# Drinking water contributes to high salt consumption in young adults in coastal Bangladesh

Mohammad Radwanur Rahman Talukder, Shannon Rutherford, Dung Phung, Abdul Malek, Sheela Khan and Cordia Chu

## ABSTRACT

Increasing salinity of freshwater from environmental and anthropogenic influences is threatening the health of 35 million inhabitants in coastal Bangladesh. Yet little is known about the characteristics of their exposure to salt (sodium), a major risk factor for hypertension and related chronic diseases. This research examined sodium consumption levels and associated factors in young adults. We assessed spot urine samples for 282 participants (19–25 years) during May–June 2014 in a rural sub-district in southwestern coastal Bangladesh and measured sodium levels of their potable water sources. The significant factors associated with high sodium consumption were determined from logistic regression analyses. Mean sodium content in tube-well water (885 mg/L) was significantly higher than pond water (738 mg/L) ($P = 0.01$). Fifty three percent of subjects were consuming sodium at levels above the WHO recommended level (≥2 g/day). The users of tube-well water were more likely to consume sodium above this recommended level than pond water users. Salinity problems are projected to increase with climate change, and with large populations potentially at risk, appropriate public health and behavior-change interventions are an urgent priority for this vulnerable coastal region along with targeted research to better understand sodium exposure pathways and health benefits of alternative water supplies.

**Key words** | Bangladesh, coastal, drinking water, salinity, young adults

**Mohammad Radwanur Rahman Talukder** (corresponding author)
**Shannon Rutherford**
**Dung Phung**
**Cordia Chu**
Centre for Environment and Population Health, School of Environment, Griffith University, Brisbane, Queensland, Australia
E-mail: *radwan.talukder@griffithuni.edu.au*

**Mohammad Radwanur Rahman Talukder**
International Centre for Diarrhoeal Disease Research, Bangladesh, Mohakhali, Dhaka, Bangladesh

**Abdul Malek**
**Sheela Khan**
Green Life Medical College, 32, Bir Uttom, K.M. Shafiullah Sarak (Green Road), Dhanmondi, Dhaka 1205, Bangladesh

## INTRODUCTION

Saltwater intrusion into surface and ground water, especially in low-lying coastal countries, is one of the major impacts of climate-induced sea level rise (Nicholls & Cazenave 2010; Mimura 2013). Apart from anthropogenic factors, climatic factors such as rising temperature and evaporation, and changing precipitation also contribute to saltwater intrusion (Werner *et al.* 2013; Wong *et al.* 2014). Moreover there is general agreement that climatic drivers including sea level rise will continue to aggravate this salinization process (Cañedo-Argüelles *et al.* 2013; Wong *et al.* 2014). In coastal Bangladesh the saline front has reached more than 100 km inland (Khan *et al.* 2011a) and is advancing further inland (BADC 2011). Of the limited evidence available on health effects of water salinity, research with pregnant mothers consuming saline water demonstrated an abnormally high level of salt consumption, well in excess of the recommended intake (>85 mmol ~ >2 g/day) (Khan *et al.* 2011b). However Bangladesh data on salt (sodium) consumption in other population and age groups from such salinity affected areas are lacking. This research examined the sodium (salt) exposure level amongst a young adult population in climate change vulnerable coastal communities of Bangladesh.

The majority of coastal areas of Bangladesh are part of the low and flat Ganges delta, between 3 and 5 meters above the sea level (Nishat & Mukherjee 2013a), with extensive river systems networking into the Bay of Bengal making the region vulnerable to water and soil salinization. This

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change in water and soil quality, apart from climate factors, is also contributed by man-made factors such as overexploitation of ground water and horizontal expansion of shrimp farming, and to a large extent, decreasing flow due to the presence of the upstream Farakka dam in India (Nishat *et al.* 2013b). Between 1973 and 2009 salt affected land areas increased by almost 27% from 833,000.45 to 1,056,000.26 hectares (SRDI 2012). This salinization of water can have serious health implications.

Among the dietary risk factors, high dietary sodium consumption is the second largest contributor to disease burden worldwide, accounting for 4 million deaths (Lim *et al.* 2012). Excess salt (sodium) consumption is associated with a rise in blood pressure (Meneton *et al.* 2005; He & MacGregor 2009; WHO 2012), which is a major risk factor for cardiovascular and renal diseases (WHO 2012; Koliaki & Katsilambros 2013). High blood pressure or hypertension is responsible for approximately 45% of deaths due to heart disease, 51% of deaths due to stroke (WHO 2013) and 29% of deaths due to chronic kidney disease (Naghavi *et al.* 2015). Moreover high intake of salt has deleterious effects on other systems in the body, for example, stomach (e.g. cancer) and bones (e.g. osteoporosis) (He & MacGregor 2009).

