500mg/l (n=220)</th>
<th>&gt;500mg/l (n=151)</th>
<th>All (n=581)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (%)</td>
<td>50.3</td>
<td>49.0</td>
<td>41.5</td>
<td>47.4</td>
<td></td>
</tr>
<tr>
<td>Hours physical work/day (median)</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Work related physical activity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light/sedentary work (%)</td>
<td>23.2</td>
<td>18.6</td>
<td>12.2</td>
<td>18.9</td>
<td>0.001*</td>
</tr>
<tr>
<td>Moderately heavy workload (%)</td>
<td>44.4</td>
<td>46.8</td>
<td>53.5</td>
<td>47.6</td>
<td></td>
</tr>
<tr>
<td>Heavy workload (%)</td>
<td>32.3</td>
<td>34.6</td>
<td>34.3</td>
<td>33.6</td>
<td></td>
</tr>
<tr>
<td>Body Mass Index (mean)</td>
<td>21.3</td>
<td>20.5</td>
<td>20.7</td>
<td>21.4</td>
<td></td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked (%)</td>
<td>70.7</td>
<td>75.8</td>
<td>73.9</td>
<td>73.6</td>
<td>0.044*</td>
</tr>
<tr>
<td>Former smoker (%)</td>
<td>10.5</td>
<td>3.5</td>
<td>3.9</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>18.8</td>
<td>20.7</td>
<td>22.3</td>
<td>20.4</td>
<td></td>
</tr>
<tr>
<td>Marital Status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married (%)</td>
<td>82.3</td>
<td>88.4</td>
<td>89.2</td>
<td>86.5</td>
<td></td>
</tr>
<tr>
<td>Single (%)</td>
<td>8.8</td>
<td>5.6</td>
<td>6.9</td>
<td>7.1</td>
<td></td>
</tr>
<tr>
<td>Separated/Widow (%)</td>
<td>8.8</td>
<td>6.1</td>
<td>3.9</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>Religion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muslim (%)</td>
<td>37.0</td>
<td>42.6</td>
<td>32.3</td>
<td>38.2</td>
<td></td>
</tr>
<tr>
<td>Hindu (%)</td>
<td>63.0</td>
<td>57.4</td>
<td>67.7</td>
<td>61.8</td>
<td></td>
</tr>
<tr>
<td>Size of Household (mean)</td>
<td>4.4</td>
<td>4.3</td>
<td>4.2</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No education/illiterate (%)</td>
<td>25.4</td>
<td>22.1</td>
<td>20.0</td>
<td>22.9</td>
<td>0.007*</td>
</tr>
<tr>
<td>Primary school (%)</td>
<td>23.2</td>
<td>34.7</td>
<td>43.1</td>
<td>32.6</td>
<td></td>
</tr>
<tr>
<td>Secondary school or higher (%)</td>
<td>51.4</td>
<td>43.2</td>
<td>36.9</td>
<td>44.5</td>
<td></td>
</tr>
<tr>
<td>Socio-economic status</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest Tertile (%)</td>
<td>35.9</td>
<td>38.4</td>
<td>30.0</td>
<td>35.4</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Intermediate Tertile (%)</td>
<td>19.3</td>
<td>34.9</td>
<td>45.4</td>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>Highest Tertile (%)</td>
<td>44.8</td>
<td>26.8</td>
<td>24.6</td>
<td>32.6</td>
<td></td>
</tr>
<tr>
<td>Salt intake per adult family member (g/month Na+Cl− [mean])‡</td>
<td>123</td>
<td>120</td>
<td>120</td>
<td>121</td>
<td></td>
</tr>
</tbody>
</table>

* Pearson Chi-square test
† Based on total salt used by the family per month / number of adult family members
Table 2: Generalised linear latent and mixed models (GLLAMM) for systolic and diastolic BP per 100 mg Na/l lower water salinity (covering baseline, follow-up 1 and follow-up 2 measurements for each participant; one random effect per person, village and sub-district)

