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Climate Change, Soil Salinity, and the Economics of High-Yield Rice Production in Coastal Bangladesh

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Abstract

It is a virtual certainty that sea-level rise will continue throughout the century and beyond 2100 even if greenhouse gas emissions are stabilized in the near future. Understanding the economic impacts of salinity intrusion thus is essential for planning adaptation in low-lying coastal areas around the world. This paper presents a case study in Bangladesh on how climate change leads to the spread of soil salinity and the impact on agricultural production in the coastal region. The analysis is conducted in two stages. The first stage predicts future soil salinity for 69 subdistricts, taking into account climate-induced changes in river salinity, temperature, and rainfall by 2050. The second stage uses econometric analysis to predict the impact of climate-induced increases in soil salinity on the output and price of high-yielding-variety rice. The findings indicate output declines of 15.6 percent in nine subdistricts where soil salinity will exceed 4 deciSiemens per meter before 2050. Without newly developed coping strategies, the predicted changes will produce significant income declines from high-yielding-variety rice production in many areas, including a 10.5 percent loss in Barisal region and a 7.5 percent loss in Chittagong region.

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Climate Change, Soil Salinity, and the Economics of High-Yield Rice Production in Coastal Bangladesh

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1. Introduction

The potential impacts of climate change on coastal regions include progressive inundation from sea level rise, heightened storm damage, loss of wetlands, and increased salinity from saltwater intrusion. Worldwide, about 600 million people currently inhabit low-elevation coastal zones that will be affected by progressive salinization (Wheeler 2011; CIESIN 2010). Recent research suggests that the sea level may rise by one meter or more in the 21st century, which would increase the vulnerable population to about one billion by 2050 (Hansen and Sato 2011; Vermeer and Rahmstorf 2009; Pfeffer et al. 2008; Rahmstorf 2007; Dasgupta et al. 2009; Brecht et al. 2012).

While most research has focused on inundation and losses from heightened storm surges, increased salinity from saltwater intrusion may actually pose the greatest threat to livelihoods and public health through its impacts on agriculture, aquaculture, infrastructure, coastal ecosystems, and the availability of fresh water for household and commercial use. Understanding the physical and economic effects of salinity diffusion and planning for appropriate adaptation will be critical for long-term development and poverty alleviation in countries with vulnerable coastal regions (Brecht et al. 2012).

Bangladesh provides an excellent setting for investigation of these issues, because it is one of the countries most threatened by sea level rise and saltwater intrusion. In Bangladesh, about 30% of the cultivable land is in coastal areas where salinity is affected by tidal flooding during the wet season, direct inundation by storm surges, and movement of saline ground water during the dry season (Haque, 2006). In consequence, the potential impact of salinity has become a major concern for the Government of Bangladesh and affiliated research institutions. Recently, the Bangladesh Climate Change Resilience Fund (BCCRF) Management Committee has highlighted salinity intrusion in coastal Bangladesh as a critical part of adaptation to climate change. Prior research on this issue has been conducted or co-sponsored by the Ministry of Environment and Forests (World Bank 2000) and two affiliated institutions: the Center for Geographic and Environmental Information Services (Hassan and Shah 2006) and the Institute of Water Modeling (IWM 2003; UK DEFR 2007). Additional research has been conducted by the Bangladesh Center for Advanced Studies (World Bank 2000; Khan et al. 2011), the Bangladesh Agricultural Research Council (Karim et al. 1982, 1990), and the Soil Resources Development Institute, Bangladesh (SRDI 1998a,b; Peterson and Shireen 2001).

In its National Adaptation Programme of Action (NAPA 2006), the Government of Bangladesh has assigned particularly high priority to projects related to adaptation of coastal agriculture to increased salinity. Resources will remain scarce, and mobilizing a cost-effective response will require an integrated spatial analysis of salinity diffusion, its socioeconomic and ecological impacts, and the costs of prevention, adaptation and remediation. The temporal and geographic pattern of appropriate adaptive investments will depend critically on the expected intensity and diffusion rate of salinization in different locations. This paper will attempt to contribute by addressing two critical components of the problem: soil salinity changes in the coastal region of Bangladesh, and their consequences for the economics of HYV (high-yielding variety) rice production in the region.

The remainder of the paper is organized as follows. In Section 2, we review existing research on climate change, salinity diffusion and agricultural production in Bangladesh. Section 3 provides an introduction to current salinity levels and agricultural production in the coastal region. In Section 4, we develop and estimate a spatial econometrical model of soil salinity change in local areas that incorporates the salinity of nearby rivers, as well as temperature and rainfall. We also use weather data for the past 30 years to estimate long-term trends for temperature and rainfall, which we compare with current estimates from several global climate models. We conclude Section 4 by using our estimation results, newly-available projections of river salinity, and our weather projections to forecast trends in soil salinity for a large number of coastal-region subdistricts (upazilas) through 2050. Section 5 lays the groundwork for our agricultural impact analysis by specifying and estimating econometric models that measure upazila-level effects of soil salinity on rice yields, prices and input use. Section 6 combines our soil salinity projections from Section 4 with econometric estimates from Section 5 to forecast the impacts of rising salinity on rice output, prices and incomes through 2050. We summarize and conclude the paper in Section 7.

