Drinking Water Salinity Associated Health Crisis in Coastal Bangladesh

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Abstract

Salinity intrusion in coastal Bangladesh has serious population health implications, which are yet to be clearly understood. The study was undertaken through the 'Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation in Populous Deltas' project in coastal Bangladesh. Drinking water salinity and blood pressure measurements were carried out during the a household survey campaign. The study explored association among Socio-Ecological Systems (SESs), drinking water salinity and blood pressure.

High blood pressure (prehypertension and hypertension) was found significantly associated with drinking water salinity. People exposed to slightly saline (1000-2000 mg/l) and moderately saline ($\geq$2000 mg/l) concentration drinking water had respectively 17% ($p<0.1$) and 42% ($p<0.05$) higher chance of being hypertensive than those who consumed fresh water (<1000 mg/l). Women had 31% higher chance of being hypertensive than men. Also, respondents of 35 years and above were about 2.4 times more likely to be hypertensive compared to below 35 years age group. For the 35 years and above age group, both prehypertension and hypertension were found higher than national rural statistics (50.1%) for saline water categories (53.8% for slightly and 62.5% for moderate saline). For moderate salinity exposure, hypertension prevalence was found respectively 21%, 60% and 48% higher than national statistics (23.6%) in consecutive survey rounds among the respondents. Though there was small seasonal variation in drinking water salinity, however blood pressure showed an increasing trend and maximum during the dry season. Mean salinity and associated hypertension prevalence were found higher for deep aquifer (21.6%) compared to shallow aquifer (20.8%).

Localized increase in soil and groundwater salinity was predicted over the study area. Shallow aquifer salinity increase was projected based on modelled output of soil salinity. Rather than uniform increase, there were localized extreme values. Deep aquifer salinity was also predicted to exhibit increasing trend over the period. Study findings and recommendations are suggested for immediate and planned intervention.

Key-words: Drinking Water Salinity, Socio-Ecological Systems, Hypertension, Health, Coastal Bangladesh

Introduction

Human life, livelihood, health and wellbeing are closely linked with local ecosystems. Water is fundamental to all forms of ecosystem services including, provisioning, cultural, regulatory and maintenance; however contaminated water is also one of the major mediums of mortality and morbidity worldwide (UNICEF and WHO, 2015). Climate change and environmental pollution drive health in complex direct and indirect ways and 'water caused diseases' are on the rise- which are linked with degraded water qualities. Salinity intrusion into drinking water and its associated health impact is one such critical issue (McMichael, 2003) with increased blood pressure (BP) or hypertension leading way to cardiovascular diseases (CVD). This is of particular concern for a country like Bangladesh where large coastal population drinks water from sources with elevated salinity level (Vineis et al., 2011).

Anthropogenic activity induced green house gases (GHGs) concentration is increasing in the atmosphere and resultant climate change and sea level rise (CCSLR) is experienced globally- with varied scale and magnitude (IPCC, 2014). The scientific community already agreed that the unprecedented impact will be greatest on human health and natural environment (Watts et al., 2015). Yet the linkage between environment-ecosystem and human health-wellbeing is poorly understood and integrated within research, policy and practice (Ford et al., 2015).

Deltas are unique natural dynamic coastal systems, linked with both land-based fluvial and coastal ocean processes (Pont et al., 2002). Deltaic areas are highly vulnerable to the impacts of climate change and anthropogenic activities; particularly the Ganges Brahmaputra Meghna (GBM) delta in Bangladesh with highest deltaic population in the world (Ericson et al., 2006). Bangladesh is one of the 'iconic' vulnerable countries to the predicted impacts of CCSLR associated changes and extremes - tropical cyclonic storm surges, floods, drought, water-logging, temperature variability and erratic rainfall, etc.; some of which are already documented (CCC, 2009, MoEF, 2009a, MoEF, 2009b).

CCSLR have significant impact on world water resources (IPCC, 2007a, IPCC, 2007b). Coupled with human pressure, local water crises are gradually increasing, with serious implications for public health, environmental sustainability, food and energy security and economic development (UNESCO, 2015). Climate change is very likely to expose large-scale coastal populations to multiple risks with increased intensity and frequency and being a low-lying deltaic country, Bangladesh is prone to the multidimensional health hazards. Salinity intrusion in fresh water and soil is one of many complexities in coastal Bangladesh (Khanom and Salehin, 2012, MoEF, 2009b). The upstream diversion and reduction of fresh water flow in Ganges and Gorai river (Gain and Giupponi, 2014, Mirza, 1998), the expansion of shrimp farming (Johnson et al., 2016) and the increased practice of agricultural irrigation (Yu et al., 2010, Shamsudduha, 2013), along with natural and environmental processes like, river salinity and interaction with ground water, tidal surge and storm surge inundation and water logging, saltwater intrusion, rainfall and evapotranspiration are the major causes of salinity propagation and saline front expansion in the Bengal delta (Rahman et al., 2000, Yu et al., 2010). With gradually pronounced CCSLR impacts, future water resources management are predicted to be quite complex in coastal Bangladesh (BADC, 2013, BWDB, 2013).

In Bangladesh, 97% of the population depends on underground sources for drinking water (Shamsudduha, 2013) and it has been estimated that about 20 million people living along the coast are affected by varying degrees of salinity in drinking water (as cited in (Khan et al., 2011)). Elevated water salinity is linked with direct health outcomes such as hypertension and pre-eclampsia, skin diseases, acute respiratory infection and diarrheal diseases and transmission of mosquito-borne diseases (Talukder et al., 2015). In 2002 the World Health Organization (WHO) recognized health impacts of consumption of highly saline waters as a priority for investigation under its public health initiatives (McMichael, 2003). Higher rates of (pre)-eclampsia and gestational hypertension in pregnant women were observed in the southwestern coast of Bangladesh compared with non-coastal areas, which was hypothesized to be caused by saline contamination of drinking water, with some seasonality effect higher particularly in dry season (Khan et al., 2011). A consecutive population-based study conducted in Dacope, Bangladesh with 202 pregnant women also reported significant association between sodium intake from the drinking water and both (pre)eclampsia and gestational hypertension (Khan et al., 2014). Higher risk of hypertension due to saline water exposure has been found among young adults in coastal Bangladesh as well (Talukder et al., 2016).

WHO identified hypertension or high blood pressure as a silent killer and global public health crisis, accounting for 9 million deaths per year (WHO, 2013). The number of adults with high blood pressure is estimated to reach about 1.56 billion by around 2025 (WHF, 2017) with the highest percentage in low income developing countries (Ibrahim and Damasceno, 2012). Hypertension is an increased risk factor for overall mortality, cardiovascular diseases, myocardial infarction, heart failure, stroke, renal disease, etc (Dennison-Himmelfarb et al., 2013) and is influenced by genetic, medical disorder, lifestyle and environmental factors, primarily by the latter two, which differ between developing and low-income developing countries (Ibrahim and Damasceno, 2012). In Bangladesh, hypertension deaths reached over 16,600 or 2.28% of total deaths. The age-adjusted death rate is 17.92 per 100,000 of population (WHO, 2011a) ranking Bangladesh 77th in the world (WLE, 2014). The National Non Communicable Disease (NCD) risk factors survey found hypertension prevalence high in urban areas and among the male population (WHO, 2011b). Another study suggested around 17.1% of the total population aged 20 years and above are hypertensive (Alam et al., 2013). On the other hand Bangladesh Demographic and Health Survey (BDHS) found hypertension prevalence higher among women (31.9%) than male (19.4%) participants for 35 years and older age group (NIPORT et al., 2013). Three small scale studies done in coastal Bangladesh with pregnant women and young adults suggested an association between drinking water salinity and hypertension (Khan et al., 2008, Khan et al., 2014, Talukder et al., 2016). Interestingly, Rasheed et al. (2014) observed that the coastal population with high salt intake practices showed a low level of awareness of hypertension. A recent systematic review also made inconclusive positive remarks on the association between saline drinking water and increased blood pressure (Talukder et al., 2017).

Though different modifiable factors were identified to influence hypertension, sodium consumption through saline drinking water as potential risk factor of hypertension has not yet been considered in hypertension prevention guidelines (Dennison-Himmelfarb et al., 2013, DGHS, 2013). The WHO guideline value for drinking water salinity is 250 mg of Chloride per liter (mg/l) for Chloride (Cl) and 200 mg/l for Sodium (Na), and is based on taste threshold, not on health consideration. The acceptable level for Chloride adopted by Bangladesh is 1000 mg/l Chloride (Ahmed and Rahman, 2000) for coastal areas. Sodium and chloride remain amalgamated in nature as salt and thus approving increased chloride consumption translates into allowing high sodium intake which is reported to have various health impacts (WHO, 2012). Consumption of saline water and practice of high salt intake from food, made coastal people already prone to increased blood pressure. The present trend of salinity intrusion and future CCSLR impacts will further exacerbate the situation making coastal population highly vulnerable to drinking water associated hypertension.