The World Health Organization (WHO) recommends daily sodium intake of < 2 g (<85 mmol) (~5 g/day salt) in adults (16 years and above) to curb the population-wide burden of hypertension and associated risk of cardiovascular disease, stroke and coronary heart disease (WHO 2012), and to prevent the additional health risks mentioned above (He *et al.* 2013). This recommended level was based on a systematic review of experimental (randomized controlled trials) and observational studies (cohort studies), that mostly related to food salt intakes in populations in developed regions like Australia, New Zealand, North America and Europe. These studies were separated for adults (16 years and above) and children and assessed against three levels of sodium consumption <2 g/day, 1.2–2 g/day and <1.2 g/day irrespective of body weight of study participants (WHO 2012). A reduction of sodium intake at this level (~2 g/day) is estimated to reduce strokes by 17% and coronary heart diseases by 12% (He 2003). However a recent global estimate indicated that the mean sodium intake (3.54 g, 95% uncertainty levels 2.98–4.21) (Powles *et al.* 2013) was still substantially higher than this WHO recommended level suggesting that dietary salt intakes remain a serious health concern.

In coastal Bangladesh people directly consume water from natural surface and ground freshwater sources, for example, rivers, ponds and tube well without any prior treatment. Some research indicates sources are already contaminated with varying levels of salinity (Khan *et al.* 2011b) threatening the wellbeing of more than 35 million inhabitants. Average sodium levels in surface and ground drinking water sources (e.g. pond, river, tube well) have been reported to be 517 mg/L where sodium content was significantly higher in groundwater (tube-well water sodium 714 mg/L), which translates to approximately 1–1.5 g of sodium (salt) intake daily from drinking water alone assuming a daily intake of 2 L of water (Khan *et al.* 2014). Given that coastal salinity has emerged as a significant environmental problem for many low-lying countries (World Bank 2013) and that many people in these low-lying developing countries do not have safe alternative water supplies, it is timely to examine exposures to sodium in these populations. Of the available studies, research by Khan *et al.* (2011b, 2014) among pregnant mothers, and Rasheed *et al.* (2014) in adults aged 25 years and above, have both demonstrated a high salt intake by these Bangladeshi populations, especially in coastal areas. But limited information is available about salt exposure in other populations in similar settings in Bangladesh.

Overconsumption of sodium, particularly if starting from an early age has the potential to increase significant risks of developing hypertension, cardiovascular and kidney diseases later in life. Intervening early in life should help to reduce the burden of raised blood pressure and related adverse chronic health effects and ensure this healthy active population remains productive. However little is known about sodium (salt) exposure among people in younger age groups, for example young adults (aged 19–25), particularly in these coastal areas in Bangladesh where salt in the drinking water has increased and safe alternative water supplies are scarce (Khan *et al.* 2011b). The objective of this research is to examine the level of, and factors contributing to, salt consumption in young adults in coastal Bangladesh in order to inform policy makers to develop appropriate intervention strategies to prevent the potential medium- to longer-term health risks associated with increased sodium intake.

## METHODS

### Study design, settings and study population

We conducted a cross-sectional survey among young adults (aged 19–25 years) during May and June 2014 in Koyra, a rural sub-district of Khulna district in southwestern coastal Bangladesh (Figure 1). This sub-district belongs to the exposed coast as it is open to the sea and lower estuaries receiving tidal water flows and is prone to salinity intrusion, cyclones and storm surges (Program Development Office for Integrated Coastal Zone Management Plan (PDO-ICZMP) 2003). Out of nine sub-districts in Khulna district, the highest level of salinity in surface and ground water sources has been found in this sub-district (Abedin & Shaw 2013).

Of the seven unions in this sub-district we selected two (Koyra Sadar and Amadi) based on the diversity of potable water sources. According to the Bangladesh Bureau of Statistics, Amadi has only 7.7% and Koyra Sadar has 90.6% of drinking water sourced from tube wells (BBS 2011). Ponds are the other major source of drinking water in this area (BBS 2011). We used a probability proportionate sampling technique to randomly select four villages, two villages from each union in our study. Household members, both male and female, of 19–25 years of age in the selected four villages who consented and were available during the data collection were recruited in the study. In the selected villages trained research staff conducted household visits,