2. **Previous Research**

During the past several years, researchers have begun to address the global economics of sectoral adaptation to higher temperatures, greater variation in rainfall, water scarcity and inundation of coastal areas (Cline 2007; Margulis et al. 2010; Dasgupta et al. 2009). In Bangladesh, a recent study by Thomas et al. (2013) has provided a detailed technical assessment of potential climate impacts on agriculture, using projections from several global climate models and technical parameters incorporated in available crop modeling software. While the authors provide results from a survey of farmers on sources of crop losses,[5] including soil salinity, they do not attempt to mobilize the requisite data for direct estimation of salinity impacts.

In Bangladesh, work on soil and river salinity has advanced rapidly in recent years. Sarwar (2005) and SRDI (1998 a,b, 2000, 2010) have documented changes in salinity that have accompanied coastal subsidence and thermal expansion of the ocean. Local survey research in Bangladesh has also suggested significant agricultural productivity losses from rising soil salinity (Karim et al. 1990; Rahman and Ahsan 2001; Petersen and Shireen 2001; Hassan and Shah 2006; Mahmood et al. 2010; Thomas et al. 2013).

[5] Thomas et al. (2013), Table 3.17, p. 45.

Detailed assessments of salinization have employed two principal methods. One approach focuses on simulation of salinity change in rivers and estuaries, using hydraulic engineering models whose results are compared with actual measures (Bhuiyan and Dutta 2011; Aerts et al. 2000; Nobi and Das Gupta 1997). Another approach focuses on local salinity impacts, using surveys and descriptive statistics (Mahmood et al. 2010; Khan et al 2008, 2011; Haque 2006; Sarwar 2005; Rahman and Ahsan 2001; Hassan and Shah 2006; Karim et al. 1982, 1990). In the most comprehensive study to date, Dasgupta et al. (2014) have developed detailed projections of river salinity through 2050 in Bangladesh's coastal region.

3. Study Area

Figure 1 displays the area chosen for our study. It comprises 140 upazilas in four regions of southern Bangladesh: Barisal (38 upazilas), Chittagong (30), Dhaka (13) and Khulna (59). Appendix Table A1 identifies these upazilas by region, district and sub-district, as well as summarizing available information on HYV rice yields. As Figure 1 shows, the study area spans the southern coastal regions of Bangladesh, with extensions to permit assessment of current and future salinity further inland. Study teams have collected available data on agricultural production for the period 2000-2012 from local offices in each upazila. In many cases, we believe that these data have not previously been available for empirical research. A complete list of study variables is provided in Appendix Table A2.

Figure 2 provides evidence of significant variation in economic conditions within the study area. The map displays mean yields for HYV rice during the period 2000-2012. Upazila-level yields vary from 1.2 to 2.8 tons/acre, with a particularly heavy concentration of low yields (1.2 - 1.5 tons/acre) in southern Khulna. In contrast, several upazilas in the northern tier of the study region