This study aims to investigate the link between drinking water salinity and associated health crises, more specifically hypertension, in coastal Bangladesh. In addition, we further assess two critical factors in future public health provisioning and water resources management: ground water salinity and population vulnerability.

Methodology

The study was carried out under the framework of 'Assessing Health, Livelihoods, Ecosystem Services and Poverty Alleviation in Populous Deltas (ESPA Deltas)' project. ESPA Deltas was a large multi-disciplinary project, which aimed to understand the link between environmental change, ecosystem services, human wellbeing (including health), poverty and development within the world's largest delta – the Ganges–Brahmaputra–Meghna (GBM) Delta.

The Bengal delta covers 19 districts and 25.7% of the population of Bangladesh (BBS, 2011) with diverse natural resources, including critical ecosystems such as the Sundarban mangrove forest, fisheries, shrimp farms, agriculture, and deposits of minerals and salt, with export promotion sites, harbors, airports, ports, tourism, and other industries- supporting the livelihoods of more than 37 million people. Poverty in the coastal area is prominent with high vulnerabilities in terms of food insecurity, income, water and health (cited from (Dasgupta et al., 2014).

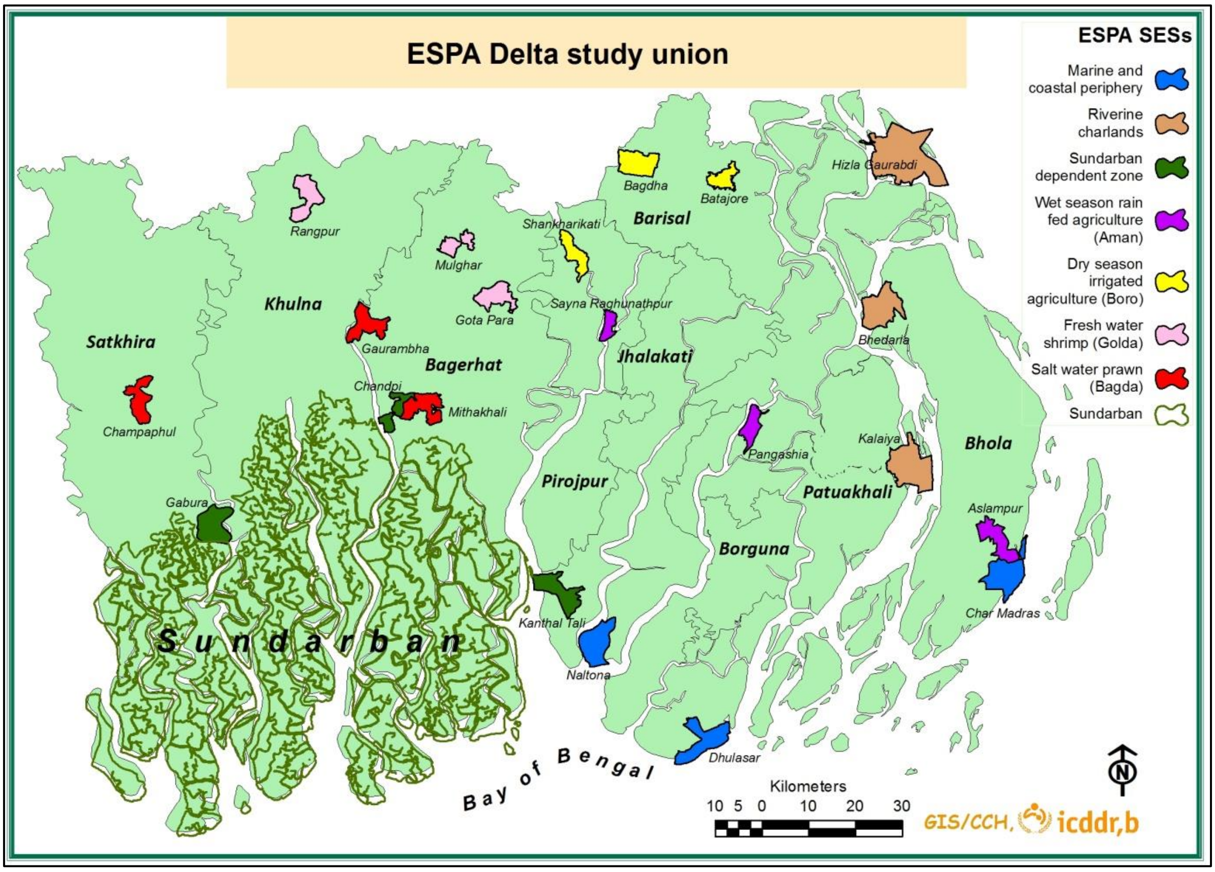

Figure 1. ESPA deltas study area map.

In ESPA deltas study, 4 Social-ecological Systems (SES) were matched with major land-use types: Aman, Boro, Bagda and Golda SESs. Unions falling in these SES were defined by greater than 80% land coverage of each of these land uses, adjusting for mudflats, river canals, sand, rural and urban settlements, water bodies and water logged land areas. 3 SES are not directly identifiable by specific land use type, but spatial environmental characteristics. Sundarban dependent SES includes all unions contiguous with the Sundarban. Marine unions are all sea facing unions and Char unions are defined as any union that has the presence of riverine chars (Adams et al., 2016).

The ESPA Deltas study area covers 21 unions from 9 coastal districts covering south-central to south-west regions of the Bengal delta in Bangladesh. These unions belong to 7 Socio-Ecological Systems, SES (Adams et al., 2016) and correspond to wet season rice only (Aman), dry season irrigated rice cultivation (Boro), saltwater shrimp aquaculture (Bagda), freshwater prawn aquaculture (Golda), Riverine char lands, Sundarban dependent zone and coastal marine periphery (Figure1). It was hypothesized that, dominant land use at a particular geographical location (i.e. SES) has an effect on the quality of ecosystem services (ES) and on health outcomes of the population.

A longitudinal survey was conducted within the ESPA Deltas project in the South West to South Central coastal zones of Bangladesh (Adams et al., 2016). The sampling strategy took ecosystem service provisioning as the base of socio-ecological stratification. A multi-level binomial logistic regression model has been used to systematically assess the contribution of provisioning ecosystem services to income across the diverse socio-ecological systems (SES). Equal number of representative households (HHs), meeting the research criteria were selected from each SES following multi-stage random sampling. Primary data was collected through three rounds of cross sectional HH survey, four months apart covering February 2014 to 2015 timeframe. Drinking water samples, food consumption information and blood pressure was collected from more than 1,500 households (1,586, 1,516 and 1,531 households in first, second and third survey round respectively). For each round, data was collected from the same respondents in the same households. The questionnaire instrument was designed to generate precise quantitative and spatially explicit data on the nature of the relationship between ecosystem services and human well-being. Data were collected at household level, with certain subjective questions and health assessment through anthropometry and blood pressure measurements at individual level. A panel dataset was created from three cross-sectional surveys; bi-variate analysis was performed to understand household characteristics and socio-demographic status within the seven SES.

Water samples were collected manually based on standard protocols and field practices (G.K.Khadse, 2010, Sundaram et al., 2009). Samples were collected from all types of drinking water sources except bottled water and rainwater since they were assumed as saline free. Water samples were tested with HACH sensION5 Electric Conductivity meter and Platinum conductivity cell (model 5060, HACH, Loveland) that reported salinity measures in terms of Electrical Conductivity (EC) in µS/cm, Salinity (SAL) and Total Dissolved Solids (TDS) in mg/l. For analysis purpose, only the result of tubewell water was used as this is the major source of drinking water in the SESs (see results section), establishing a cutoff point of 150 meter (~500 feet) to differentiate between shallow and deep tubewell (BBS, 2011). Blood pressure was measured with OMRON digital automatic blood pressure monitor (model M2 (HEM-7119-E(V), OMRON Healthcare, Hoofddorp). Basic anthropometric measurement (height and weight) were collected from one eligible male (18-54 years), female (15-49 years) and oldest under 5 children. Blood pressure was collected from all respondents in 15-59 age group due to the selection criteria based on kinship. Blood pressure was measured during the questionnaire survey, 3 readings were taken within a 10 minute interval based on standard procedure followed in national surveys (NIPORT et al., 2013, WHO, 2011a).

The average value of the last two readings of systolic and diastolic blood pressure was used to report respondent's blood pressure, setting cut-off points 'Normal' for Systolic blood pressure (SBP) under 120 mmHg and the diastolic blood pressure (DBP) under 80 mmHg as followed in national surveys (AHA, 2016, Dennison-Himmelfarb et al., 2013, DGHS, 2013, NIPORT et al., 2013). SBP within the range of 120-139 mmHg or DBP from 80 to 89 mmHg was considered as prehypertension. Hypertension was measured when SBP was greater than or equal to 140 mmHg or DBP was greater than or equal to 90 mmHg. Among participants, those who were taking medication were considered as hypertensive. A Generalized Estimating Equation (GEE) and Population Average (PA) model was fitted in the logistic regression to quantify the association between health statuses with SESs. Inter dependency within group was minimized for clustering on individuals by adjusting robust standard error. Age, sex, religion, educational status, depth of the tube-well, occupation as a proxy of physical activity, dietary intake, landownership, SES and drinking water salinity level were controlled during regression analysis. STATA 13.0 (StataCorp LLC, College Station) was used for analysis.