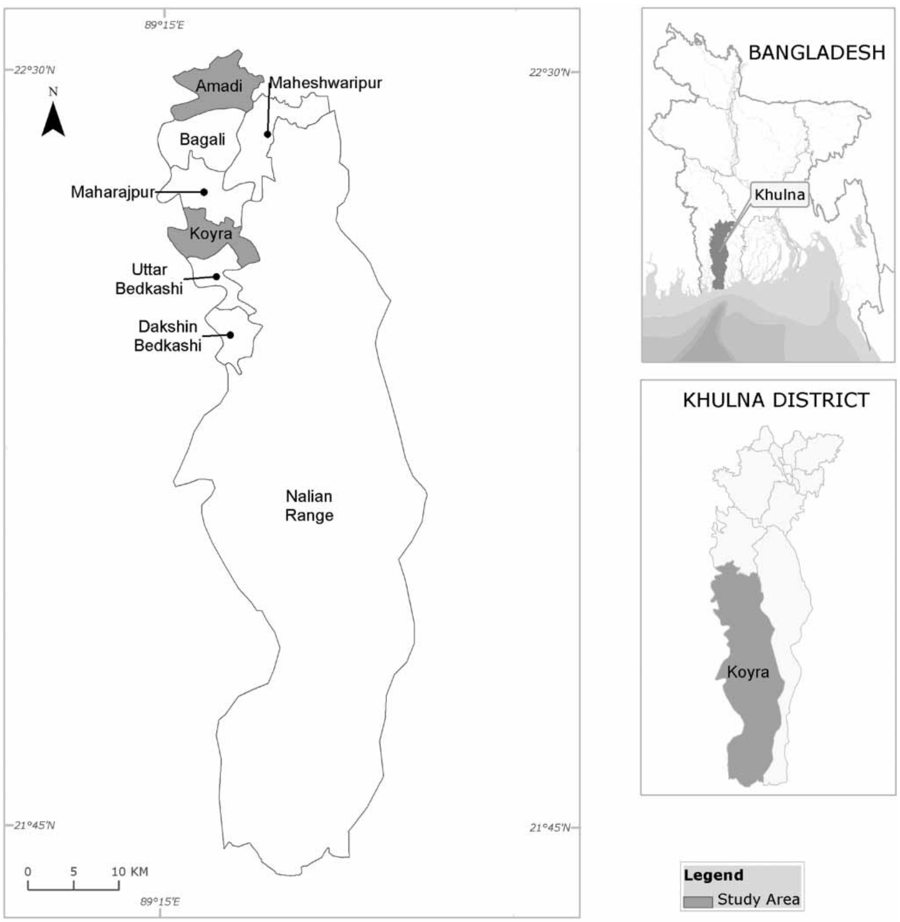


**Figure 1** | Map showing the study areas in Koyra sub-district of Khulna district in southwestern coastal Bangladesh.

identified and listed 418 eligible participants of 19–25 years age. Of those eligible, 340 subjects were available for interview and health assessments. We excluded 21 pregnant women due to their physiological changes (e.g. increased glomerular filtration, changes in hormonal concentrations) during pregnancy, which affect sodium handling in body and kidney (Institute of Medicine, Panel on Dietary Reference Intakes for Electrolytes & Water 2005) and four participants who refused to participate resulting in 315 (92.6%) successful interviews. Urinary sodium content data were available for 282 subjects (Figure 2). The research was approved by the ethical committee of Griffith University and the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR, B) and written informed consent was obtained from all the participants before data collection commenced.

## Data collection

The trained research staff (The research staff who had a Bachelors' level of formal education received 2 days of training on data collection, standard anthropometric procedures and blood pressure measurements. Following classroom training, field experience was provided on human subjects (not related to the study) to improve their technical skills. The research investigator was present in the field full time, and made regular and random household visits to monitor the quality of the data collected.) visited the households of eligible participants to obtain information on socio-demographic conditions, occupation, the sources of

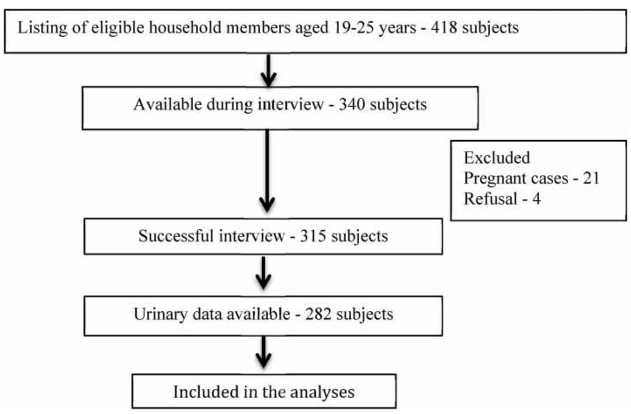


**Figure 2** | Recruitment of study participants.

drinking and cooking water, duration of use in a year and in their life time, family history of hypertension and diet including use of additional salt during meals.

Weight and height of each participant was measured following standard anthropometric techniques. Weight was measured on a digital electric balance (TANITA HD 318 Digital weighing scale, $150\ \text{kg} \pm 0.1\ \text{kg}$) and height was measured using S + M height measure scale-2 m (Aaxis Pacific Healthcare, Australia). Three measurements of blood pressure, with 10 minute intervals between each measurement, were taken from the right arm of the seated participant after a 30-minute rest period using OMRON HEM-7111 automated sphygmomanometer following standard guidelines (Pickering et al. 2005). The mean of the last two measurements was used in the analysis.

