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Khatun Mst Asma
School of Economics and Management, Kochi University of Technology

Koji Kotani
School of Economics and Management, Kochi University of Technology
Research Institute for Future Design, Kochi University of Technology

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School of Economics and Management
Research Institute for Future Design
Kochi University of Technology

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Khatun Mst Asma* Koji Kotani*,†,‡,§,¶

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Abstract

An increase in surface and ground-water salinity due to climate change is reported to have become a great threat to the health of coastal inhabitants in Bangladesh. However, little is known about how much such salinity affects the risk of water-related diseases and how such risk can be mitigated in the field. This research examines the association between water-related diseases and coastal salinity along with sociodemographic and anthropometric factors. We conduct questionnaire surveys with 527 households: 273 subjects from the non-salinity and 254 subjects from the salinity rural coastal areas of Bangladesh. The logistic regression analysis demonstrates that the probability of suffering from water-borne, water-washed and water-related diseases are 8 %, 14 % and 11 % higher in the salinity areas than in the non-salinity areas, respectively. However, it is identified that people who consume rainwater as a drinking source and/or belong to "normal body mass index" have less chances of being affected by water-related diseases even in the salinity areas than those who drink ground/pond water and/or belong to "underweight body mass index." Overall, the results suggest that the long-term reservation of rainwater and addressing community-based food security & nutrition programs shall be effective countermeasures to reduce the risk of health problems in the coastal population and to sustain their lives even under the threat of land salinity.

Key Words: Water-borne diseases; water-washed diseases; water-related diseases; salinity; body mass index

*School of Economics and Management, Kochi University of Technology
†Research Institute for Future Design, Kochi University of Technology
‡Urban Institute, Kyusyu University
§College of Business, Rikkyo University
¶Corresponding author, E-mail: kojikotani757@gmail.com

Contents

Nomenclature

BMI Body mass index

1 Introduction

Water and food are two basic elements of human life, however, supplying clean water and adequate food for people is a great challenge throughout the world at present. For instance, it is reported that contaminated water and inadequate food are the major concerns for human health and mortality worldwide (UNICEF and WHO, 2015, Elahi, 2016, Nahian et al., 2018). Contamination of both surface and groundwater resources by different degrees of salinity in the deltaic and coastal regions poses a significant threat for 600 million people in the world (Talukder et al., 2016, Jevrejeva et al., 2018). Being a low-lying country, Bangladesh is highly susceptible to climate change and its coastal area is more vulnerable than any other part of the country due to the salinity level associated with a sea-level rise by climate change (Alam and Murray, 2005, Brammer, 2010, Mallick et al., 2011, Brammer, 2014, Huq et al., 2015, Alam et al., 2017). Salinity intrusion is a particular concern for Bangladesh where more than 35 million people drink water with elevated salinity level (Vineis et al., 2011, Talukder et al., 2016). Salinity prevalence drives human health in complex direct and indirect ways (Paul and Jabed, 2018, Shammi et al., 2019) and it is also linked with higher water-related diseases (Nahian et al., 2018). However, research on the human health risks of salinity in such context is scarce. Therefore, this paper addresses the association between salinity and water-related diseases.

Past studies explore the cumulative effects of salinity, finding that salinity deteriorates the general health of the coastal population. Salinity and its relationship with a rise in blood pressure are well documented (Khan et al., 2011a, Aburto et al., 2013, He et al., 2013, Talukder et al., 2016, Scheelbeek et al., 2017, Talukder et al., 2017, Shammi et al., 2019). Khan et al. (2014) show a significant association between high saltwater intake and both (pre)eclampsia (or gestational hypertension). Talukder et al. (2015), Rasheed et al. (2016) and Nahian et al. (2018) find a positive relation between salinity and the risk of stroke & cardiovascular disease. Müller et al. (2019) report that salinity adversely affects skin or other target organs, causing regulatory effects on cardiovascular disease, inflammation, infection and autoimmunity. To make matters worse, several studies suggest that contemporaneous exposure to saline water may change a menstrual cycle of women, increasing the risk of pre-term birth, miscarriage and restrict infants' neuro-metabolism (Warner et al., 2012, Khan et al., 2014, Stocher et al., 2018). Drinking high saline water may increase the risk of kidney stone disease, reducing bone mass (Yamakawa et al., 1992, Matkovic et al., 1995, Akter, 2019).

Relationship between coastal salinity and water-related diseases is mentioned by another group of studies. Frequent cholera and diarrhoea are linked with drinking elevated salinity (Hunter et al., 2010, Khan et al., 2011b, Braun and Saroar, 2012, Schellnhuber et al., 2013, Talukder et al., 2015, Saha, 2017).[1] Warner et al. (2012) report that water-borne diseases such as diarrhoea and dysentery are increasing in the coastal areas because of high salinity. Salinity intrusion and expansion of brackish water bodies due to climate change increase vector-borne diseases, such as malaria and dengue (Guterres, 2008, Ramasamy and Surendran, 2012). Some evidence also suggests that drinking elevated salinity is also linked with water-washed diseases. Khan et al. (2011b), Braun and Saroar (2012), Talukder et al. (2015) and Nahian et al. (2018) document that there is a positive association between elevated salinity and the risk of skin diseases & acute respiratory infections. Jabed et al. (2018) present that coastal people are suffering from skin diseases and hair loss due to the use of saline water.