Sodium was calculated at the individual level from table salt and drinking water sources. Sodium from food was calculated at household level and then attributed to individual consumption at the SES level. The amount of water a person drinks per day was collected through questionnaire survey and salinity was measured testing sample from that specific source. Amount of raw salt (table salt- NaCl) consumed by respondent during the meal was also collected through questionnaire survey. A standard food table with 45 food items was created to measure per capita sodium intake from food at HH level and then attributed to individual consumtion. Details of sodium intake from dinking water, food and raw table salt is given in Annex 1.

The future potential groundwater salinity levels of the first, unconfined aquifer were predicted with the Delta Dynamic Integrated Emulator Model (ΔDIEM) (Nicholls et al., 2016). The groundwater hydrology and water quality of this aquifer in coastal zone were modelled by the coupled MODFLOW-SEAWAT models (Harbaugh, 2005, Langevin et al., 2008). The model was set-up for the southwest and south central hydrologic zones, with appropriate boundary conditions and representation of a wide network of coastal rivers. Simulations were conducted in a number of steps, including generation of initial salinity distribution as a result of lateral seawater intrusion, followed by baseline simulation for 1971-2010 time period. Validation of the baseline model simulation was done with measured shallow aquifer salinity (by Bangladesh Water Development Board, BWDB and Bangladesh Agricultural Development Corporation, BADC). The model was then used to simulate different scenarios, to investigate the impact of changed freshwater flow and river salinity together with sea level rise on shallow aquifer salinity. ΔDIEM emulates the results of the model application with a root mean square (RMS) error of 72 mg/l (0.072ppt) (Payo et al., 2017). Deep aquifers were not modelled due to the unavailability of baseline line data, rather present day observations were collated and presented in this manuscript. All the maps have been prepared with ArcGIS ver. 10 (ESRI, Redlands).

The research protocol was reviewed and approved by the Research Review Committee (RRC) and the Ethical Review Committee (ERC) at the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b). The icddr,b ERC is registered under Institutional Review Board with Federal Wide Assurance (#FWA0001468) and Human Welfare Assurance (#IRB00001822) since November 2001 (Adams et al., 2016).

Results

Coastal communities drink water from a number of different sources; however, these can be brought under 4 major categories: ground water sources (shallow/ deep tubewell, borehole, piped water system and dug wells), surface sources (river/dam/lake/pond/stream/canal/irrigation channel, etc.), rainwater and others like, bottled water. It was found that, the majority (about 80%) of coastal communities are dependent on ground water sources with only about 11% on surface water and 7% on rainwater. Ground water was the main source of drinking water in 5 SESs except Sundarban dependent and Saltwater Shrimp SES (Figure 2). The shifting of sources was also visible in these two SES, depicting the poor water quality and salinization problem in the areas. In the Sundarban SES, surface water sources were primarily used for drinking purpose with shifting to rainwater in round 2 which intersects with the monsoon season in the country. The same type of shifting was visible in saltwater shrimp SES. Only a very few respondents took water from bottled water in Sundarban SES.

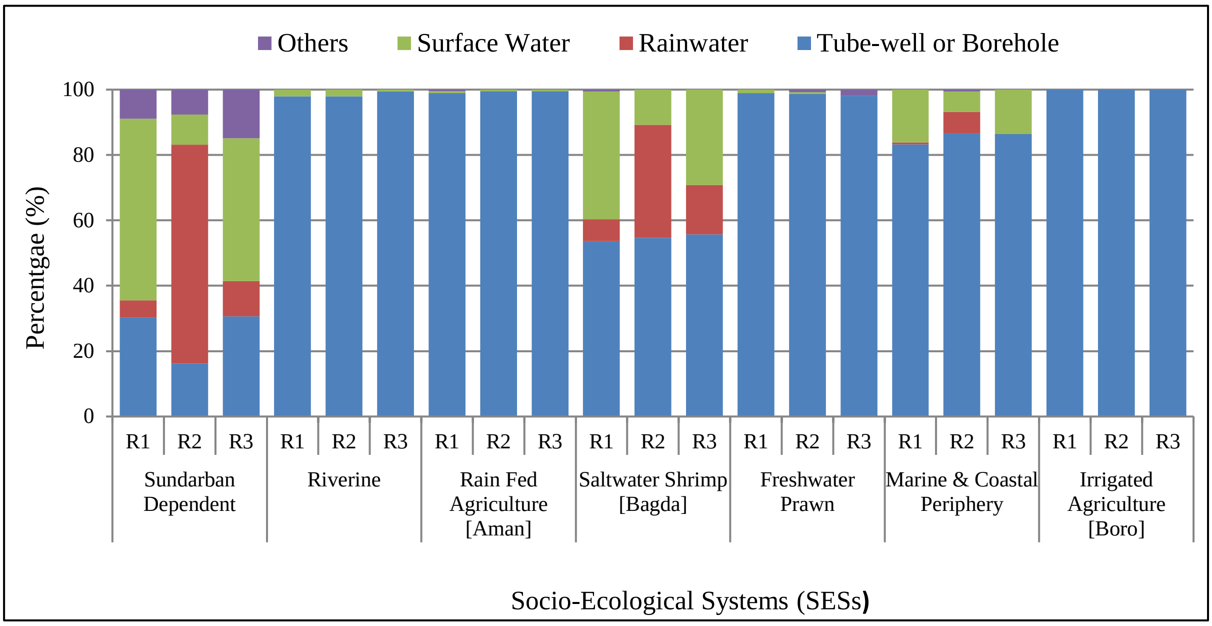

Figure 2. Percent utilization of water sources by Socio-Ecological System. Major drinking water sources in the ESPA delta study area, that covers central to south west coastal regions of Bangladesh; with reference to three survey rounds- R1, R2 and R3 representing round 1, 2 and 3. The major drinking water source in this area was groundwater - more precisely shallow and deep tubewells. There are very few piped water systems. The seasonal shifting only occurs in Sundarban, Saltwater shrimp and Marine SES with higher dependency on surface water sources and rainwater. The seasonal shifting is only prominent in round 2 that is the monsoon season in the country. It is hypothesized that this shifting occurs because rainwater is of better quality than the other common sources.

It is well established that salt or sodium consumption accelerates the rate of hypertension, thus consumption should be limited to <2 g Sodium a day (WHO, 2012). In the study area, it was found that people are habituated with higher sodium intake practice than WHO recommendation. Daily per capita mean sodium consumption from food sources was almost the same (around 0.3 gram) in all the SES and was lower compared to other sources. The highest proportion of sodium comes from direct intake of salt (table salt) ranging from 5.1 gram to 6.1 grams within the SES (see, Annex 1: Sodium calculation) that greatly exceeds the WHO recommendation. Average drinking water salinity was found as 915 mg/l for tubewell water (considering all sources mean salinity was 854 mg/l) with lowest concetrations in Riverine and highest in Sundarban dependent SES. Figure 3 shows that higher concentrations of drinking water salinity indicates higher consumption of sodium from drinking water. The lowest mean drinking water salinity was found in Riverine SES (eventually lowest daily per capita sodium consumption, around 0.4 grams) and the highest was in Sundarban dependent SES (likewise the highest daily per capita sodium consumption, near 1.2 g). The higher intake of sodium might influence the high blood pressure among the study participants (Figure 3).