## Environmental assessment

Water samples (200 mL) from drinking water sources identified by the participants were collected in a clean plastic container by the field staff and were analysed at the ICDDR, B laboratory. Salinity of the water samples was measured in parts per thousand (ppt) using a conductivity meter (Model: Session5, company: HACH, origin: USA), which was then converted into milligrams per liter (mg/L) (1 ppt = 1,000 mg/L) for analysis purposes. For each sampled batch, the conductivity meter (Model: SensIon5, HACH, USA) was calibrated using sodium chloride standard solutions (HACH, USA. Cat#14400-42 and Cat#27143-49).

## Biological assessment

Twenty-four hour urinary excretion of sodium is recommended for assessing sodium intake (Elliott & Brown 2007). However, the 24-hour urine collection is limited by a high participant burden resulting in poor compliance and incomplete collection (Elliott & Brown 2007) rendering it not practical in public health practice or in epidemiological surveys (Tanaka et al. 2002). An alternative low burden and low cost method for measuring sodium intake at the population level is to estimate 24-hour excretion based on a spot sample. Several studies have reported significant positive correlations between spot (casual) and 24-hour urinary sodium excretion (Kawasaki et al. 1993; Tanaka et al. 2002; Brown et al. 2013; Mente et al. 2014). In our research we measured spot urine sodium. Urine samples were analysed at the ICDDR, B. Urinary sodium was measured by Ion Selective Electrode (ISE) method, using an Automated Chemistry Analyzer, Olympus, Model AU640, Beckman Coulter International, Japan and calibrated by ISE calibration. The standards used were ISE Low/High Urine Standard. The ISE standard values are traceable to the National Institute of Standards and Technology Standard Reference Material 2201 for sodium and chloride. Spot urinary excretion values for sodium, potassium and chloride were measured in millimoles per litre (mmol/L) and creatinine was measured in micromoles per litre (micromol/L). Based on this measure we then estimated the 24-hour sodium level applying a direct approach using the INTERSALT (International Cooperative Study on Salt, Other factors and Blood pressure) study formula and considering its application in a wider population (Cogswell et al. 2013).

### Statistical analyses

We checked normality of the data and calculated mean, standard deviation, median and ranges for continuous variables and proportions for categorical variables and for comparison used Student's *t*-test or Pearson's $\chi^2$ test, as appropriate. Abnormal sodium consumption was defined for urinary sodium level using the WHO cut-off point (≥2 g sodium/day) and dichotomized into above (2 g or above) and below (<2 g) the WHO recommended level (WHO 2013). A principal component analysis of basic housing construction materials (materials used to construct wall, roof, and floor of houses) and household belongings was applied to construct a wealth index score for each household. The scores were divided into low, middle and high tertiles. Body mass index (BMI) was calculated from measured weight and height for each subject and categorized into underweight (<18.5), normal weight (18.5–24.9) and overweight (>24.9). For each food item the mean of 7-day intake frequency was calculated to represent usual diet consumption.

To determine the factors associated with high salt (sodium) consumption a logistic regression model was used. The independent variables – sex, marital status, education, occupation, household wealth index, BMI, salt added in meals and major source of drinking water, with potential influence on the outcome ($P < 0.20$) in bivariate analyses were included in multivariate model using the stepwise backward mode. The odds ratio with 95% CIs were calculated in order to assess the adjusted risk of independent variables and those with $P < 0.05$ were retained in the final model. All data were analyzed using STATA version 13.

## RESULTS

### Sodium consumption and characteristics of the study participants

The mean level of sodium excretion was 106 mmol/L (±74.62) ~ 2.4 g. Over 50% of the study subjects were calculated as consuming sodium above the WHO recommended level (≥2 g sodium/day) (Table 1).

Table 2 summarizes the characteristics of the study participants and their drinking water sources. About 66% of the respondents were female and the majority of them were housewives. Sixty-seven percent of the respondents were married. More than 70% of the respondents had education above primary level. One third of the participants belonged

**Table 1** | Urinary electrolytes, urinary Na/Cr* and 24-hour estimated sodium in young adults ($n = 282$) in Koyra, Bangladesh, 2014

| | Urinary sodium (UNa) mmol/L (sd) | Urinary potassium mmol/L (sd) | Urinary chloride mmol/L (sd) | Urinary creatinine (UCr) mmol/L (sd) | UNa/UCr* | Estimated 24-hour urinary sodium mmol/d (sd) |
|---|---|---|---|---|---|---|
| Mean ± Sd | 106.3 (74.6) | 31.6 (23.3) | 136.2 (89.6) | 8.4 (6.6) | 15.7 (9.5) | 120.5 (31.0) |
| Median (IQR^) | 92.5 (43.7, 155.5) | 27.8 (2.0, 97.7) | 122.1 (54.2, 207.8) | 6.8 (3.4, 11.4) | 13.2 (9.0, 21.2) | 115.8 (101.0, 134.8) |
| Range | 10.5, 394.0 | 2.0, 159.8 | 12.0, 415.2 | 0.3, 39.8 | 1.6, 62.4 | 42.0, 291.7 |

*Urinary sodium/creatinine ratio; $n = 279$; ^IQR = interquartile range.