Inhabitants of coastal communities are reported to have suffered from salinity problems for a long time. However, few studies systematically investigate the relationship between salinity and the risk of water-related diseases in relation to anthropometric and sociodemographic factors. This research seeks to empirically characterize the effects of salinity on human health by segregating water-borne, water-washed and water-related diseases, using a survey with 527 households in two types of coastal regions, non-salinity and salinity south-western areas of Bangladesh. Although there are a few studies that examine salinity effects on human health, they focus on examining the occurrences for only one type of diseases. A novelty in our research lies in (i) evaluating overall water-related health risk in coastal population by considering six types of water-related diseases (diarrhoea, malaria, dengue, respiratory infections, skin diseases and ocular diseases) depending on whether people live in non-salinity or salinity areas; (ii) systematically comparing and estimating the effects of salinity for water-borne, water-washed and water-related diseases along with a new set of sociodemographic and an-

[1] The *Vibrio cholera* is an agent of water-borne diarrheal disease, so-called cholera, prospers in brackish coastal water (Akanda et al., 2011, Grant et al., 2015).

thropometric factors, such as body mass index (BMI), within a single framework.

2 Methods

Study design, setting and study population

Jashore and Satkhira districts are located in the south-western coastal region of Bangladesh. In Jashore, three Upazilas (sub-districts) are selected purposively. Within these Upazilas, six villages are selected randomly and categorized as the non-salinity areas. Again, by following the same procedure, an Upazila from Satkhira district is selected. Within this Upazila, six villages are selected randomly and regarded as the salinity areas in this study (See figure 1). Categorization of the non-salinity and salinity areas is based on the absence and presence of salinity in these areas. In Satkhira district, most of the unions are regarded as high salinity hazard areas adjacent to the tidal river near to the mangrove forest and they are highly vulnerable to climate change, sea-level rise, cyclonic storm and flooding hazards (Rakib et al., 2019).

[Figure 1 about here.]

To implement random sampling of subjects in each area, we obtained the list of all households in the selected villages with help and support of local NGOs. During February-March 2019, we randomly identified 550 households by using the list and random number generator, and 275 households from the non-salinity areas and 275 households from the salinity areas were finally selected. The trained research staff contacted each household and conducted a survey for data collection with a pre-defined questionnaire. All households willingly participated in this survey and a household head mainly answered the questionnaire, providing data with written consent signed at the beginning. The first author was the chief administrator of this survey. Before administering the survey, discussions were made with the local people and field observations were conducted. Overall, 527 questionnaires were successfully collected, with 23 ones containing missing observations. Therefore, the 527 samples are mainly utilized for the statistical analyses that follow.

Key variables

A simple baseline survey was conducted to gather information on diarrhoea, malaria, dengue, respiratory infections, skin diseases and ocular diseases in the study area. For each disease, at first, a household head (sometimes, a household head's wife was asked, if the household head was absent) was asked whether he had suffered from these diseases during the last 6 months or not and data were recorded. If the household head was not affected by these diseases, then the same question was asked to other family members and if any member had suffered from these kinds of diseases, then data were documented. If the numbers of suffering disease cases were the same in some of the family members, then we would give the priority to adult age. At the time of data collection, trained research staff asked the subjects to show the evidence of diseases such as prescription/test documents that were provided by doctor/hospital/diagnosis centers. In this study, diarrhoea, malaria, dengue, respiratory infections are grouped into one category and named as water-borne diseases. Skin and ocular diseases are categorized into water-washed diseases. The final categorization is developed based on the combination of water-borne and water-washed diseases and called water-related diseases. Suffering from water-borne, water-washed and water-related diseases are the three dependent variables in this research. A household is categorized as "suffering from diseases" if any family member had suffered from any of the above-mentioned diseases.

Information was collected on households' sociodemographic characteristics such as age, gender, family structure, education, occupation, income, household's drinking sources and anthropometric characteristics such as height & weight of the subjects during household visits. Height and weight of each subject were measured by standard anthropometric methods. In this study, a digital electronic machine was used for measuring the weight and height for each subject. Accordingly, body mass index (BMI) of each subject is calculated by using their height and weight. Body mass index can be categorized into three groups namely underweight (below 18.5), normal weight (18.5 - 24.9) and overweight (above 24.9) on the basis of body mass score. The description of all variables is presented in Table 1.

[Table 1 about here.]

Statistical analysis

We compute the descriptive statistics such as mean, median, standard deviation of the key variables, and compare the differences between the non-salinity and salinity areas. One of our focuses is on occurrences of water-borne, water-washed and water-related diseases between the non-salinity and salinity areas and compare them by using statistical testing such as chi-square test. In addition, some sociodemographic and anthropometric variables such as gender, education of the household's head, occupation of the household's head, family structure, drinking water sources and body mass index (BMI) are assessed by areas (non-salinity and salinity areas).

We apply logit regression to identify the effects of salinity on health by separating water-borne, water-washed and water-related diseases. Each category of the disease has a binary value 0 or 1. Let y_i denotes a variable such that $y_i = 1$ if subject i suffers from any kind of water-related diseases, and $y_i = 0$ otherwise. The probability of suffering from disease of subject i, $pr(y_i = 1)$, is represented by the distribution function F evaluated at $X_i\beta$, where X_i is a vector of explanatory variables and β is a vector of unknown parameters. The distribution function of the logit regression model is as follows:

$$\text{Prob}(y_i = 1) = \frac{\exp(X_i\beta)}{1 + \exp(X_i\beta)}. \tag{1}$$

enabling us to compute the probability of diseases occurrence.

The empirical analysis is categorized into three parts, depending on the types of diseases. In the first part, we aim at identifying the effect of salinity on the occurrences of water-borne diseases. The logit analysis uses the variable y_i^a satisfying that $y_i^a = 1$ if subject i suffers from any kind of the above mentioned water-borne diseases, and $y_i^a = 0$ otherwise where the superscript of a in y_i^a represents "suffering from water-borne diseases." In the second part, we identify the effect of salinity on the occurrences of water-washed diseases. The logit analysis uses the dependent variable y_i^b, satisfying that $y_i^b = 1$ if subject i suffers from any kind of the aforementioned water-washed diseases, otherwise $y_i^b = 0$ where the superscript b represents "suffering from water-washed diseases." In the final part, we combine water-borne and water-washed diseases into one group called water-related diseases, we run logit model for identifying the effect of salinity on water-related diseases, taking the choice variable

y_i^c satisfying that $y_i^c = 1$ if subject i suffers from the above mentioned water-related diseases, and $y_i^c = 0$ otherwise where the superscripts c represents "suffering from water-related diseases."