<table>
<thead>
<tr>
<th></th>
<th>Model 1: Adjusted for age &amp; sex</th>
<th>Model 2: Adjusted for age, sex, physical activity, smoking, BMI</th>
<th>Model 3: Adjusted for multiple confounders *</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 2:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Model 3:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Diff. in BP</strong></td>
<td><strong>P-value</strong></td>
<td><strong>95% CI</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>Diff. in BP</td>
<td><strong>P-value</strong></td>
<td><strong>95% CI</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>Systolic BP</td>
<td><strong>P-value</strong></td>
<td><strong>95% CI</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>100mg Na/l decrease</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(All)</td>
<td>-0.89</td>
<td>&lt;0.001</td>
<td>-1.14 / -0.64</td>
</tr>
<tr>
<td>Women</td>
<td>-0.92</td>
<td>&lt;0.001</td>
<td>-1.25 / -0.55</td>
</tr>
<tr>
<td>Men</td>
<td>-0.93</td>
<td>&lt;0.001</td>
<td>-1.28 / -0.58</td>
</tr>
<tr>
<td><strong>Diastolic BP</strong></td>
<td><strong>P-value</strong></td>
<td><strong>95% CI</strong></td>
<td><strong>P-value</strong></td>
</tr>
<tr>
<td>100mg Na/l decrease</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(All)</td>
<td>-0.45</td>
<td>&lt;0.001</td>
<td>-0.64 / -0.26</td>
</tr>
<tr>
<td>Women</td>
<td>-0.38</td>
<td>0.006</td>
<td>-0.66 / -0.11</td>
</tr>
<tr>
<td>Men</td>
<td>-0.49</td>
<td>&lt;0.001</td>
<td>-0.76 / -0.23</td>
</tr>
</tbody>
</table>

* Adjusted for age, sex, physical activity, smoking status, BMI, maximum daily temperature, underlying disease, marital status, religion, number household members, education, use of paan, hukka and gul, water treatment, dietary salt intake, socio-economic status, exposure to insecticides and chemical manure and important changes in life.
Table 3 - Mixed logistic regression models for hypertension per 100mg Na/l lower water salinity (covering baseline, follow-up 1 and follow-up 2 measurements for each participant; one random effect per person, village and sub-district)

<table>
<thead>
<tr>
<th></th>
<th>Model 1: Adjusted age &amp; sex</th>
<th>Model 2: Adjusted age, sex, physical activity, smoking, BMI</th>
<th>Model 3: Adjusted for multiple confounders *</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR</td>
<td>P-value</td>
<td>95% CI</td>
</tr>
<tr>
<td>Hypertension (All)</td>
<td>0.901</td>
<td>0.005</td>
<td>0.84 / 0.97</td>
</tr>
<tr>
<td>Women</td>
<td>0.877</td>
<td>0.011</td>
<td>0.79 / 0.97</td>
</tr>
<tr>
<td>Men</td>
<td>0.909</td>
<td>0.075</td>
<td>0.82 / 1.01</td>
</tr>
</tbody>
</table>

* Adjusted for age, sex, physical activity, smoking status, BMI, maximum daily temperature, underlying disease, marital status, religion, number household members, education, use of paan, hukka and gul, water treatment, dietary salt intake, socio-economic status, exposure to insecticides and chemical manure and important changes in life.
Figure 1: Description of a Managed Aquifer Recharge System
Figure 2: Sodium Concentration (mg/l) per source and per measurement period (Rain, Pond, Managed Aquifer Recharge [MAR] and Tube Well [TW])
Supplemental Material

Drinking water salinity and raised blood pressure: evidence from a cohort study in coastal Bangladesh