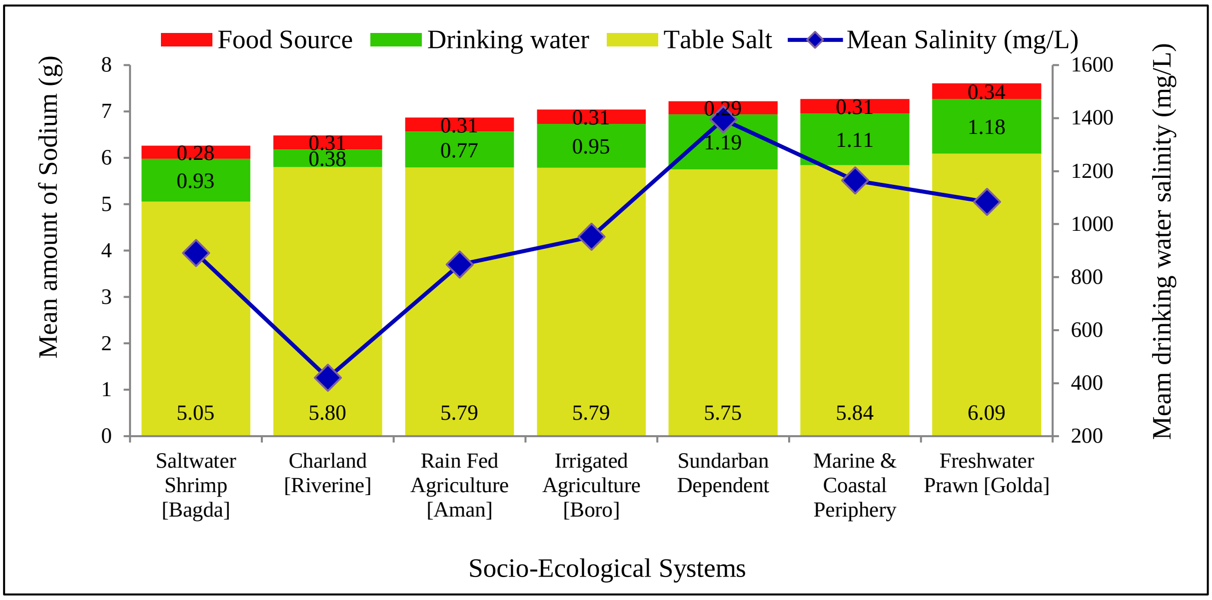

Figure 3.Sodium consumption from different sources (bars) and mean drinking water salinity concentration (line).

Average salinity in tubewell water was 915 mg/l with lowest salinity in Riverine and highest in Sundarban dependent SES. Sodium intake was measured from all types of sources: food, water and table salt. Mean Salinity level was high in almost every SES except Riverine SES. People's daily per capita sodium intake was found to be quite high compared to WHO recommendation.

For analysis purpose and to see the association more closely between water salinity level and blood pressure, the drinking water salinity was further divided into 3 salinity concentration categories and respondents (only eligible male and female, no children; 15-59 years) were separated into 2 age categories, namely, 'below 35 (15-34 years, N = 2,895; 46.6%)' and '35 and above (35-59 years, N = 3,319; 53.4%) to assess the hypertension prevalence in different age group and also to compare with previous national studies. Safe water limit (Fresh water < 1,000 mg/l) has been made following the Bangladesh guideline of safe drinking water (Ahmed and Rahman, 2000), the other two categories under unsafe water- slightly saline (1,000-2,000 mg/l) and moderate saline (≥ 2,000 mg/l) was made based on authors expertise and judgment as no specific standards are currently available. A high saline category (≥ 3,000 mg/l) was initially created but due to very limited number of samples with such concetrations, was combined with the moderate category.

This study reveals a linkage between drinking water salinity concentration and blood pressure (Figure 4). It was found that, the higher the salinity concentration in drinking water, the higher the prevalence of the high blood pressure (HBP) among the respondents in prehypertension and hypertension stages. This was clearly visible for both age groups. Among the respondents below 35 years age, having exposure to drinking water salinity concentration less than 1000 mg/l, the percentage of HBP status (prehypertension and hypertension) was 34.3% whereas it was 42.6% for salinity level of 2000 mg/l or more. Among this age limit and in the high saline exposed group, hypertension was roughly 6% higher compared to the national rural communities. This scenario was much worse for the older population (35 years and above). In this group those who were exposed to less than 1000 mg/l concentration salinity, have 47.8% HBP related disorder which was close to 2011 BDHS rural statistics (50.1%) (NIPORT et al., 2013). Specifically hypertension was around 12% higher among the study population with respect to national rural statistics. It was found that, for above 35 years age study participants, prevalence of hypertension increased with elevated salinity level in drinking water that were 29.4% (overall HBP 53.8%) and 34.0% (overall HBP 62.5%) respectively for slightly saline (1000-2000 mg/l) moderate saline (≥2000 mg/l) water.

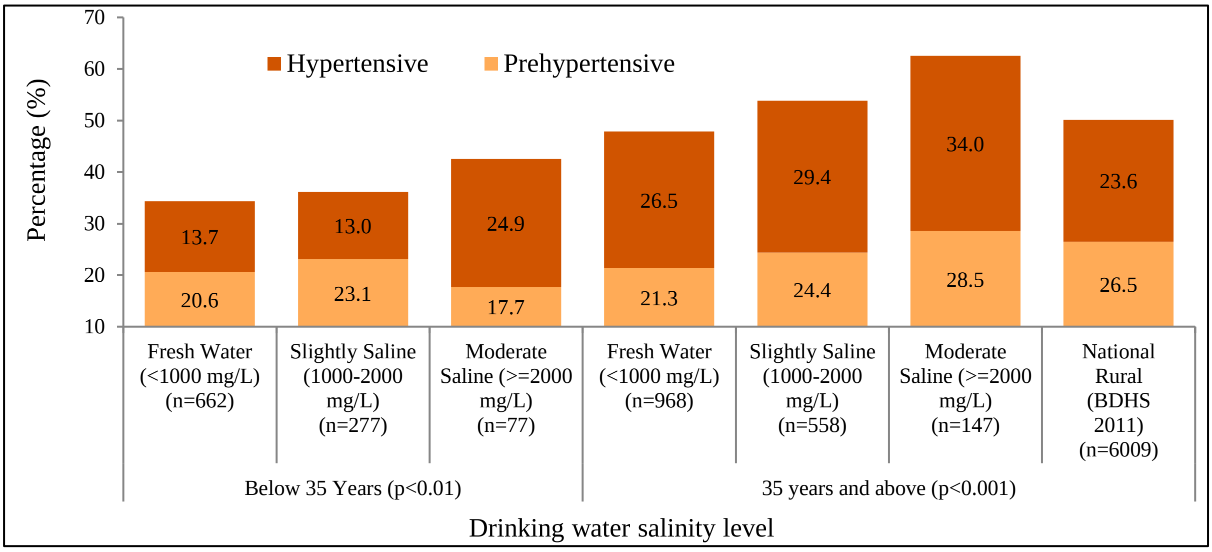

Figure 4. Association of drinking water salinity and age group with adult high blood pressure (prehypertension and hypertension).

High blood pressure (both prehypertension and hypertension) is prevalent in the higher age group. In both categories it was higher than national rural statistics from BDHS 2011 survey (NIPORT et al, 2013). Especially for moderate saline exposure hypertension was 44% higher among the 35 years and above age group than national figure. Prehypertension and hypertension also found to be associated with drinking water salinity levels.

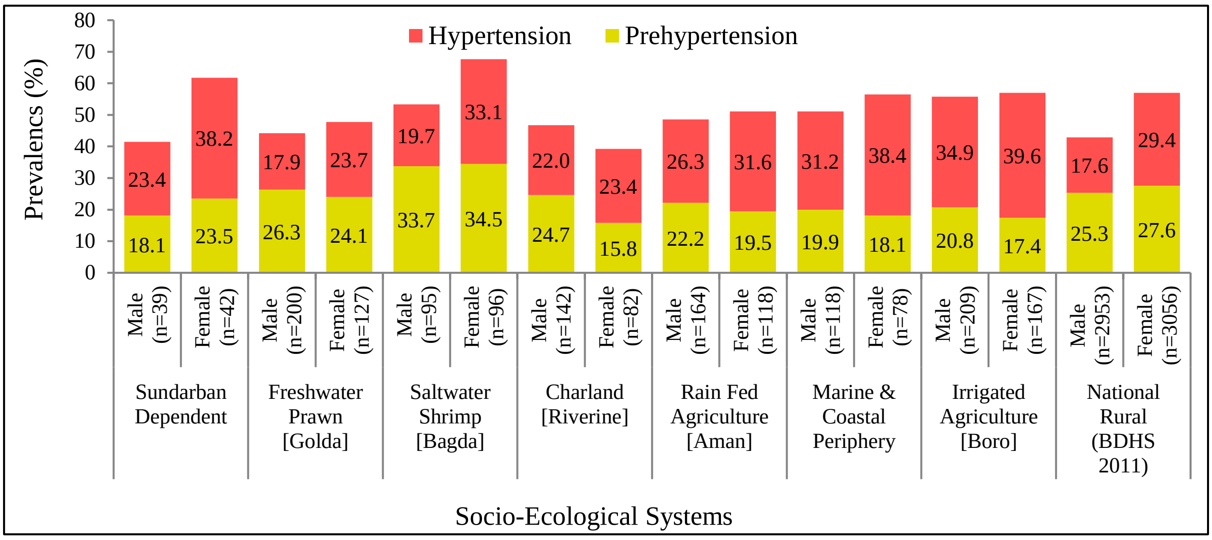

Figure 5. Gender specific adult high blood pressure in different SESs for the 35 years and above age group.

Women were found to be more hypertensive in all SESs compared to men except Charland SES. Both Women and men from Irrigated agriculture SES are found to be most hypertensive among the respondents. The prevalence of hypertension is also higher than national rural statistics in most of the SESs for both men and women aged 35 years and above.