**Table 2** | Characteristics of the study population in Koyra, a coastal sub-district, Bangladesh, 2014 ($n = 282$)

| | N | % | Percent above the WHO recommended level (*P*-value) |
|---|---|---|---|
| Sex | | | |
| Female | 185 | 65.6 | 55.7 |
| Male | 97 | 34.4 | 47.4 |
| Marital status | | | |
| Married | 189 | 67.0 | 59.3 (0.002) |
| Religion | | | |
| Islam | 254 | 90.1 | 52.4 |
| Education ($n = 278$) | | | |
| Primary or below (0–5 y) | 79 | 28.4 | 55.7 |
| Secondary incomplete (6–9 y) | 113 | 40.6 | 54.0 |
| Secondary or higher (>= 10 y) | 86 | 30.9 | 48.8 |
| Occupation | | | |
| Non labour | 72 | 25.5 | 40.3 |
| Housewife | 102 | 36.2 | 61.8 |
| Physical labour | 108 | 38.3 | 52.8 (0.020) |
| Wealth index$ ($n = 239$) | | | |
| Low | 83 | 34.7 | 53.0 |
| Middle | 72 | 30.1 | 50.0 |
| High | 84 | 35.1 | 52.4 |
| Drinking water | | | |
| Tube well | 180 | 63.8 | 61.1 |
| Surface/pond water | 102 | 36.1 | 38.2 (<0.001) |
| BMI | | | |
| Underweight <18.5 | 75 | 26.6 | 53.3 |
| Normal weight 18.5–24.9 | 153 | 54.3 | 52.3 |
| Overweight >24.9 | 54 | 19.1 | 53.7 |
| Added salt in meals | | | |
| Yes | 151 | 53.6 | 58.9 |
| No | 131 | 46.4 | 45.8 (0.027) |
| Blood pressure (mean, sd) | | | |
| SBP | 110.7 (10.4) | | |
| DBP | 66.5 (9.2) | | |

$ Based on number of households.

to the highest wealth quintile. Tube well and ponds were the only major sources of drinking water, of which tube-well water was used predominantly (63.8%). Tube-well water had significantly higher water sodium levels (mean 885 mg/L) compared to pond water (738 mg/L) (Figure 3). Use of additional salt during meals was very common (53.6%).

## Factors associated with high sodium consumption: bivariate and multivariate analyses

According to bivariate analyses, sodium consumption was significantly higher among those married, housewives, those who added salt to their meals and those were from the middle wealth quintile. The source of drinking water

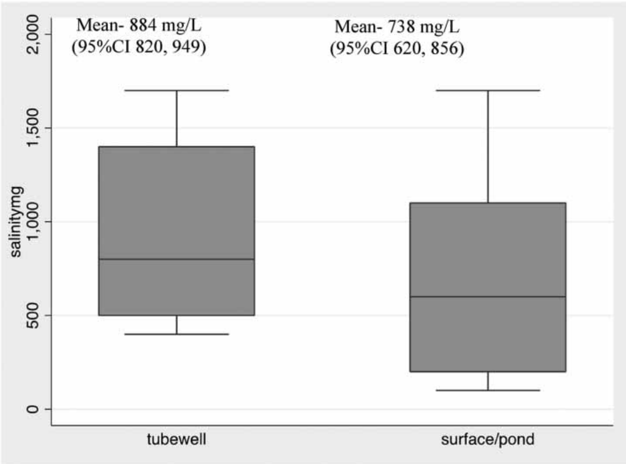


**Figure 3** | Mean water sodium level (mg/L) in drinking water sources of the study participants in Koyra, Bangladesh ($n = 282$). Boxes represent IQR with the line at the median, $P$ for mean value = 0.01.

was also associated with increased consumption of sodium. Compared to pond water, tube-well water was associated with significantly higher intake of sodium in the study respondents.

In the multiple regression analyses, being married, using tube-well water and being in the middle wealth quintile remained statistically significant as predictors of high sodium consumption. The users of tube-well water were more than 2 times more likely to consume high sodium than the users of pond water (AOR 2.43, 95%CI 1.38–4.30). Among the subjects who were married the odds of high salt consumption were 2.5 times higher than the non-married group and the odds of high salt consumption was higher among the middle wealth quintile group (AOR-middle 2.24, 95% CI 1.13–4.44) (Table 3).