In this study, a series of logit regression models are applied step by step for checking robustness of the results. First, the relationship between water-borne diseases and areas (non-salinity and salinity) are examined. Second, some sociodemographic characteristics (not including body mass index) are added. Finally, we include the anthropometric variable such as BMI in the model. The same procedure is applied in each regression for water-borne, water-washed and water-related diseases. The results in what follows are confirmed to be consistent with respect to the non-salinity and salinity areas, irrespective of regression specifications in the above three steps, being interpreted to be the marginal effects of the independent variables. Specifically, our focus is to identify the effects of salinity on the likelihood for the occurrences of water-borne, water-washed and water-related diseases along with sociodemographic and anthropometric factors. The main results of logit regression analyses are summarized in Table 3.

3 Results

Table 2 presents the summary statistics of the major dependent and independent variables for the non-salinity and salinity areas. The percentages of the subjects who suffer from water-borne, water-washed and water-related diseases are $54\,\%$, $20\,\%$, $60\,\%$ in the non-salinity areas, respectively, while these percentages are $62\,\%$, $29\,\%$, $69\,\%$ in the salinity areas, respectively. This result appears to show that people in the salinity areas are likely to suffer more from these diseases than the non-salinity areas. The overall age of the sample is 39 years old (see the "overall" column in Table 2), and the mean age of the subjects does not vary in terms of the non-salinity and salinity areas. Table 2 shows that $58\,\%$ of the subjects are male in the non-salinity areas, while $65\,\%$ of the subjects are male in the salinity areas.

With respect to education, subjects in both of the non-salinity and salinity areas possess 8 years of schooling (usually receive secondary education degree) as the median. Regarding occupation, $44\,\%$ and $42\,\%$ of subjects in the non-salinity and salinity areas are engaged in agriculture. In Bangladesh, rural societies are still agriculture- and nature-based societies. However, most subjects in this research have a main occupation with non-agricultural activities, and are engaged in agricultural activities as a side job. More specifically, the agricultural activities are based on seasonality, and most people do their job in agriculture only three months. In the other nine months, they are involved in other different types of activities. We gather information on the primary occupation with the longest engagement in a year. A similar result is observed in Paul et al. (2011) stating that agriculture is not the primary source of income for the coastal people because the incidence of landlessness is higher in coastal areas than non-coastal areas.

The average household income in the non-salinity areas (approximately 16 thousand BDT per month) is higher than in the salinity areas (around 12 thousand BDT per month). The SD of household income in the non-salinity areas (9144.17) is relatively higher than the SD of the household income in the salinity areas (5804.32). This finding indicates that the income disparity among the subjects is high in the non-salinity areas compared to the salinity areas. The popular family structure of the sample in both areas is nuclear family, however, the number of the extended family is high in the salinity areas compared to the non-salinity areas. Regarding drinking water sources, ground/pond water is the major source in both areas. However, the percentage of ground/pond water users is relatively high (95 %) in the non-salinity areas than in the salinity areas (76 %). The anthropometric variables of the subjects in the non-salinity areas (underweight BMI (0.09) & overweight BMI (0.29)) do not differ so much from those in the salinity areas (underweight BMI (0.11) & overweight BMI (0.22)) and most of the subjects belongs to normal BMI. In summary, subjects in the salinity areas are considered to have suffered more from water-borne, water-washed and water-related diseases than the subjects in the non-salinity areas. Some sociodemographic variables such as household income, family structure and drinking water sources vary between the non-salinity and salinity areas.

[Table 2 about here.]

Figure 2 shows the percentages of subjects that suffer from water-borne, water-washed and water-related diseases. The vertical axis presents the percent of the diseases occurrences and the horizontal axis denotes the area. An overwhelming number of subjects report sufferings from water-related diseases. In both study areas, a majority of subjects comment that they are in high risk of water-borne diseases. It can be confirmed that the percentages of water-borne, water-washed and water-related diseases are high in the salinity areas compared to the non-salinity areas. Figure 2 highlights that $60\,\%$ subjects in the non-salinity areas, while $69\,\%$ subjects in the salinity areas had suffered from any types of water-related diseases.

[Figure 2 about here.]

Chi-square tests are applied to qualitatively examine whether the frequencies or occurrences of the key variables are independent of areas (salinity or non-salinity areas). The following pairs of the variables are considered: (1) water-borne diseases *vs* areas, (2) water-washed diseases *vs* areas, (3) water-related diseases *vs* areas, (4) family structure *vs* areas, (5) BMI *vs* areas and (6) drinking water sources *vs* areas. We find that cases (1), (2) and (3) reject the null hypotheses at $5\,\%$ significance level, meaning that the occurrences of water-borne, water-washed and water-related diseases depend on non-salinity and salinity areas. Cases (4) and (6) also reject the null hypotheses at $1\,\%$ significance level, whereas case (5) does not. Overall, it appears that the key variables are qualitatively correlated with areas. Finally, to characterize the income data, we run a Mann-Whitney test with the null hypothesis that the income distributions between the non-salinity and salinity areas are the same. The result shows that there is a difference in the income distributions between the non-salinity and salinity areas at $1\,\%$ significance level ($Z = 5.60$). The summary statistics, diagram of diseases occurrences and statistical tests suggest that not only the occurrences of the diseases but also the household characteristics vary between the non-salinity and salinity areas.