Confounders and effect modifiers

Physical activity was determined by job-related physical activity and any additional self-reported physical activity that the respondents carried out in their leisure time. Respondents were asked how many hours they worked per day, in what type of activities they were involved and whether it changed a lot over time (i.e. whether it was a day-to-day or unusual activity). For each activity type, energy use per hour was estimated based on the compilation of energy expenditures by Vaz et al 2005 [1]. For each reported type of activity a “match” was sought in the tables compiled by Vaz et al; it was attempted to match mostly on tables from countries with similar climatological conditions (India, Burma, and other areas in Bangladesh) and where possible use figures based farmer communities. Some inaccuracies were expected, as studies were done among participants in other settings. Therefore, each activity was categorised as low-, medium or high intensity (cut-off points: <150 kcal/h; 150 – 300 kcal; >300kcal) with an allocated activity score of 1, 2, and 3 respectively. Each of the expenditure scores were than multiplied by the number of hours and minutes self-reported execution of these activities to calculate the total physical activity score. As also some inaccuracy was expected in the number of hours reported, final scores were grouped into 4 categories, classifying the participants as non-, low-, medium or highly active. Weight was measured with an analogue scale (Yamasa TY6). The scale was calibrated prior to the baseline and again prior to follow-up 1. Participants were asked to remove any (heavy) coats or jumpers. Weight was rounded to the nearest 0.5 kilogram. Height was measured with an aluminium tape-measure. The data collectors were instructed to find the combination of a flat floor and a straight wall to be able to accurately measure height. Measurements were rounded to the nearest 0.5 cm. Upper arm circumference was measured with a measuring tape. Participants were asked to remove any thick coats or jumpers if they could not be rolled up enough. Upper arm circumference was rounded to the nearest 0.1 cm. Anthropometric data were obtained only at baseline. Weather data were obtained from the Bangladesh Meteorological Institute on a daily basis for the entire study period, including the two weeks prior to the first baseline measurements. All reported underlying diseases were confirmed with the administrative books of the Health Assistants (HAs) themselves – if it did not appear in their books it was up to the judgement of the HA to declare the reported diseases as plausible or reliable. Socio-economic status was determined by collecting data on land ownership, type of house and roofing, as well as ownership of certain goods, such as a TV, motor cycle and bicycle, which were later used for a principal component analysis per location to determine for each participant whether they were from a relatively high, an intermediate or lower socio-economic class. Food history data for 3 days prior to the interview day were taken to estimate dietary salt intake. Furthermore, food samples were taken from 27 locations (2x12 households and 3 restaurants) for the 16 main dishes consumed in the study and analysed in the Nutrition and Food Science Laboratory from the Dhaka University. All data collectors were instructed to find two samples of each of the items on the list from participant or non-participant households in their study site. Convenience sampling was used: just before lunch time (which varied by Upazilla), families around the household
that was last interviewed were asked if they had food ready, and whether they agreed to the data collectors measuring portion size and taking a sample of each food item/dish. Subsequently neighbours were asked if they had prepared other items from the 16 “main dishes” list. Due to time constraints not all items were collected twice for each study site. Also, 7 samples were obtained from restaurants. Results were used to assign an estimated sodium content to each reported dish in the participants’ dietary recall data. The list of 16 main dishes was also to simplify the recording of dietary histories. **Added salt** was reported in “pinches” per meal. A pinch was considered as 0.25 g of salt (0.1 g sodium). **GPS coordinates** were measured with a handheld GPS device (Garmin eTrex 10). Minimum accuracy of 3 meters was observed. All coordinates were documented in the WGS-1984 format (hd.ddddd).

**Sample collection**

**Urine samples**
To obtain spot urine samples, participants were asked to collect urine in a small sample pot. They were instructed to fill the sample pot up to the indicated line. Sample pots were labelled prior to sample taking and firmly sealed immediately after the participant returned the pot, and placed in an ice-box. Participants selected for the 24h urine collection were asked to collect their urine for 24 hours on the day prior to the interview. In a pilot study – conducted prior to the cohort study – participants were asked to discard the morning urine, however this was often misunderstood/ not correctly practised and often two morning samples were collected in a 24h period. Therefore protocols were changed: participants collected all urine from the morning onwards, and were asked to completely empty their bladder before they went to sleep in the evening. The importance of the completeness and proper collection was strongly emphasized by the data collectors. Participants received a cup and 24 hour container as well as a polystyrene box, to keep the 24-h urine container cool and avoid spillage. Samples were collected the following day by the health assistants when they came back for the interview.