**Table 3** | Factors associated with high sodium intake (^) in young adults in Koyra, Bangladesh, 2014

| Variables | Unadjusted OR | 95% CI | Adjusted OR | 95% CI |
|---|---|---|---|---|
| *Sex* | | | | |
| Male | 1.00 | | | |
| Female | 1.39 | 0.85–2.28 | | |
| Currently not married | 1.00 | | | |
| Married | 2.20** | 1.33–3.65 | 2.52** | 1.38–4.59 |
| *Education* | | | | |
| Primary or below | 1.00 | | | |
| Secondary incomplete | 1.23 | 0.70–2.15 | | |
| Secondary or higher | 1.32 | 0.71–2.43 | | |
| *Occupation* | | | | |
| Non labour | 1.00 | | | |
| Housewife | 2.39** | 1.29–4.44 | | |
| Physical labour | 1.66 | 0.91–3.03 | | |
| *Wealth quintiles* | | | | |
| Low | 1.00 | | | |
| Middle | 1.95* | 1.03–3.71 | 2.24* | 1.13–4.44 |
| High | 1.30 | 0.71–2.39 | | |
| *Drinking water sources* | | | | |
| Surface/pond water | 1.00 | | 1.00 | 1.38–4.30 |
| Tube well | 2.54*** | 1.54–4.18 | 2.43** | |
| *Added salt in meals* | | | | |
| Yes | 1.70* | 1.06–2.72 | | |
| No | 1.00 | | | |
| *BMI* | | | | |
| Underweight <18.5 | 1.04 | 0.60–1.81 | | |
| Normal weight 18.5–24.9 | 1.00 | | | |
| Overweight >24.9 | 1.06 | 0.57–1.97 | | |

^Based on WHO (≥2 g sodium/day) recommendations.
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

## DISCUSSION

We have observed 53% of the young adults (19–25 years) in coastal Bangladesh having average urinary sodium content (106 mmol ≈ 2.4 g sodium ≈ 6.2 g salt i.e. sodium chloride) above the recommended level. Using the WHO cut-off point for sodium intake Rasheed *et al.* (2014) reported 59% of the adult population (25 years and above) was exposed to high levels of sodium in this area. Assessment of sodium intake in our study was based on spot urine collection rather than 24-hour urine collection. However, our estimated value for 24-hour sodium, which is considered 'gold standard' for daily sodium consumption (Elliott & Brown 2007), also showed a similar level of sodium consumption as spot urine. This high level of sodium consumption is also comparable to that reported in adults (>25 years) in coastal Bangladesh

(Rasheed et al. 2014), in adults (18 years and above) in southeast Asia, for example in Indonesia and Malaysia (Batcagan-Abueg et al. 2013) and in children (2–16 years) in Australia (Grimes et al. 2013). But the level of sodium consumption is lower than reported in pregnant mothers in similar settings of Bangladesh (Khan et al. 2011b, 2014), 2010 regional estimates for adults in south Asia (Powles et al. 2013) and other southeast Asian countries such as Singapore and Thailand (Batcagan-Abueg et al. 2013). The average level of urinary sodium in pregnant women in coastal Bangladesh was 3.4 g/day (Khan et al. 2011b) and 4.6 g/day (Khan et al. 2014). However in pregnant women this higher consumption of sodium to some extent could be due to their overall increased intake of drinking water, and altered salt appetite during pregnancy (Brown & Toma 1986).

On the basis of the health evidence used to establish the WHO guideline, these findings suggest significant health consequences at the population level for this majority of young adults who are consuming elevated sodium so early in life. The current recommended guideline for sodium of less than 2 g/day is independent of body weight but mostly based on evidence from developed countries as mentioned before, where average adult body weight is far above that of individuals in developing regions like ours. For example, average body weights of an adult male and female aged 18–24 years are 79.9 kg and 66.5 kg in Australia (ABS 2013). In our study average body weights of adult male and female were 54 and 46 kg. Therefore, the biological effect of similar levels of sodium consumption on systems of the body in the Bangladeshi population is potentially much higher than those estimated from studies based on higher body weight populations in developed countries used to derive the current WHO sodium recommended daily intake.