To further characterize the relationship of key variables with the diseases, we run logit regression by taking the occurrence of each disease as a dependent variable and other key variables as independent variables (see table 1 for the definitions of the variables). Models 1-1, 1-2 and 1-3 in table 3 report the estimated marginal effects of the independent variables on the likelihood of suffering from water-borne, water-washed and water-related diseases with the same specification, respectively. Likewise, the results in models 2-1, 2-2 and 2-3 can be interpreted.[2] In model 1-1, family structure, underweight

[2]The marginal effects of each independent variable on the likelihood of suffering from the diseases in models 1-1, 1-2,

BMI, area and drinking water sources have positive effects at $1\,\%$, $5\,\%$, $10\,\%$ and $1\,\%$ significance levels, while age and gender have negative ones on the likelihood of suffering from water-borne diseases at $1\,\%$ significance levels, respectively. In model 1-2, age, household income, area and drinking water sources exhibit positive effects at $10\,\%$, $5\,\%$ and $1\,\%$ significance levels, while only one variable gender shows negative ones on the likelihood of suffering from water-washed diseases at $1\,\%$ significance level, respectively. In model 1-3, we find that occupation, family structure, underweight BMI, area and drinking water sources have positive effects at $5\,\%$, $1\,\%$, $5\,\%$ and $1\,\%$ significance levels, while age and gender have negative ones on the likelihood of suffering from water-related diseases at $1\,\%$ significance levels, respectively.

The estimated coefficients of both age and its square variables are significant with negative and positive signs, respectively (see table 4 in Appendix for the estimated coefficients of the logit regression). It means that the marginal effect of age non-monotonically changes, and the chances or likelihood of suffering from water-borne and water-related diseases are high at younger & older age and low at middle age (see, e.g., figure 3 for the predicted probabilities of suffering from water-borne and water-related diseases in Appendix, holding other independent variables at the sample means). This tendency is consistent with some of previous literature reporting that children and adult age people are more vulnerable to fall into any kind of diseases than the middle age people (Bhunia and Ghosh, 2011).

Among the subjects, females are $29\,\%$, $10\,\%$, $22\,\%$ less likely to suffer from water-borne, water-washed and water-related diseases, respectively than males (table 1). The possible reason behind this is that males always stay outside for their activities and they force to drink contaminated water because fresh drinking water is not available all time. Large family size has a significant relationship with suffering from water-borne and water-related diseases. Specifically, the probabilities for households with large family size to suffer from water-borne and water-related diseases are $15\,\%$ and $12\,\%$ higher than those for households with nuclear family, respectively (see table 1). Our results are consistent with Sarker et al. (2016), showing that the prevalence of diarrhoea is to be found high in households

1-3, 2-1, 2-2 and 2-3 are derived from the estimated coefficients of the logit regression in table 4, being evaluated at the sample means (Wooldridge, 2010, 2019).

having more family members and male children suffered more than do female children.

Occupation is statistically significant in model 1-3 in table 1, indicating that the households which are engaged with agricultural activities have $9\,\%$ higher chances of suffering from water-related diseases than the households which are engaged with non-agricultural activities. Agricultural activities are mainly related to soil and water which are mostly affected by salinity, and this result can generally be considered quite intuitive in Bangladesh. Household income has a significant effect on water-washed diseases. If household income increases by $1\,\%$, then the chances of suffering from water-washed disease increases by $9\,\%$ (see table 1). It is known that people are affected with water-washed diseases by several uses of contaminated water. High-income people are considered to be affected because they typically use more water for their daily life such as food preparation, washing clothes than low-income people. In many cases, the high-income households also have their own pond, usually using pond water for their daily activities and cultivating fish in the pond. As a result, they frequently contact with contaminated water and suffer a lot from water-washed diseases. Paul et al. (2011) demonstrate the same result via household surveys to study post-cyclone illness patterns in Bangladeshi coastal areas, finding that the disease occurrence among high-income people is high as compared with low-income people.

The regression results reveal that subjects in the salinity areas have more significant chances of being affected by water-borne, water-washed and water-related diseases than in the non-salinity areas (logit regression 1 in table 1). The probabilities of suffering from water-borne, water-washed and water-related diseases are $8\,\%$, $14\,\%$ and $11\,\%$ higher in the salinity areas than the non-salinity areas, respectively. Some literature claims that elevated salinity in coastal areas through drinking, cooking, bathing increases the chances of skin diseases, acute respiratory infection and diarrheal diseases (Talukder et al., 2015). Jabed et al. (2018) also claim that an overwhelming number of villagers in the salinity areas are suffering from skin-related diseases such as skin paleness, allergy, rashes and skin infections. In terms of drinking water sources, we find that the users of ground/pond water are $16\,\%$, $15\,\%$ and $19\,\%$ more likely to fall into water-borne, water-washed and water-related diseases than the rainwater users. Several other studies also show that the salinity level in drinking water is positively associated with consumption of sodium which have negative effects on human health (Khan et al., 2014, Talukder et al., 2016). Overall, our results with respect to the salinity areas are in line with past literature.

Body mass index (BMI) is an important health indicator that assesses people's health status. Underweight is the deficiency of body weight gain according to the age of growth. We identify that the underweight BMI is a statistically significant predictor of water-borne and water-related diseases, indicating that the subjects who belong to underweight BMI are $16\,\%$ and $15\,\%$ more chances of being affected by water-borne and water-related diseases, respectively, than the subjects who belong to normal BMI. It is established that people with poor nutritional status could be easily affected by any type of diseases. A study by Rahman et al. (2004) is consistent with our result, demonstrating that maternal depression is a risk factor for malnutrition and illness in infants living in a low-income country and that low birth weight of infants is likely to suffer from excessive diarrheal episodes. The effects of poor nutrition have impact upon the social, economic and cultural development of societies and nations. It will be impossible to achieve many of the sustainable development goals, including the goals on extreme poverty and hunger, primary education, child mortality, and other diseases, if malnutrition cannot be reduced and prevented.