**Food samples**
Food samples were taken just before lunch time, when families finished their cooking process. At each sample point, family members were asked to serve themselves a plate, a bowl, big spoon, etc. of the dish they prepared. This was then weighed on a digital kitchen scale (Topwe, sx-7001). Subsequently a small sample (± 5 grams) of each dish was collected in a clean plastic box and placed in an ice-box. An average weight/volume was assigned to each unit size - bowl, plate, big spoon, small spoon and piece of the 16 main dishes. Also, an estimated sodium content was determined for each dish.

**Transport and analysis of samples**

**Water samples**
After collection, water samples were transported to the study office in Dacope, where they were kept at room temperature in a polystyrene box. In the same box they were transported to the laboratory in the Department of Geology, Dhaka University, where they were analysed. Sodium and potassium concentrations were measured using the Atomic Absorption Flame Photometry (direct aspiration) method with Air-Acetylene (oxidizing) flame.
**Urine Samples**

After collection of the urine samples, they were immediately transported in an ice-box (approximately 10°C) to the study centre in Dacope and stored at 4°C. A laboratory technician homogenised the 24h-specimen using a glass rod, and measured and recorded the total volume. He kept aside 10 ml of each sample for further analyses. From there the specimens were transported in a cool-box (approximately 4°C) to the clinical biochemistry laboratory of the International Center for Diarrhoeal Disease Research Bangladesh (icddr,b) for analysis. Urinary sodium and potassium were measured by indirect Ion Selective Electrode method (ISE). The lab used an automated biochemistry analyser (Beckman Coulter AU-680), which automatically dilutes the sample and potentiometrically determines the ion-activity of K+, Na+ and Cl-. Individual 24-hr sodium excretion values were calculated as the product of concentrations in urine and the total urine volumes, measured in millimoles per day (mmol/d). Spot urine samples were collected after each interview and the same procedures were followed for analysis of urinary sodium and potassium concentrations.

**Food Samples**

Food samples were all collected on the same day and transported within 12h in an icebox (approximately 10°C) to the Nutrition and Food Science Laboratory at the University of Dhaka. On arrival they were directly stored in a freezer at -20°C. All samples were analysed in the following week using photoelectric flame photometry.
Intra-Cluster Correlation Coefficient

The intra-cluster correlation coefficient (ICC) for the selected sites was estimated based on a previously conducted case control study [2]. Blood pressure for 534 women of 24 villages over 9 unions were analysed and within and between village variations in BP values were calculated. A description of the villages and the protocols for BP measurements are described by Khan et al [2]. There were three new villages included in this study that were not part of the previous study, hence could not yet be included in the ICC calculations as no (representative) BP data were available. They were however situated in the same unions as some other villages. ICC of villages and unions showed very similar results: ICC=0.066 and 0.064 respectively. Therefore, an ICC of 0.065 was used for power calculations. It should be noted that these calculations were based on data on pregnant women and may under- or overestimate the ICC for non-pregnant adults.

Standard deviations of previously collected blood pressure means were used (9.2 and 6.1 mmHg – for SBP and DBP respectively) together with the expected changes in blood pressure, and calculated ICC to estimate power to detect a change for various significance levels.
Results Generalised Linear Mixed Models

The dNa group had the highest proportion of Hindu and the lowest proportion of people of low socioeconomic status compared with the other two groups, but there were no differences in job related physical activity or dietary salt intake between groups (Table S1).

In the between-year comparison, the median increase of sodium in the iNa group was 363 mg/l (IQR 288/1023 mg/l), compared to the control group. The median decrease in the same period for those in the dNa group was 248 mg/l (IQR -368/-223). In the controls sodium levels changed marginally (-27 mg/l [-118/-1]). In the within dry-season comparison the corresponding numbers were 524 (271/748), -308 (-690/-307) and 30 (4/108) respectively (Table S2).