The study also assessed gender specific vulnerability of adult HBP for which only the '35 years and above age' group was considered, in order to compare with national statistics. Women of age 35 years and above were at higher risk of high blood pressure in all SESs compared to men except the Charlands area (Figure 5). Among older women, the highest percentage of hypertension was 39.6% in the Irrigated agriculture SES followed by Marine & coastal periphery (38.4%) and Sundarban dependent (38.2%) SES. The lowest vulnerable women group to HBP was in the Riverine SES (23.4%). For male respondents, hypertension was also highest in Irrigated agriculture SES (34.9%) and the lowest was in Freshwater prawn SES (17.9%). Findings clearly depicted that women were more prone to adult HBP compared to men and this varied among SESs.

The HBP is found to be affected by drinking water salinity level and it exhibited seasonal variation over the rounds (Figure 6). A clear association was found between drinking water salinity level and high blood pressure with seasonal variation and increasing trend towards dry season (round 3).

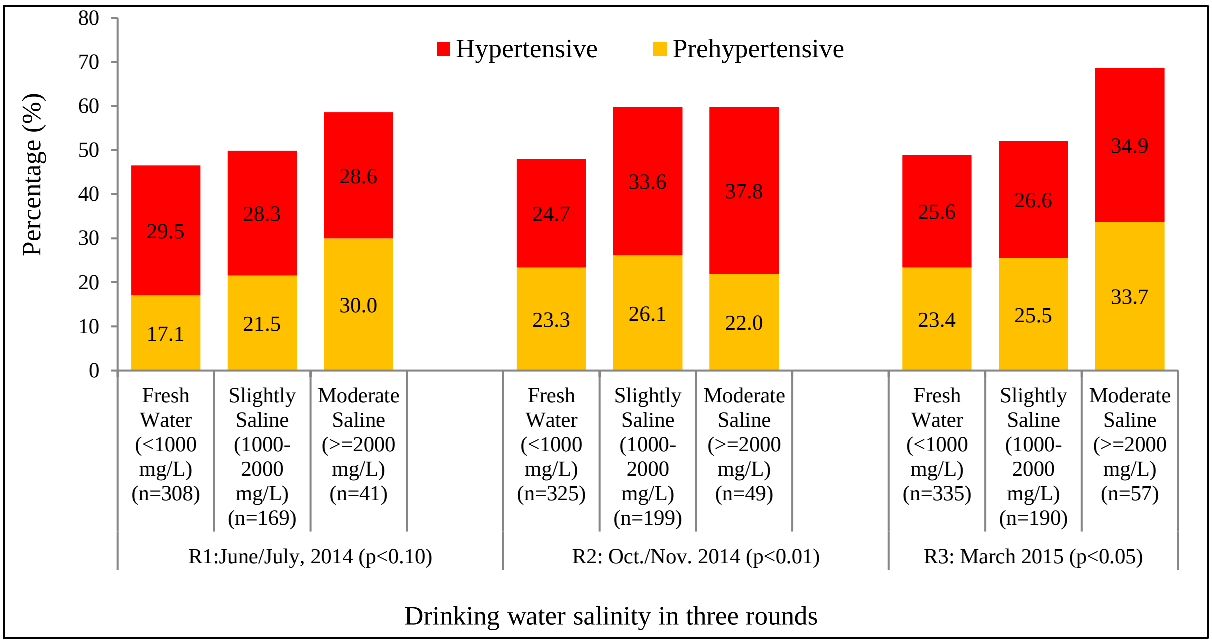

Figure 6. Association of HBP with drinking water salinity and study rounds (seasons) in the 35 years and above age group.

Seasonal variation of HBP is visible in the three rounds. Though the socio-economic information were collected for a four months recall period in HH survey, however blood pressure and drinking water salinity were measured in a point time. The data collection periods were for Round 1: June/ July, 2014, Round 2: October/ November, 2014 and Round 3: March, 2015. Gradual increase in HBP is visible which coincide with Bangla seasons representing pre-monsoon to dry season in one year timeframe. Highest level of prehypertension and hypertension were found in dry season with moderate saline drinking water category.

The mean salinity level in drinking water from tubewell showed slight fluctuation among the rounds; in round 1, mean salinity was 890 mg/l, which increased to 934 mg/l in round 2 and slightly decreased to 921 mg/l in round 3. However, HBP shows increasing trends over the rounds. In round 1, the overall HBP increased from 46.6% for fresh water (< 1000 mg/l) to 58.6% for moderate saline (≥ 2000 mg/l) water exposure. In round 2, there was increase in HBP from 48.0% to 59.8% with increase in drinking water salinity. Finally, in round 3, the HBP was 49.0% for low salinity exposure and 68.6% for highest salinity exposure. It was noticed that, for people who drank fresh water, the HBP was close to national statistics of 50.1% but for moderate saline exposure it was significantly higher (58.6%, 59.8% and 68.6% respectively in round 1, round 2 and round 3) comparing to national statistics. Though in the first round, prevalence of hypertension was almost the same between fresh and moderate saline exposure group, however, in second and third round the prevalence was roughly 53% and 36% higher respectively, findings suggest that, salinity might have a delayed impact on HBP.

Further logistic regression (population average model) was carried out, controlling for age, sex, education, religion, occupation, landownership, household dietary diversity, socio-ecological systems, drinking water salinity concentration and depth of the tube-well to signify the outcome variable (see Table 1, model design and description). It was found that, women had a 31% higher chance of being hypertensive than men and it was statistically significant ($p<0.001$). 35 and above age respondents were about 2.4 times more likely to be hypertensive compared to below 35 years of age group. At a 5% level of significance, Non-Muslims had 22% lower chance of being hypertensive than Muslims, which we hypothesize is due to differences food intake. The few publications on this topic that are available also suggest the same phenomenon - non-hinudus were found to be more hypertensive in India (Kishore et al., 2016, Jindal et al., 2016) and muslim women were found more hypertensive in Indonesia than others (Jansen, 2017); however, further epidomological evidence is necessary to identify religion as a potential risk factor for hypertension.

Association between hypertension and food diversity varied slightly but not significantly. With respect to Sundarban Dependent SES peoples from Irrigated Agriculture (53%, $p<0.05$) and Marine and Coastal Periphery (16%) were more likely to be hypertensive. Interestingly in spite of higher salinity concentration and per capita sodium intake, hypertension prevalence was found to be 39% lower in Freshwater Prawn SES ($p<0.05$), which requires further investigation to be fully understood. In comparison with participants with no formal education (never passed any class), hypertension was around 26% lower among secondary attended participants but gradually increases with higher educational attainment. Respondents who have completed secondary and higher education were at 7% higher risk of hypertension than the no education group but this was not statistically significant. Respondents with exposure to slightly saline (1000-2000 mg/l) and moderate saline (≥2000 mg/l) concentration drinking water have respectively 17% ($p<0.1$) and 42% ($p<0.05$) higher chance of being hypertensive than those exposed to fresh water (<1000 mg/l).

Discussion

Hypertension is one of the major risk factors for cardiovascular diseases (CVD). Studies done by Khan and Talukder showed that increased salinity in drinking water has an association with hypertension among coastal population (Khan et al., 2011, Khan et al., 2014, Talukder et al., 2016). However, Khan in her studies worked with pregnant women (both proxy and direct water salinity measurement and blood pressure measurement with sphygmomanometer) and Talukder with young adults (both male and female, multiple respondent from the same household, direct salinity measurement and blood pressure measurement with digital BP monitor); both of the studies used urinary sodium excretion as a proxy to calculate salt consumption. However, these studies worked with small target populations and from urine sodium measurement to back-calculate the sodium intake. Contrary to that study, the ESPA Delta survey took a much larger population sample; salt intake was measured from different sources for attribution and linked to blood pressure to direct drinking water consumption. This study also found that the highest percentage of hypertension among women aged 35 years and above, more precisely in 30 to 39 range, which is quite similar to the result of Bangladesh Demographic and Health Survey 2011 (NIPORT et al., 2013). A statistically significant association was found between drinking water salinity and hypertension that showed seasonal variation and increasing trend in dry season and prevalent in women and above 35 years age group. A slight fluctuation in tubewell drinking water salinity was found in the 3 rounds and associated increase in hypertension with moderate saline drinking water group. Women and those above 35 years of age among the coastal population were more prone to prehypertension and hypertension compared to men and those below 35 years of age. Higher prevalence of hypertension was found among respondents by 21%, 60% and 48% respectively in 1st, 2nd and 3rd round, in comparison to national statistics (23.6%), who consume moderate saline water which is two times more saline comparing to Bangladesh safe water guideline value.

Informal discussion with respondents reveiled that, consuming saline water might have already made some impact on their taste bud and taste threshold. People consider quite high level of saline water as sweet/ fresh- which people from outside can't consume. The coastal community was found to be associated with high raw salt intake practice, which might have some impact for raising the bloodpressure anomaly, however, further investigation is required to fully understand the situation.