In logit regression 2, we create a new variable named area-wise drinking sources by combining with area and drinking water sources to clearly see the effects of different combinations on the diseases. We find that households which consume rainwater or ground/pond water in the salinity areas have different effects on likelihood of suffering from water-borne, water-washed and water-related diseases than the households which consume ground/pond water in the non-salinity areas. The households which live in the salinity areas and consume ground/pond water have more chances of suffering from water-related diseases than the non-salinity areas with the same drinking water sources. The reason is that the salinity level in drinking water sources is high in the salinity areas. The households which consume rainwater as a drinking source have less chances of suffering from water-related diseases even in the salinity areas. The results of this study show that subjects who live in the salinity areas and consume ground/pond water have $10\,\%$, $15\,\%$ and $13\,\%$ higher chances of being affected by water-borne, water-washed and water-related diseases, respectively, than subjects who live in the non-salinity areas and using same drinking water sources (see model 2-3). In model 2-1, we also observe that subjects who live in the salinity areas but consume rainwater as a drinking source have $10\,\%$ lower probability to suffer from water-borne diseases than subjects who live in the non-salinity areas but consume ground/pond water. Other variables used in the logit regression model 2 have shown similar results of logit regression model 1.

[Table 3 about here.]

In Bangladesh, a main water drinking source is groundwater and nearby $97\,\%$ of people depend on this source (Shamsudduha, 2013, Nahian et al., 2018). In the salinity areas, $61\,\%$ of households use pond water for drinking and $81\,\%$ use it even for household purposes (Khan et al., 2011b). However, the water salinity level in coastal areas is reported to increase due to climate change & the associated anthropogenic activities (Khan et al., 2011a, Talukder et al., 2016, Rahman et al., 2019). From 1973 to 2009, salinity areas in Bangladesh expands by $27\,\%$ (Talukder et al., 2016), and the water salinity levels in both surface and groundwater in the salinity areas are < 600 ppm and $1000 - 1500$ ppm that exceed the critical level according to the Bangladesh drinking water standard (Abedin and Shaw, 2013). In summary, coastal people currently end up using saline water to meet all sorts of purposes, such as bathing, washing, cooking and drinking. As a result, they are at risk of developing a number of serious health problems especially water-related diseases as shown in this research. Our analysis suggests that harvesting rainwater is an effective countermeasure to get rid of water-related diseases. Coastal people should be able to reserve rainwater at family & community levels by using rain barrel or making a big tank. At the same time, some support from the government, donor agencies and non-government organizations may be required to make this type of rainwater projects sustainable in practice.

Malnutrition is an important health indicator as well as a risk factor for the disease. Nutritional status of coastal people is also reported to decrease due to the impacts of soil and water salinity (Parvin and Ahsan, 2013, Talukder et al., 2015, Szabo et al., 2016, Rahman et al., 2019). About $49.1\,\%$ of the children are moderately malnourished on weight for age (underweight) in the salinity areas (Alam et al., 2019). In Bangladesh, about 60 million subsistence farmers face food security problems and this problem is worsened in rural areas with elevated salinization (Rahman et al., 2019).

One-fifth of the total area of the country nearly 2.8 million hectares of land is affected by salinity (Khan et al., 2011b). As a consequence of salinity, rice production is predicted to decrease by 7.6 and 7.3 million by the year of 2050 and 2080, respectively (Khan et al., 2011b). Our findings suggest that improvement of nutritional status is crucial for people to be in normal BMI, and to this end, some tailor-made interventions are recommended to focus on different food security & nutritional programs for mitigating the risk of water-related diseases. The public food distribution and different government safety net programs can be expanded & redesigned to improve food security status of coastal population.

Information on the age and gender specific prevalence rate of water-related diseases is limited in Bangladesh and many other countries. It is essential to know how age and gender are related to the occurrences of water-related diseases. Along with the results related to drinking water sources and normal BMI, our analysis finds an interesting nonlinear relationship between age and likelihood of suffering from water-related disease, that is, the probability of suffering from water-related diseases is high at younger & older age but low at middle age. In addition, it is found that males are more likely to suffer from water-related diseases than females. This type of studies that clarify the relation between sociodemographic variables and the occurrence of water-related diseases will be vital for the government to take appropriate polices to the specific groups for reducing the disease risk. Overall, we have identified that coastal people have suffered from salinity hazards as compared to people in the non-salinity areas. On the other hand, our study successfully demonstrates that the chances of suffering from water-related diseases by living in the salinity areas can be eliminated if the households follow the two countermeasures. First, drinking water sources should be shifted from ground/pond water to rainwater. Second, BMI should be improved and maintained up to normal weight. We believe that the results of this study can be a guidance to mitigate the risk of water-related diseases in other low-lying developing countries where natural water resources are contaminated by elevated salinity due to climate change & the associated sea level rises.

4 Conclusion

We have systematically examined the quantitative impacts of salinity and some possible determinants on the likelihood of suffering from water-borne, water-washed and water-related diseases along with a new set of sociodemographic and anthropometric factors within a single analytical framework. To this end, we have conducted questionnaire surveys, collecting data from 527 households in the two types of rural coastal regions, non-salinity and salinity south-western areas of Bangladesh. The statistical analysis shows that the probabilities of being affected by water-borne, water-washed and water-related diseases are high in the salinity areas, as compared to the non-salinity areas. To counter the risk, we find that consuming rainwater as a drinking water and/or being in normal BMI are quite effective. We also identify that age, gender and family size are the significant determinants of water-related diseases.