Data were analysed using GLMMs. With adjustment for multiple potential confounders (Model 3, see Methods main article), compared to the control group, systolic BP of individuals in the dNa group dropped on average by 8.61 (-12.74 /-4.91) mm Hg (Figure S2.1), and for those in the iNa group, it rose on average by 8.48 (4.21/12.74) mm Hg. Similar patterns for diastolic BP changes were found: for those in the dNa group, compared to the controls, diastolic pressure dropped on average by 3.19 (-5.96/-0.41) mm Hg, while in the increased sodium group it rose by 7.05 (3.72/10.38) mm Hg. Also, for the within-dry season comparisons, increasing and decreasing salinity levels were associated with significant changes in systolic and diastolic BP (Figure S5).

These associations remained significant when sensitivity analysis was performed excluding participants who switched between dNa, iNa and the control group between measurements. Associations did not alter significantly when using water sodium consumption estimates based on average water intake instead of person specific (self-reported) water intake in the models.
Table S1: Baseline characteristics participants

<table>
<thead>
<tr>
<th></th>
<th>dNa (n=114)</th>
<th>Controls (n=330)</th>
<th>iNa (n=63)</th>
<th>All</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (median)</strong></td>
<td>38</td>
<td>37</td>
<td>38.5</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td><strong>Male sex (%)</strong></td>
<td>52.6</td>
<td>45.8</td>
<td>49.2</td>
<td>47.7</td>
<td></td>
</tr>
<tr>
<td><strong>Hours of work per day (median)</strong></td>
<td>7</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td><strong>Physical activity though job</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light/sedentary work (%)</td>
<td>14.3</td>
<td>17.4</td>
<td>8.3</td>
<td>15.5</td>
<td></td>
</tr>
<tr>
<td>Moderately heavy workload (%)</td>
<td>46.9</td>
<td>49.3</td>
<td>46.7</td>
<td>48.5</td>
<td></td>
</tr>
<tr>
<td>Heavy workload (%)</td>
<td>38.8</td>
<td>33.3</td>
<td>45.0</td>
<td>36.1</td>
<td></td>
</tr>
<tr>
<td><strong>Body Mass Index (mean)</strong></td>
<td>21.0</td>
<td>21.7</td>
<td>21.1</td>
<td>21.4</td>
<td></td>
</tr>
<tr>
<td><strong>Smoking</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Never smoked (%)</td>
<td>73.7</td>
<td>74.0</td>
<td>69.8</td>
<td>73.4</td>
<td></td>
</tr>
<tr>
<td>Former smoker (%)</td>
<td>3.5</td>
<td>7.0</td>
<td>6.4</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Current smoker (%)</td>
<td>22.8</td>
<td>19.1</td>
<td>23.8</td>
<td>20.5</td>
<td></td>
</tr>
<tr>
<td><strong>Marital Status</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married (%)</td>
<td>84.2</td>
<td>87.6</td>
<td>85.7</td>
<td>86.6</td>
<td></td>
</tr>
<tr>
<td>Single (%)</td>
<td>9.7</td>
<td>5.8</td>
<td>7.9</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>Separated/Widow(%)</td>
<td>6.1</td>
<td>6.7</td>
<td>6.4</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td><strong>Religion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Muslim (%)</td>
<td>28.1</td>
<td>42.9</td>
<td>31.8</td>
<td>38.1</td>
<td>0.011*</td>
</tr>
<tr>
<td>Hindu (%)</td>
<td>71.9</td>
<td>57.1</td>
<td>68.3</td>
<td>61.9</td>
<td></td>
</tr>
<tr>
<td><strong>Size of Household (mean)</strong></td>
<td>4.2</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td><strong>Education</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No education/illiterate (%)</td>
<td>22.8</td>
<td>24.2</td>
<td>14.3</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>Primary school (%)</td>
<td>28.1</td>
<td>31.5</td>
<td>47.6</td>
<td>32.7</td>
<td></td>
</tr>
<tr>
<td>Secondary school or higher (%)</td>
<td>49.1</td>
<td>44.2</td>
<td>38.1</td>
<td>44.6</td>
<td></td>
</tr>
<tr>
<td><strong>Socio-economic status</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lowest Tertile (%)</td>
<td>22.8</td>
<td>37.9</td>
<td>44.4</td>
<td>35.3</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Intermediate Tertile (%)</td>
<td>49.1</td>
<td>27.0</td>
<td>27.0</td>
<td>32.0</td>
<td></td>
</tr>
<tr>
<td>Highest Tertile (%)</td>
<td>28.1</td>
<td>35.2</td>
<td>28.6</td>
<td>32.7</td>
<td></td>
</tr>
<tr>
<td><strong>Salt intake per adult family member (g/month Na+Cl- [mean])</strong></td>
<td>123</td>
<td>121</td>
<td>117</td>
<td>121</td>
<td></td>
</tr>
</tbody>
</table>