Educational status and landownership (a proxy indicator of wealth status) has a positive association with risk of hypertension as findings show in the study which might be related to types of livelihood and physical activity. In Bangladesh, similar findings were found by Chowdhury et al.(2016) and also for other low and middle income countries (Basu and Millett, 2013, Chow et al., 2013). To quantify the outcome variable controlling some other explanatory variables, population average model was used adjusting robust standard error to minimize the inter dependency of individuals. In this model the controlled variables were age, sex, education, religion, occupation, landownership, household dietary diversity, socio-ecological systems, and concentration of drinking water salinity and depth of the tubewell. The outcome variable was hypertension status of the study participants. From the logistic regression analysis it was evident that, the higher the level of salinity concentration in drinking water, higher the risk of hypertension and 35 years and above age group was more prone to become hypertensive. National status of blood pressure anomaly was only collected in the BDHS 2011 survey which only considered the 35 years and above age group due to their increased vulnerability (NIPORT et al., 2013). This study also found higher HBP anomaly among the old age group, however, the higher prevalence in coastal area comparing to national statistics, and also the HBP status of below 35 years age group close to national statistics is a serious public health concern.

The study considered water intake at individual level. The mean volume of water consumption didn't vary much; it ranged from 2.18 to 2.67 litre per person per day within the SES. Regression analysis suggested only 2% higher chance of hypertension among those who consume more than 2 litre water per day compared to those who took less than or equal to 2 litre water per day.

The blood pressure status of respondents was analyzed as per their drinking water sources. The blood pressure status among the '35 years and above' respondents, who drank from shallow tubewell was normal 55.9%, prehypertension 23.2% and hypertension 20.9%, whereas the same for deep tubewell was normal 56.6%, prehypertension 21.8% and hypertension 21.6%. Though the difference was quite low regarding elevated blood pressure (both prehypertension and hypertension) between shallow and deep tubewell users, the increased level of salinity in deep aquifer is of great concern from public health perspective and water resources management. Considering all respondents, about 56.6% was found with normal blood pressure and 21.9% as prehypertensive and 21.5% as hypertensive.

Bangladesh has already prepared guidelines for managing hypertension health risks (DGHS, 2013) and it also acknowledges the bad practice of increased salt consumption from cooking and table salt; however, the policy document is primarily centered on medical intervention. This study found that drinking water salinity level is associated with increased hypertension. Though the document reports higher hypertension among urban areas (19.9%) when compared to rural areas (15.9%), this latest study exhibits greatly increased hypertension prevalence among the coastal population. Thus more importance should be given to the drinking water salinity issue to manage future hypertension risks. Interestingly, the global risk of hypertension was reported to be higher for men compared to women and in urban areas (Ibrahim and Damasceno, 2012, WHO, 2013), but this study reports coastal areas to be more vulnerable and women were found to be more prone to hypertension and the hypertension risk is highest among the people aged 35 years and above.

Present day observations on the drinking water salinity in the survey indicate high risk for most of the coastal areas (shallow tubewell - mean: 837 mg/l, range: 216-3153 mg/l; deep tubewell – mean: 923 mg/l, range: 170-6580 mg/l). The deep aquifer system in coastal Bangladesh, that is the most important for drinking water purposes, has a salinity of below 2000 mg/l in most of the study area. Only the Barguna district showed differential gradient with its close proximity to the sea; ranging from 3000-6000 mg/l. These tubewell water samples were tested with field instrument kit rather than lab testing and the magnitude and spatial distribution is still valuable even though the accuracy of the measurements are thought to be lower. The projection of this aquifer into the future is not possible without baseline data. Model results of the shallow aquifer, however, indicate a moderate increase in soil salinity by 2050 (21-44%) for the south-west coastal zone of Bangladesh (Payo et al., 2017). Although this shallow aquifer is dominantly used for irrigation and only occasionally for drinking purposes, it can be used as a proxy for future salinity changes in the deeper aquifers. The results imply that the issue of drinking water salinity and hypertension will slowly intensify in the future. Saline water intrusion is expected in both the shallow and deep aquifers due to both anthropogenic activities and CCSLR impacts. This study found that, >2000 mg/l concentration significantly increases the likelihood of hypertension for the older generations and particularly for women. As the coastal population is aging due to the migration of the younger people and of low fertility (Szabo et al., 2015), and the groundwater slowly becomes more saline, the vulnerability of the people will likely be exacerbated in the future. This will put additional pressure on the Bangladeshi health system and will likely affect the wellbeing of the coastal population.

Conclusion

People in coastal Bangladesh depend on ground water for major drinking water source- a critical ecosystem service in the area. The salinity level in drinking water was found to be of higher concentration in the study area and substantially contributes to overall sodium intake among coastal communities. This study found a significant association between drinking water salinity concentration and adult hypertension. Study findings show that hypertension is more prevalent in female, at higher age group and among those who drink higher concentration saline water. With predicted increase of salinity in coastal Bangladesh, it is imperative to promote alternative drinking water sources with mass level awareness creation and community sensitization against the bad practice of high table salt consumption. During the study, only a very few respondents were found dependent on surface and rain water, also, in SES the number of different sources were often non-comparable; hence further study with larger population and surface and ground water based drinking sources is required to fully understand the present situation and future adaptation options.

The coastal people of Bangladesh are at the forefront of climate change. This study shows critical findings in relation to health and climate change that is likely to worsen in predicted future scenarios. Thus for future water resources management and public health provisioning, well planned adaptation and mitigation projects need to be implemented managing critical ecosystem services in line with country's development trajectory.

Reference

ADAMS, H., ADGER, W. N., AHMAD, S., AHMED, A., BEGUM, D., LÁZÁR, A. N., MATTHEWS, Z., RAHMAN, M. M. & STREATFIELD, P. K. 2016. Spatial and temporal dynamics of multidimensional well-being, livelihoods and ecosystem services in coastal Bangladesh. *Scientific data,* 3.

AHA. 2016. *About High Blood Pressure* [Online]. American Heart Association. Available: http://www.heart.org/HEARTORG/Conditions/HighBloodPressure/GettheFactsAboutHighBloodPressure/The-Facts-About-High-Blood-Pressure_UCM_002050_Article.jsp [Accessed March 28 2017].

AHMED, M. F. & RAHMAN, M. 2000. Water Supply and Sanitation: Rural and low income urban communities, ITN-Bangladesh. *Center for water supply and waste management, BUET, Dhaka, Bangladesh*.

ALAM, D. S., CHOWDHURY, M. A., SIDDIQUEE, A. T., PERVIN, S., AHMED, S. & NIESSEN, L. W. 2013. Abstract P371: Raising Awareness Leads to High Provider Visits and Blood Pressure Reduction Among Hypertensive Patients in Bangladesh-A Population-Based Cohort Study. Am Heart Assoc.

BADC 2013. Detection of electrical conductivity after 10 feet interval (depth) of 118 nos. observation well in selected upazillas under Barisal, Chittagong, Khulna and Dhaka division by using data logger and EC meter. Dhaka: Bangladesh Agricultural Development Corporation (BADC), Ministry of Agriculture, Government of the Peoples' Republic of Bangladesh.

BASU, S. & MILLETT, C. 2013. Social Epidemiology of Hypertension in Middle-Income CountriesNovelty and Significance. *Hypertension,* 62**,** 18-26.

BBS 2011. Bangladesh national drinking water quality survey of 2009. Dhaka, Bangladesh: Bangladesh Bureau of Statistics, Planning division, Ministry of planning, Government of the Peoples' Republic of Bangladesh.

BWDB 2013. Hydrogeological Study and Mathematical Modelling to Identify Sites for Installation of Observation Well Nests, Selection of Model Boundary, Supervision of Pumping Test, Slug Test, Assessment of Different Hydro-geological Parameters Collection and Conduct Chemical Analysis of Surface Water and Groundwater. Institute of Water Modelling (IWM), Bangladesh Water Development Board (BWDB), Ministry of Water Resources, Government of the Peoples' Republic of Bangladesh.

CCC 2009. Characterizing Country Settings: Development of a Base Document in the Backdrop of Climate Change Impacts. Dhaka, Bangladesh: Climate Change Cell, DoE, MoEF, Component 4b, CDMP & MoFDM.

CHOW, C. K., TEO, K. K., RANGARAJAN, S., ISLAM, S., GUPTA, R., AVEZUM, A., BAHONAR, A., CHIFAMBA, J., DAGENAIS, G. & DIAZ, R. 2013. Prevalence, awareness, treatment, and control of hypertension in rural and urban communities in high-, middle-, and low-income countries. *Jama,* 310**,** 959-968.

CHOWDHURY, M. A. B., UDDIN, M. J., HAQUE, M. R. & IBRAHIMOU, B. 2016. Hypertension among adults in Bangladesh: evidence from a national cross-sectional survey. *BMC cardiovascular disorders,* 16**,** 22.