Overall, our results suggest that the collection & preservation of rainwater and/or the community-based food & nutrition security programs shall be effective measures to get relief from water-related diseases and to maintain healthy lives of coastal population. For instance, it shall be recommended to introduce public food-intake and safety net programs to improve nutritional status of coastal people for being in normal BMI. To further tackle the coastal hazards, an integrated policy measure that considers drinking water sources can be organized by the government along with local people and non-government organizations, focusing on how to efficiently store and utilize rainwater as drinking sources in coastal communities. The lesson learned from this study is applicable in other low-lying developing countries or deltas such as the Mekong delta, Ganges and Brahmaputra delta, Nile and Mississippi deltas and other Asian deltas which are highly vulnerable to salinity problems due to climate change & sea-level rises.

We note some limitations of this research and suggest some possible research in the future. First, there may be additional environmental determinants of water-related diseases such as cleanliness and/or sanitation at community and city levels. Second, we did not consider the variation of sodium consumption in individual food intake, although it will possibly affect individual health risks. Third, we only conduct cross-sectional analysis, implying that seasonality of salinity levels is not explicitly considered.[3] We could not take into account the above factors in our questionnaire surveys because of several constraints we have faced with respect to time, subjects and budgets. In the future, more detailed data collection and analysis should be made regarding environmental factors, per person sodium intake and seasonality with panel data structures. By doing so, the relationship between health risks and salinity shall be fully characterized. These caveats notwithstanding, it is our belief that the findings of this study are robust enough and become the first important step that quantitatively clarifies health risks of salinity associated with climate change.

5 Appendix

In this appendix, we present the results for the estimated coefficients in logit regressions, which are used to compute the marginal effects in table 3 and the nonlinear predicated probability over age in figure 3.

[Table 4 about here.]

[Figure 3 about here.]

[3] However, our data were collected during February-March, well approximating the representative scenarios of salinity effects in Bangladesh.

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List of Figures

Figure 1: Study area

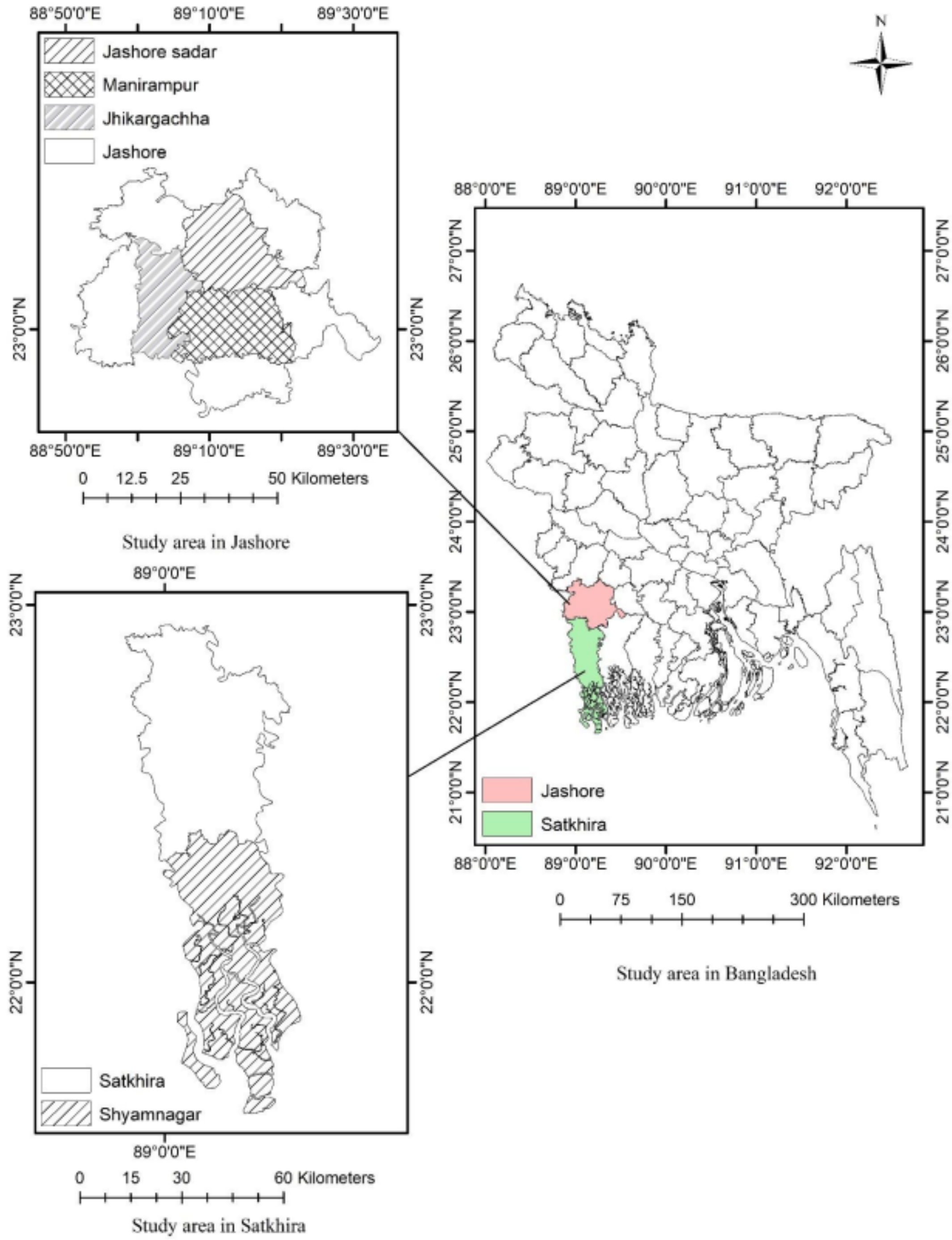


Figure 2: Percentages of subjects who suffer from water-borne, water-washed and water-related diseases