**dNa**: Decreased sodium group (sodium concentration decreased between measurement points)
**iNa**: Increased sodium group (sodium concentration increased between measurement points)
* *Pearson Chi-square test
† Based on total salt used by the family per month / number of adult family members
Table S2: Median drinking water sodium concentration differences between measurement periods for each comparison group

<table>
<thead>
<tr>
<th>Sodium Group</th>
<th>Between-year comparison</th>
<th>Within-year comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median difference in sodium concentration (mg/l)*</td>
<td>Interquartile range (mg/l)</td>
</tr>
<tr>
<td>“Controls”</td>
<td>-27</td>
<td>-118 to -1</td>
</tr>
<tr>
<td>Increased sodium group (iNa)</td>
<td>363</td>
<td>288 to 1023</td>
</tr>
<tr>
<td>Decreased sodium group (dNa)</td>
<td>-248</td>
<td>-368 to -223</td>
</tr>
</tbody>
</table>

* between measurement point 1 and 2
** between measurement point 2 and 3
Figure S1 – Map of the study area (Khulna and sub-districts Paikghaccha, Dacope and Batiaghata)
Figure S2 - Schematic representation of the study design

**Adult men and women from 12 villages**

**Salinity**
- Drinking water sodium of all drinking and cooking water sources – 24h and spot urinary sodium

**BP**
- Sitting systolic and diastolic blood pressure (WHO Steps protocol)

**Confounders**
- Dietary: food sodium, water treatment - Personal /lifestyle: age, sex, physical activity, BMI, smoking status, use of paan, hukka & gul. Chemicals, Stress and underlying disease, Socio-economic proxies: number HH members, Weather data

Mar ‘13  |  Mar ‘14  |  May ‘14
--- | --- | ---
Baseline  | Follow-up 1  |  Follow-up 2
N=581     | N=521        | N=507

N=581     | N=521        | N=507
Figure S3 – Criteria for inclusion of villages and families into the scheme.

223 villages / drinking water sites in Study Area (Dacope, Batiagatha and Paigachha)

195 villages excluded based on “less urgent” water needs

28 villages / drinking water sites selected

3 villages excluded due to lack of acceptability

25 villages / drinking water sites selected

6 villages / drinking water sites with MAR construction during study period &
6 villages randomly selected from remaining 19 MAR priority sites

- **All 303 families** from 6 MAR sites included in the study
- 1 adult per family selected through Kish-grid method

- At each of the other 6 sites: all families recruited to a maximum of 60
- Total **321 families** included
- 1 adult per family selected through Kish-grid method
Figure S4 - Participant flow diagram for baseline and follow-up data collection periods

- **624 participants invited to study**
- **581 participants included in baseline**

**Baseline**
- 21 refusals
- 4 people with recent emotional life event
- 18 people planning to travel outside the area

**Follow-up 1**
- 521 participants*
  - 114 participants with decreased Na
  - 330 participants with no change in Na
  - 63 participants with increased Na
  - *14 with missing water sample

**Follow-up 2**
- 507 participants**
  - 48 participants with decreased Na
  - 316 participants with no change in Na
  - 124 participants with increased Na
  - **5 with missing water sample**
  - *14 missed sample in follow-up 1

**Follow-up 1**
- 8 people contracted serious illness
- 52 lost to follow-up

**Follow-up 2**
- 1 person contracted a serious illness
- 13 lost to follow-up
Figure S5 Changes in blood pressure per sodium exposure group
References