DASGUPTA, S., KAMAL, F. A., KHAN, Z. H., CHOUDHURY, S. & NISHAT, A. 2014. River salinity and climate change: evidence from coastal Bangladesh.

DENNISON-HIMMELFARB, C., HANDLER, J., LACKLAND, D. T., LEFEVRE, M. L., MACKENZIE, T. D., OGEDEGBE, O., SMITH JR, S. C., SVETKEY, L. P., TALER, S. J. & TOWNSEND, R. R. 2013. 2014 Evidence-Based Guideline for the Management of High Blood Pressure in Adults Report From the Panel Members Appointed to the Eighth Joint National Committee (JNC 8).

DGHS 2013. *National Guidelines for Management of Hypertension in Bangladesh,* Dhaka, Bangladesh, Director General of health Services, Ministry of Health and Family Affairs.

ERICSON, J. P., VÖRÖSMARTY, C. J., DINGMAN, S. L., WARD, L. G. & MEYBECK, M. 2006. Effective sea-level rise and deltas: causes of change and human dimension implications. *Global and Planetary Change,* 50**,** 63-82.

FORD, A. E., GRAHAM, H. & WHITE, P. C. 2015. Integrating human and ecosystem health through ecosystem services frameworks. *EcoHealth,* 12**,** 660-671.

G.K.KHADSE 2010. Collection and Preservation of Samples and Field Analysis. *Training Programme on QAQC in Water Quality Monitoring and Assessment, Oct. 21-22, 2010.* New Delhi, India.

GAIN, A. K. & GIUPPONI, C. 2014. Impact of the Farakka Dam on thresholds of the hydrologic flow regime in the Lower Ganges River Basin (Bangladesh). *Water,* 6**,** 2501-2518.

HARBAUGH, A. W. 2005. *MODFLOW-2005, the US Geological Survey modular ground-water model: the ground-water flow process*, US Department of the Interior, US Geological Survey Reston, VA, USA.

IBRAHIM, M. M. & DAMASCENO, A. 2012. Hypertension in developing countries. *The Lancet,* 380**,** 611-619.

IPCC 2007a. *Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC,* Geneva, Switzerland, Cambridge University Press.

IPCC 2007b. Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ML Parry, OF Canziani, JP Palutikof, PJ van der Linden and CE Hanson, Eds. *Cambridge University Press, Cambridge, UK***,** 23-78.

IPCC 2014. *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change,* Geneva, Switzerland, IPCC.

ISLAM, S. N., KHAN, M. N. I. & AKHTARUZZAMAN, M. 2010. A food composition database for Bangladesh with special reference to selected ethnic foods. *Dhaka: Institute of Nutrition and Food Sciences, University of Dhaka*.

JANSEN, N. 2017. Between-and Within-Religion Differences in Hypertension Risks for Indonesian Women. *Annual Population Association of America Meeting.* Chicago, IL, USA

JINDAL, R., JINDAL, N. & DASS, A. 2016. Prevalence of hypertension and its association with various risk factorsa survey in Uttar Pradesh. *International Journal of Contemporary Medical Research,* 3**,** 3410-3412.

JOHNSON, F. A., HUTTON, C. W., HORNBY, D., LÁZÁR, A. N. & MUKHOPADHYAY, A. 2016. Is shrimp farming a successful adaptation to salinity intrusion? A geospatial associative analysis of poverty in the populous Ganges–Brahmaputra–Meghna Delta of Bangladesh. *Sustainability Science,* 11**,** 423-439.

KHAN, A., MOJUMDER, S. K., KOVATS, S. & VINEIS, P. 2008. Saline contamination of drinking water in Bangladesh. *The Lancet,* 371**,** 385.

KHAN, A. E., IRESON, A., KOVATS, S., MOJUMDER, S. K., KHUSRU, A., RAHMAN, A., VINEIS, P. & LABRESE EJ, V. 2011. Drinking water salinity and maternal health in coastal Bangladesh: implications of climate change. *Environmental health perspectives,* 119**,** 1328-1332.

KHAN, A. E., SCHEELBEEK, P. F. D., SHILPI, A. B., CHAN, Q., MOJUMDER, S. K., RAHMAN, A., HAINES, A. & VINEIS, P. 2014. Salinity in drinking water and the risk of (pre) eclampsia and gestational hypertension in coastal Bangladesh: a case-control study. *PLoS One,* 9**,** e108715.

KHANOM, S. & SALEHIN, M. 2012. Salinity constraints to different water uses in coastal area of Bangladesh: A case study. *Bangladesh Journal of Scientific Research,* 25**,** 33-41.

KISHORE, J., GUPTA, N., KOHLI, C. & KUMAR, N. 2016. Prevalence of hypertension and determination of its risk factors in rural Delhi. *International journal of hypertension,* 2016.

LANGEVIN, C. D., THORNE JR, D. T., DAUSMAN, A. M., SUKOP, M. C. & GUO, W. 2008. SEAWAT Version 4: A computer program for simulation of multi-species solute and heat transport. Geological Survey (US).

MCMICHAEL, A. J. 2003. *Climate change and human health: risks and responses*, World Health Organization.

MIRZA, M. M. Q. 1998. Diversion of the Ganges water at Farakka and its effects on salinity in Bangladesh. *Environmental management,* 22**,** 711-722.

MOEF 2009a. Bangladesh Climate Change Strategy and Action Plan Dhaka, Bangladesh: Ministry of Environment and Forests (MoEF),Government of the People's Republic of Bangladesh.

MOEF 2009b. National Adaptation Programme of Action (NAPA). Dhaka, bangladesh: Ministry of Environment and Forests (MoEF). Government Republic of Bangladesh.

NICHOLLS, R., HUTTON, C., LÁZÁR, A., ALLAN, A., ADGER, W., ADAMS, H., WOLF, J., RAHMAN, M. & SALEHIN, M. 2016. Integrated assessment of social and environmental sustainability dynamics in the Ganges-Brahmaputra-Meghna delta, Bangladesh. *Estuarine, Coastal and Shelf Science,* 183**,** 370-381.

NIPORT, MITRA AND ASSOCIATES & ICF INTERNATIONAL 2013. Bangladesh Demographic and Health Survey 2011. Dhaka, Bangladesh and Maryland, USA: National Institute of Population Research and Training (NIPORT), Mitra and Associates & ICF International.

PAYO, A., LÁZÁR, A. N., CLARKE, D., NICHOLLS, R. J., BRICHENO, L., SALEHIN, M. & HAQUE, A. 2017. Modelling daily soil salinity dynamics in response to agricultural and environmental changes in coastal Bangladesh. *Earth's Future*.

PONT, D., DAY, J. W., HENSEL, P., FRANQUET, E., TORRE, F., RIOUAL, P., IBÀNEZ, C. & COULET, E. 2002. Response scenarios for the deltaic plain of the Rhone in the face of an acceleration in the rate of sea-level rise with special attention toSalicornia-type environments. *Estuaries and Coasts,* 25**,** 337-358.

RAHMAN, M. M., HASSAN, M. Q., ISLAM, M. S. & SHAMSAD, S. 2000. Environmental impact assessment on water quality deterioration caused by the decreased Ganges outflow and saline water intrusion in south-western Bangladesh. *Environmental Geology,* 40**,** 31-40.

SHAMSUDDUHA, M. 2013. Groundwater-fed Irrigation and Drinking Water Supply in Bangladesh: Challenges and Opportunities. *In:* ZAHID, A., HASSAN, M. Q., ISLAM, R. & SAMAD, Q. A. (eds.) *Adaptation to the Impact of Climate Change on Socio-economic Conditions of Bangladesh.* Dhaka: Alumni Association of German Universities in Bangladesh, German Academic Exchange Service (DAAD).

SUNDARAM, B., FEITZ, A., DE CARITAT, P., PLAZINSKA, A., BRODIE, R., CORAM, J. & RANSLEY, T. 2009. Groundwater sampling and analysis–a field guide. *Geoscience Australia, Record,* 27**,** 95.

SZABO, S., BEGUM, D., AHMAD, S., MATTHEWS, Z. & STREATFIELD, P. K. 2015. Scenarios of population change in the coastal Ganges Brahmaputra delta (2011-2051). *Asia-Pacific Population Journal,* 30**,** 51-72.

TALUKDER, M. R. R., RUTHERFORD, S., HUANG, C., PHUNG, D., ISLAM, M. Z. & CHU, C. 2017. Drinking water salinity and risk of hypertension: A systematic review and meta-analysis. *Archives of environmental & occupational health,* 72**,** 126-138.

TALUKDER, M. R. R., RUTHERFORD, S., PHUNG, D., ISLAM, M. Z. & CHU, C. 2016. The effect of drinking water salinity on blood pressure in young adults of coastal Bangladesh. *Environmental Pollution,* 214**,** 248-254.

TALUKDER, R., RADWANUR, M., SHANNON, R. & CORDIA, C. 2015. Salinization of Drinking Water in the Context of Climate Change and Sea Level Rise: A Public Health Priority for Coastal Bangladesh. *International Journal of Climate Change: Impacts & Responses,* 8.