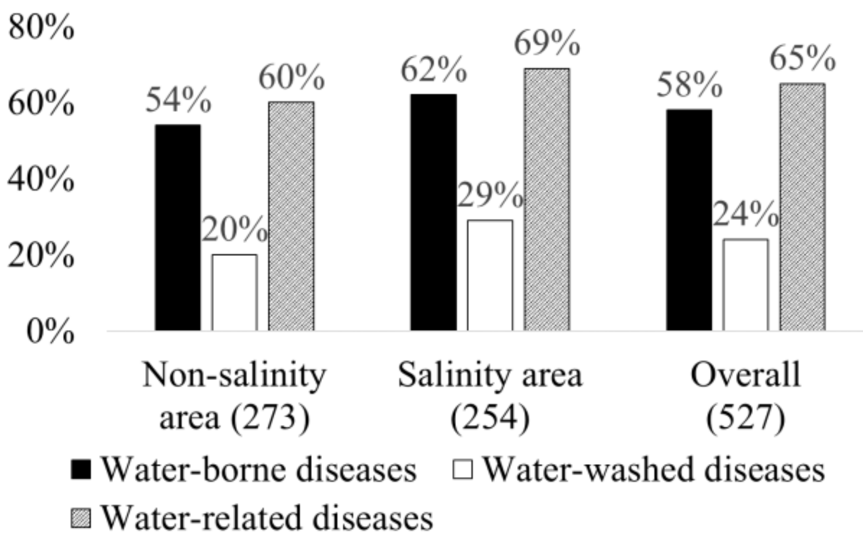
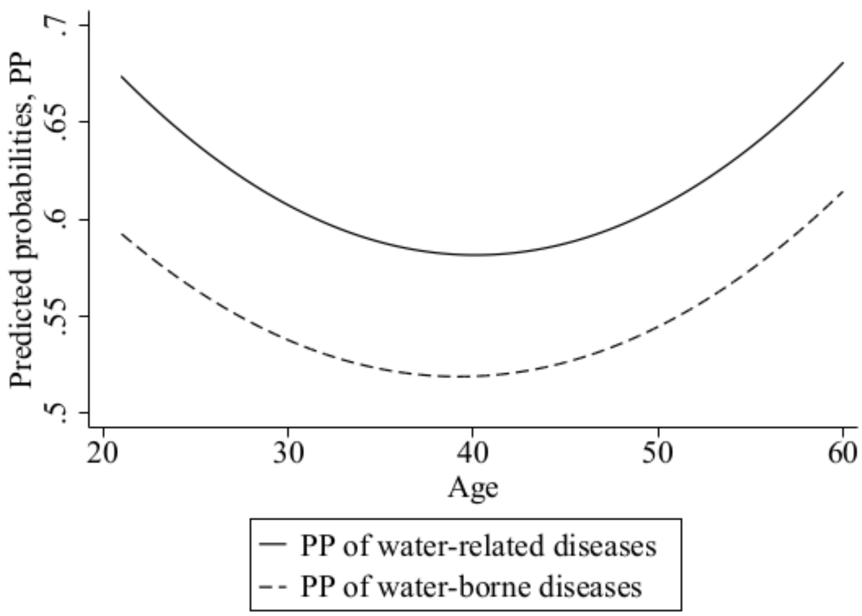


Figure 3: Predicted probabilities of suffering from water-borne and water-related diseases



List of Tables

Table 1: Definitions of variables

Variables	Description
Water-borne diseases	If a person of a household had suffered from any types of water-borne diseases, then the value of dependent variable is 1, otherwise 0 (reference category).
Water-washed diseases	If a person of a household had suffered from any types of water-washed diseases, then the value of dependent variable is 1, otherwise 0 (reference category).
Water-related diseases	If a person of a household had suffered from any types of water-related diseases, then the value of dependent variable is 1, otherwise 0 (reference category).
Age	Years
Gender	Male (0) and female (1)
Education of the household head	Years of schooling (0 to 14) (0 = No schooling, 1 = Class one, 2 = Class two, 3 = Class three, 4 = Class four, 5 = Class five, 6 = Class six, 7 = Class seven, 8 = Class eight, 9 = Class nine, 10 = SSC/equivalent, 11 = Eleven class equivalent, 12 = HSC/twelve class, 13 = Graduate/equivalent, 14 = Post graduate/equivalent)
Occupation of the household head	Non-agriculture (0) and Agriculture (1)
Household income	Monthly household income in BDT.
Family structure	Nuclear family (0) and Extended family (1).
Body mass index (BMI) dummy variables (Base group = Normal BMI)	
Underweight BMI	Normal weight (0) and Underweight (1).
Overweight BMI	Normal weight (0) and overweight (1).
Drinking sources	Rainwater (0) and Ground/pond water (1).
Area	Non-salinity area (0) and Salinity area (1).
Area-wise drinking sources (Base group = Households who live in non-salinity area and drink ground/pond water, NSG/P (0))	
NSR	Households who live in non-salinity area and drink rainwater, NSR (1), otherwise 0.
SR	Households who live in salinity area and drink rainwater, SR (1), otherwise 0.
SG/P	Households who live in salinity area and drink ground/pond water, SG/P (1), otherwise 0.