Sources of water in these communities have been found to be strongly associated with high salt consumption. This study has demonstrated a higher level of salinity (sodium) in tube wells (ground) than pond (surface) water and average sodium consumption was significantly higher among the tube well than pond water users. An average sodium level of 884.6 mg/L in tube-well water, measured in our study, may be alone contributing to ~1.7 g sodium intake daily (assuming 2 L intake from drinking). Previous studies in coastal Bangladesh also reported elevated levels of sodium in tube-well water, which was associated with high sodium consumption in the pregnant women (Khan et al. 2011b, 2014). While tube-well water is believed to be microbiologically safe and widely used all over Bangladesh including in coastal parts (in our study more than 60% used it), the contamination of fresh water resources with saltwater may contribute to a high level of sodium exposure in populations even from their early life. Moreover the lifetime contribution of saltwater contaminated surface water (ponds) to elevated/cumulative sodium exposure cannot be ignored, which can also potentially increase the risk of blood pressure rise and subsequent health effects. In our study we have found that almost one-fifth of the young population had blood pressure above normal range (Systolic Blood Pressure >120 mmHg or Diastolic Blood Pressure >80 mmHg). This implies potential of being hypertensive in later life and risk of developing other chronic diseases (such as cardiovascular and kidney diseases). However detailed analyses are required to better establish the relationship between high salinity water, sodium consumption and blood pressure in such a young population.

In coastal Bangladesh natural freshwater sources such as pond, tube well and rivers are used not only for bathing but also for cooking, bathing and washing in coastal Bangladesh (Khan et al. 2011a). Other than drinking, cooking water could potentially contribute to high intake of sodium, but this has rarely been considered. A study by Page et al. (1974) among the six tribal communities in the Solomon Islands demonstrated that those who cooked vegetables in seawater had the highest salt intake. Rowan & Calabrese (1981) demonstrated consuming a one-cup serving of vegetables per day cooked in water with 100 or 250 mg Na/L would lead to an additional intake of 37 and 96 mg of sodium, respectively. In our study, we also observed that the same sources (e.g. tube well) were used for drinking as well as for cooking. Our rural study population was found to have a typical Bangladeshi diet prepared at home that included regular rice intake and less frequent consumption of fish, poultry or red meat, fruits and vegetables. Such a dietary pattern is likely to contribute only 10–12% of total sodium intake naturally and is in contrast to the food pattern in many other western countries where processed food is the major source (75–80%) of dietary sodium (Brown et al. 2009; Koliaki & Katsilambros 2013). As people consume food prepared at home it is also more likely that salt used during cooking could further contribute to high salt consumption. In addition accumulation of sodium in produced crops due to saline water intrusion into soil and groundwater in this area could be a potential source of dietary sodium and demands further investigation (Rasheed *et al.* 2014). We also observed that salt addition in meals was very common in this study population. Given the direct and continuous relationship between salt intake and blood pressure (Koliaki & Katsilambros 2013) and the difficulties in reducing exposure from salt contaminated freshwater sources, reduced salt input to food during cooking and table use should be considered as a starting point to minimize dietary salt intake and reduce population health risk.

We also observed that salt consumption was significantly higher among the married study population. The majority of the married population (80%) was female aged 19–25 years. This is to some extent in contrast to the observation that men consume more salt than women in other parts of the world (Powles *et al.* 2013) and as explained by researchers could be attributable to more food intake by men (Elliott & Brown 2007). Higher salt consumption by females in our study could be due to changing female roles, i.e. being married means taking on the role of caregiver for the whole family in such settings and hence increased involvement with the food preparation, therefore potentially consuming more salt (Rasheed *et al.* 2014). High salt exposures in their early reproductive age period may make these young women more prone to develop eclampsia or pre-eclampsia during pregnancy, a finding already reported in similar settings (Khan *et al.* 2014).

Non-communicable diseases (NCDs) account for 59% of total deaths in Bangladesh (WHO 2014). In recent years deaths related to cardiovascular and cerebrovascular diseases have increased substantially (Karar *et al.* 2009). An increased prevalence of chronic kidney diseases among Bangladeshi population has also been reported (Anand *et al.* 2014). Hypertension is not only a disease of its own but also a risk factor for other major NCDs such as stroke, coronary heart disease, heart failure and renal impairment (Dean & Shuaib 2011; He *et al.* 2011). In Bangladesh 18% of the adults aged 25 years and above have been found to be hypertensive (WHO 2011), a figure which is anticipated to grow further in the years to come with the rising trend (National Institute of Population Research and Training, Mitra and Associates & ICF International 2013). Reduction in sodium (salt) intake is one of the most cost-effective interventions to reduce cardiovascular disease burden. A 15% reduction in mean population salt intake could avert 8.5 million cardiovascular deaths (He *et al.* 2013).