UNESCO 2015. The United Nations world water development report 2015: water for a sustainable world. Paris: United Nations World Water Assessment Programme, UNWWAP.
UNICEF & WHO 2015. Progress on sanitation and drinking water – 2015 update and MDG assessment. *World Health Organization and United Nations Children's Fund Monitoring Programme for Water Supply and Sanitation (JMP). UNICEF, New York and WHO, Geneva.* United States of America.
VINEIS, P., CHAN, Q. & KHAN, A. 2011. Climate change impacts on water salinity and health. *Journal of Epidemiology and Global Health,* 1**,** 5-10.
WATTS, N., ADGER, W. N., AGNOLUCCI, P., BLACKSTOCK, J., BYASS, P., CAI, W., CHAYTOR, S., COLBOURN, T., COLLINS, M. & COOPER, A. 2015. Health and climate change: policy responses to protect public health. *The Lancet,* 386**,** 1861-1914.
WHF. 2017. *Hypertension: Hypertension and cardiovascular disease* [Online]. World Heart Federation. Available: http://www.world-heart-federation.org/cardiovascular-health/cardiovascular-disease-risk-factors/hypertension [Accessed February 26 2017].
WHO 2011a. Non-Communicable Disease Risk Factor Survey Bangladesh 2010. *Dhaka: WHO.* Dhaka, Bangladesh: World Health Organization.
WHO 2011b. Non-Communicable Disease Risk Factor Survey Bangladesh 2010. Dhaka, bangaldesh: World Health Organization.
WHO 2012. Guidelien: Sodium intake for adults and children. Geneva, Switzerland: World Health Organization.
WHO 2013. A global brief on hypertension: silent killer, global public health crisis. Geneva, Switzerland: World Health Organization.
WLE. 2014. *BANGLADESH : HYPERTENSION* [Online]. World Life Expectancy. Available: http://www.worldlifeexpectancy.com/bangladesh-hypertension [Accessed February 26 2017].
YU, W., VOSS, C., MICHAEL, H., AHMED, K., FEINSON, L., KHAN, M. & TUINHOF, A. 2010. Implications of climate change for fresh groundwater resources in coastal aquifers in Bangladesh. *Washington, DC: World Bank*.

Annex 1

Sodium calculation from different sources

Drinking water: Individual status of drinking water was calculated first. The amount of water a person drink per day was collected through questionnaire survey. The salinity concentration value was collected from testing the specific drinking water source. Then, we estimated the amount of salt a person took per day in that area. Finally we converted this estimated amount of salt into sodium using standard procedures. For instances, 1000 mg Salt = 400 mg Sodium or 1 mg Salt = 0.4 mg Sodium.

[WHO recommended value was considered for calculation, 5 gram Salt equivalent to 2 grams Sodium. It means that 1 gram Salt = 0.4 gram Sodium.]

Direct salt (table salt): Through questionnaire survey, respondents were asked, how much salt they consumed during meals. The focus was on raw salt (table salt- NaCl). From the salt measurement, sodium was calculated.

Food Intake: A standard food table was created with 45 food items that the respondents usually took on a weekly basis. The amount of food was recorded in grams and numbers where applicable (e.g, number of egg or banana). From this amount, Sodium was calculated for each food item by multiplying the concentration amount of sodium of that amount of food. For example, Sodium from Rice = (Amount of Rice in gram) X Concentration of Sodium in Rice (0.1097 mg/g) (Islam et al., 2010). For this calculation, household size was also taken into account to estimate per capita intake per SES.

Sodium was calculated at the individual level from table salt and drinking water sources. Sodium from food was calculated at hte household level and then attributed to individual consumption in SES level.

Table 1. Logistic regression analysis outputs using Generalized Estimating Equation (GEE) - population average model adjusting standard error.

Explanatory variables	Adult Hypertension	
	Adjusted OR	**CI**
Socio-Ecological Systems		
Sundarban Dependent	Ref	
Charland-Riverine	0.77	(0.50-1.19)
Marine & Coastal Periphery	1.16	(0.76-1.77)
Irrigated Agriculture [Boro]	1.53*	(1.03-2.29)
Rain Fed Agriculture [Aman]	1.00	(0.67-1.51)
Saltwater Shrimp [Bagda]	0.66†	(0.43-1.03)
Freshwater Prawn [Golda]	0.61*	(0.41-0.92)
Sex		
Male	Ref	
Female	1.31***	(1.11-1.56)
Age Group		
Below 35 years	Ref	
35 yrs and Older	2.41***	(2.01-2.88)
Educational Level		
No Education	Ref	
Primary Incomplete	0.86	(0.69-1.08)
Primary Complete	0.90	(0.69-1.18)
Secondary Incomplete	0.74*	(0.57-0.96)
Secondary Complete & Higher	1.07	(0.77-1.48)
Occupation		
Agriculture	Ref	
Aquaculture	1.24†	(0.98-1.59)
Inland/Offshore Fishing	1.27*	(1.01-1.60)
Forest Collection/Livestock/Poultry/	1.22	(0.95-1.57)
Unskilled Labour	1.01	(0.82-1.23)
Businessman	1.06	(0.84-1.36)
Professional/Skilled Worker-Mechanic	1.80**	(1.25-2.60)
Others	1.35*	(1.04-1.75)
Religion		
Muslim	Ref	
Non-Muslim	0.78*	(0.63-0.97)
Landownership		
Landless (<=0.01 Acres)	Ref	
Homestead (<0.5 Acres)	1.21	(0.94-1.54)
Small Land (>=0.5 to <=2.5 Acres)	1.37*	(1.04-1.81)
Large land (>2.5 Acres)	1.61*	(1.13-2.31)
Household Dietary Diversity Score		
Ate 1-3 food groups	Ref	
Ate 4-6 food groups	0.74†	(0.53-1.03)

Ate 7-12 food groups	0.72†	(0.52-1.01)
Drinking water salinity level		
Fresh Water (<1000 mg/L)	Ref	
Slightly Saline (1000-2000 mg/L)	1.17†	(0.97-1.42)
Moderate Saline (>=2000 mg/L)	1.42*	(1.05-1.91)
Depth of tube-well		
Shallow tube-well (<=500 ft)	Ref	
Deep tube-well (> 500 ft)	0.74*	(0.56-0.98)
†p<0.1, * P<0.05, ** p<0.01, *** p<0.001; CI: 95% Confidence Intervals of Odd Ratios (OR), N = 6172. (Reference category)		

In logistic regression analysis we consider the variables that were significant in bi-variate analysis. Socio-Ecological Systems, Sex, Age Group, Educational Level, Occupation, Landownership and Drinking water salinity level were significant in bi-variate analysis so these were considered in the Generalized Estimating Equation (GEE model). In contrast, Sources of getting foods, Sodium consumption and Seasons of the study were insignificant in bi-variate analysis, so these were not included in the final regression analysis. Moreover, wealth quintiles, ecosystems service dependency and household size were also excluded from the regression analysis though they were significant in bi-variate analysis. This is because, there are some confounding effects, like between landownership and wealth quintiles. In addition, the model shows that landownership is more significant than that of wealth quintiles. Likewise, between ecosystems service dependency and socio-ecological systems, there were also confounding factors. In aggregate level, household dietary diversity, depth of tubewell and religion become significant in regression analysis but they were insignificant in bi-variate analysis. Household size was the reverse in this case.

Contributions

Contributed equally to conception and design: MAN, AA

Contributed to analysis and interpretation of data: MAN, AA, ANL

Revised the article: ANL, CWH, MS, PKS

Approved the submitted version for publication: MAN, AA

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Competing interests

"The authors have declared that no competing interests exist." MAN, AA

Figure legends:

Figure 1. ESPA deltas study area map.

Figure 2. Percent utilization of water sources by Socio-Ecological System.

Figure 3. Sodium consumption from different sources (bars) and mean drinking water salinity concentration (line).

Figure 4. Association of drinking water salinity and age group with adult high blood pressure (prehypertension and hypertension).

Figure 5. Gender specific adult high blood pressure in different SESs for above 35 years age group.

Figure 6. Association of HBP with drinking water salinity and round of the study (seasons).

Tables:

Table 1. Logistic regression analysis outputs using Generalized Estimating Equation (GEE) - population average model adjusting standard error.

Data accessibility statement

The household survey data is available at UK Data Service website.

Adams H, Neil A, Ahmad S, Ahmed A, Begum D, Matthews Z, Rahman MM, Streatfield PK. 2016. Spatial and temporal dynamics of multidimensional well-being, livelihoods and ecosystem services in coastal Bangladesh. [Data Collection]. Colchester, Essex: UK Data Archive. 10.5255/UKDA-SN-852179 (http://reshare.ukdataservice.ac.uk/852179/)

The drinking water salinity data has not yet been opened for public access.