Table 2: Summary statistics of the variables

	Area		Overall
	Non-salinity area	Salinity area	
Water-borne diseases			
Average (Median)[1]	0.54 (1.00)	0.62 (1.00)	0.58 (1.00)
SD[2]	0.50	0.49	0.49
Water-washed diseases			
Average (Median)	0.20 (0)	0.29 (0)	0.24 (0)
SD	0.40	0.45	0.43
Water-related diseases			
Average (Median)	0.60 (1.00)	0.69 (1.00)	0.65 (1.00)
SD	0.49	0.46	0.48
Age			
Average (Median)[1]	37.93 (39.00)	37.56 (39.00)	37.76 (39.00)
SD[2]	14.78	13.96	14.38
Gender (Base group = Male)			
Average (Median)	0.42 (0.00)	0.35 (0.00)	0.39 (0.00)
SD	0.49	0.48	0.49
Education of the household head			
Average (Median)	7.36 (8.00)	7.19 (8.00)	7.28 (8.00)
SD	3.97	3.66	3.82
Occupation of the household head			
Average (Median)	0.45 (0.00)	0.42 (0.00)	0.43 (0.00)
SD	0.50	0.49	0.50
Household income			
Average (Median)	15548.18 (13500.00)	11887.19 (10208.33)	13783.68 (12000)
SD	9144.17	5804.32	7924.38
Family structure (Base group = Nuclear family)			
Average (Median)	0.19 (0.00)	0.31 (0.00)	0.24 (0.00)
SD	0.39	0.46	0.43
Body mass index (BMI) dummy variables (Base group = Normal BMI)			
Underweight BMI			
Average (Median)	0.09 (0.00)	0.11 (0.00)	0.10 (0.00)
SD	0.29	0.31	0.0.30
Overweight BMI			
Average (Median)	0.29 (0.00)	0.22 (0.00)	0.26 (0.00)
SD	0.45	0.42	0.44
Drinking water sources (Base group = Rainwater)			
Average (Median)	0.95 (1.00)	0.76 (1.00)	0.86 (1.00)
SD	0.22	0.43	0.34
Area-wise drinking sources (Base group = Ground/pond water in the non-salinity areas, NSG/P)			
Rainwater in the non-salinity areas, NSR[4]			
Average (Median)	0.05 (0.00)	0.00 (0.00)	0.03 (0.00)
SD	0.22	0.00	0.16
Rainwater in the salinity areas, SR			
Average (Median)	0.00 (0.00)	0.24 (0.00)	0.11 (0.00)
SD	0.00	0.43	0.32
Ground/pond water in the salinity areas, SG/P			
Average (Median)	0.00 (0.00)	0.76 (1.00)	0.37 (0.00)
SD	0.00	0.43	0.48
Sample size	273	254	527

[1] Median in parentheses.
[2] SD stands for standard deviation.

Table 3: Marginal effects of the independent variables in the logit regression

	Logit regression 1			Logit regression 2		
	Water-borne	Water-washed	Water-related	Water-borne	Water-washed	Water-related
	Model 1-1	Model 1-2	Model 1-3	Model 2-1	Model 2-2	Model 2-3
Age	−0.01***	0.003*	−0.01***	−0.01***	0.003*	−0.01***
Gender (Base group = Male)	−0.29***	−0.10**	−0.22***	−0.29***	−0.10**	−0.22***
Education of the household head	−0.01	−0.001	−0.01	−0.005	−0.001	−0.005
Occupation of the household head (Base group = Non-agriculture)	0.05	0.01	0.09**	0.05	0.01	0.10**
Household income[1]	−0.001	0.09**	0.06	0.003	0.09**	0.06
Family structure (Base group = Nuclear family)	0.15***	0.03	0.12***	0.15***	0.03	0.12***
BMI dummy (Base group = Normal weight)						
Underweight BMI	0.16**	−0.05	0.15**	0.15**	−0.05	0.15**
Overweight BMI	0.02	0.05	0.06	0.02	0.05	0.06
Area (Base group = Non-salinity)	0.08*	0.14***	0.11***			
Drinking water sources (Base group = Rainwater)	0.16***	0.15***	0.19***			
Area-wise drinking sources (Base group = NSG/P)						
NSR				0.004	−0.13	−0.07
SR				−0.11*	−0.04	−0.09
SG/P				0.10**	0.15***	0.13***

***significant at the 1 percent level, **at the 5 percent level and *at the 10 percent level.
NSG/P stands households who live in non-salinity area and drink ground/pond water,
NSR stands for households who live in non-salinity area and drink rainwater,
SR stands for households who live in salinity area and drink rainwater,
SG/P stands households who live in salinity area and drink ground/pond water.
[1] The logit regressions are computed with the natural logarithm of household income.

Table 4: Coefficients of the independent variables in the logit regression

	Logit regression 1			Logit regression 2		
	Water-borne	Water-washed	Water-related	Water-borne	Water-washed	Water-related
	Model 1-1	Model 1-2	Model 1-3	Model 2-1	Model 2-2	Model 2-3
Age	−0.11***	0.003	−0.15***	−0.11***	0.003	−0.14***
Age square	0.001**	0.0002	0.001***	0.001**	0.0002	0.001***
Gender (Base group = Male)	−1.38***	−0.60**	−1.06***	−1.40***	−0.60**	−1.07***
Education of the household head	−0.03	−0.005	−0.03	−0.02	−0.005	−0.02
Occupation of the household head (Base group = Non-agriculture)	0.24	0.09	0.49**	0.25	0.09	0.50**
Household income[1]	−0.01	0.55**	0.31	0.01	0.56**	0.32
Family structure (Base group = Nuclear family)	0.73***	0.18	0.62**	0.76***	0.18	0.64**
BMI dummy (Base group = Normal weight)						
Underweight BMI	0.81*	−0.35	0.87*	0.80*	−0.35	0.86*
Overweight BMI	0.08	0.29	0.31	0.12	0.30	0.34
Area (Base group = Non-salinity)	0.37*	0.82***	0.57***			
Drinking water sources (Base group = Rainwater)	0.78***	1.08***	0.93***			
Area-wise drinking sources (Base group = NSG/P)						
NSR				0.02	−0.96	−0.33
SR				−0.54*	−0.27	−0.46
SG/P				0.47**	0.83***	0.65***

***significant at the 1 percent level, **at the 5 percent level and *at the 10 percent level.
NSG/P stands households who live in non-salinity area and drink ground/pond water,
NSR stands for households who live in non-salinity area and drink rainwater,
SR stands for households who live in salinity area and drink rainwater,
SG/P stands households who live in salinity area and drink ground/pond water.

[1] The logit regressions are computed with the natural logarithm of household income.