The predicted climate change and associated sea level rise for coastal Bangladesh will further increase the saltwater contamination of both surface and ground freshwater resources, increasing the sodium related health threats to larger populations in these areas. Modeling of climate related changes in sea levels, temperature/rainfall patterns, and upstream riverine flows for different climate change scenarios according to IPCC's fourth assessment report along with projected estimates for land subsidence and river water abstraction indicate that climate change will cause significant changes in river salinity in the southwest coastal area of Bangladesh during the dry season (October to May) by 2050 (Dasgupta *et al.* 2014). This prediction suggests that both the extent and the magnitude of sodium exposure from increased salinization of water will increase in coastal Bangladesh. The freshwater river area (0–1 ppt) is anticipated to decline from 40.8 percent in 2012 (March) to 19.7 and 17.1 percent in the best and worst case future scenarios for 2050, respectively. The same projection case scenarios also indicate an increase of moderate to highly saline river areas (3 to above 5 ppt) and a decrease of slight to moderately saline river areas (~0 to 3ppt) from the baseline in 2012 (Dasgupta *et al.* 2014). This will result in an increasing number of people in coastal areas exposed to higher sodium in water with significant scarcity of freshwater supply. For example, in our current study area (Koyra Sub-district) and adjacent areas (districts and sub-districts) the river salinity level is projected to range from 4 to 25 ppt (i.e. 4–25 g/L), with some areas projected to have salinity levels more than 25 ppt (World Bank 2015), a figure which is twice the upper value of the current range reported (Khan *et al.* 2011b) and well above the ~1 ppt of Bangladesh standard level for salinity in drinking water (Abedin & Shaw 2013). These projected changes paint an alarming picture for sodium related health risk in coastal areas of Bangladesh in the coming years, warranting investment into the development and promotion of alternative water options and the execution of effective water resources management strategies in vulnerable coastal communities.

Our study is the first to describe salt (sodium) consumption among young adults in coastal Bangladesh. Though this may not be representative of national level salt consumption, our finding has strong implications for large populations in many low-lying low-income coastal countries who predominantly rely on natural water resources with limited opportunities for desalination. Water resources in all the 11 Asian mega-deltas and other large deltas such as the Nile and Mississippi are vulnerable to climate change, sea level rise and saline intrusion (Nicholls *et al.* 2007). Considering the adverse health effects of high salt consumption, direct influence on blood pressure rise in particular (Meneton *et al.* 2005; WHO 2012; He *et al.* 2013), the life time consequences of a large proportion of young population exposed to a high level of sodium during their early life in coastal Bangladesh and arguably in other similar deltas globally will be significant if efforts are not made to reduce exposure.

The findings presented here fill some gaps but also indicate that more research is needed to explore and quantify all potential routes of salt exposure in such settings: consumption through direct ingestion of salt contaminated water, through cooking either from water or addition during food preparation, from food grown and manufactured in saline environments or added to food. Considering the context and all the routes of salt exposure multipronged adaptation strategies, either dietary modifications or promotion of alternative safe water options (e.g. rainwater harvesting) or both, should be designed and evaluated. Researchers should also evaluate long-term health benefits from decreasing chronic disease burden of reducing salt exposure and different intervention strategies to support the policy makers' decision process.

### Strengths and limitations of the study

We assessed water salinity once during the late in the dry season. Seasonal variation of water salinity has been reported in another study with higher salinity level during the dry season (Khan *et al.* 2011b). The water sodium level in our study is also comparable with the level reported in a previous study that found consistently higher water sodium levels in all the seasons (Khan *et al.* 2014). Furthermore rainfall during the late dry season (May–June) is likely to affect water salinity levels, therefore it is believed that figures reported represent the conservative case estimate of the sodium level in water. Our estimate of salt consumption is based on spot urine analyses due to resource constraint and practical limitation of non-compliance. To address the variability in sodium excretion, repeated measures of urine samples are recommended (Elliott & Brown 2007). Urine samples were collected during both morning and afternoon, and were equally distributed and well representative of diurnal variation. The sample size was small and the participants were selected, as those available at the household during the visit, which could have biased the sample.

## CONCLUSION

More than half of the study population in coastal Bangladesh had sodium above the recommended level and water sources contaminated with higher sodium were significantly associated with the high sodium consumption. Climate-induced sea level rise is likely to exacerbate salinity levels i.e. sodium content, in both surface and ground waters of many low-lying coastal countries in the years to come. Yet, the people in these areas have limited safe water options and water treatment capacity and hence are more likely to remain exposed to high salt if no population-based responses are implemented. However data on different pathways of salt exposure, salt consumption and subsequent chronic health effects in these settings are particularly pertinent for designing and implementing intervention strategies and require further investigation. Specific health promotion interventions addressing the harmful effects of high salt consumption and backed by appropriate policy steps to reduce salt exposure with special attention to climate change vulnerable coastal communities need to be adopted. Simultaneously adaptation strategies should also focus on promotion of alternative safe water options such as rainwater harvesting and appropriate management of freshwater sources in coastal communities.

## COMPETING INTERESTS

No conflict of interests declared by the authors.

## AUTHORS' CONTRIBUTIONS

MRR, SR and CC contributed to the research design and data analyses. MRR, SR, DP, AM and SK contributed to the literature review, manuscript drafting, and interpretation of results. All authors provided critical intellectual input in editing and revising the manuscript, and finally approved the manuscript for submission.

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