Figure 1: Study regions and upazilas in Bangladesh

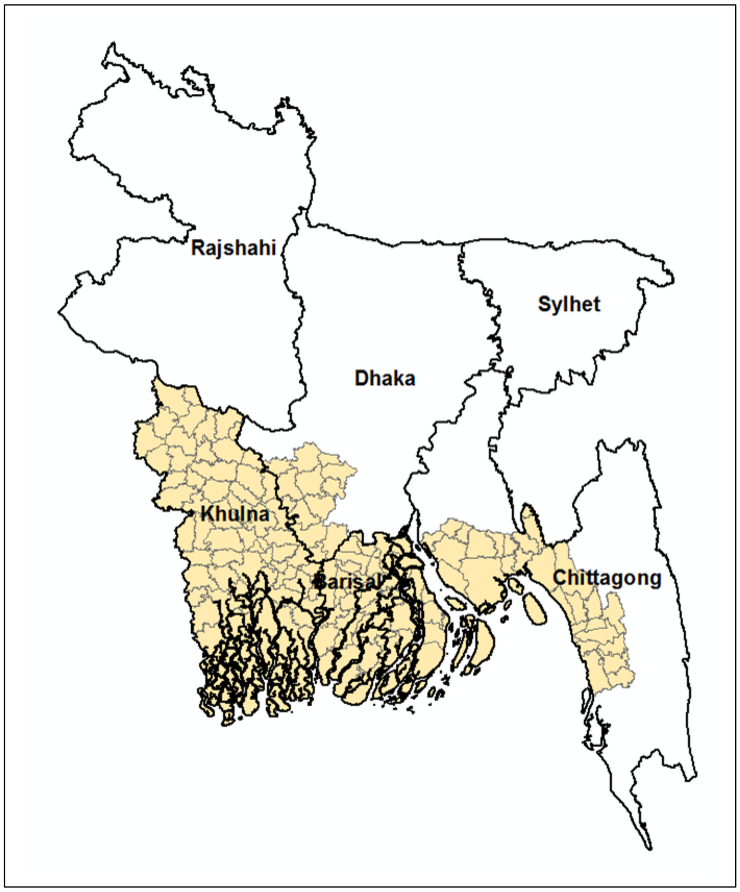
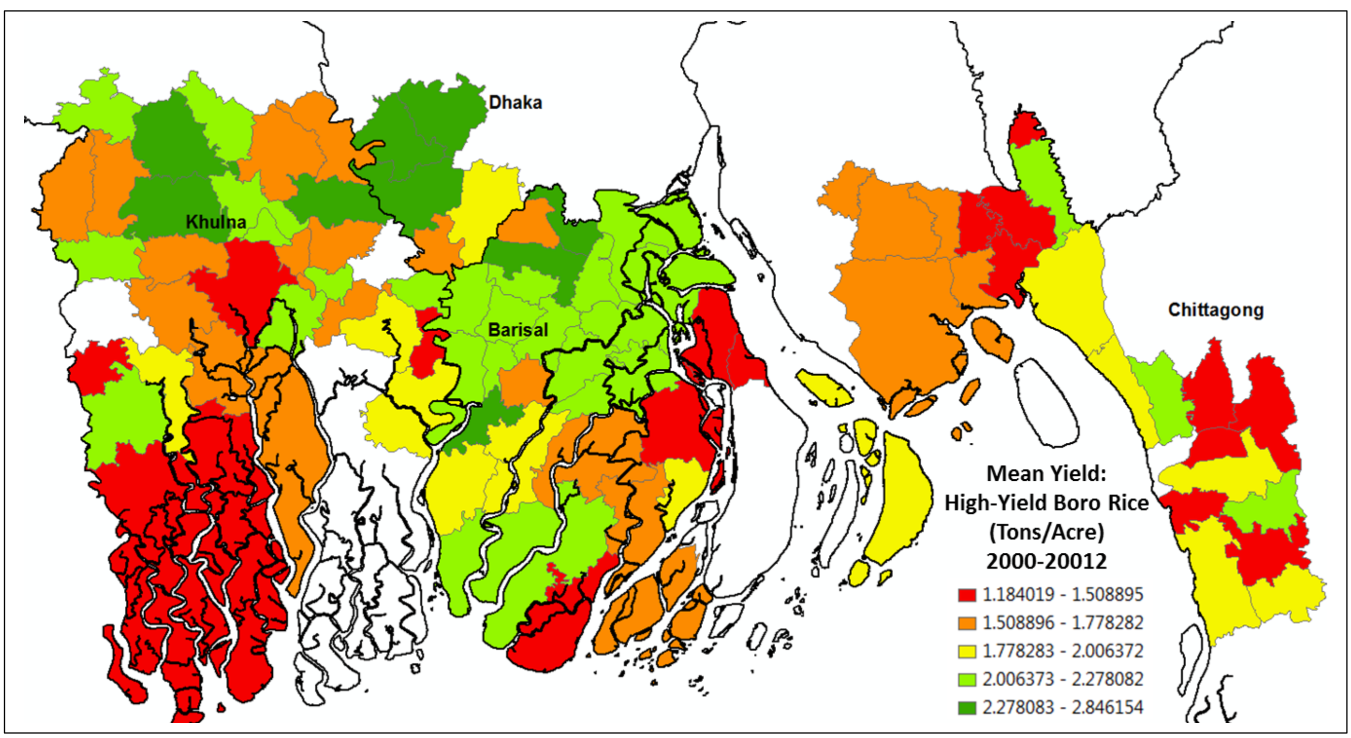


Figure 2: Mean yield, HYV rice (tons/acre): 2000-2012



(central Khulna, southern Dhaka, northern Barisal) have among the highest observed yields (2.3-2.8 tons/acre). Although there is an apparent tendency for low-yield areas to concentrate near the coast and in coastal river estuaries, this is not always the case. An evident counter-example is in southern Barisal, where the coastal area includes a cluster of upazilas with relatively high yields.

4. Salinity Incursion in Coastal Bangladesh

4.1 Salinity in Coastal Rivers

As we have previously noted, recent local surveys (e.g. Thomas et al. 2013) and technical studies suggest that the incursion of salinity from sea level rise and changing river flows is beginning to have an impact on agriculture in the coastal region of Bangladesh. Recent research by Dasgupta et al. (2014) provides detailed evidence on salinity trends in coastal rivers. This evidence is augmented by a projection model that links climate-induced changes in sea level, temperature, rainfall, and altered riverine flows from the Himalayas to the spread and intensity of salinity in coastal rivers through 2050.

We adopt current river salinity measures and projections from the Dasgupta study as benchmarks for projecting changes in soil salinity during the next four decades. Appendix Table A3 presents mean monthly salinity measures for all river stations in 2001 and 2008, as well as potential salinity in 2050. Figures 3a - 3b provide color-coded salinity measures from 29 river monitoring stations on coastal rivers, as well as potential salinity in 2050. In 2000 (Figure 3a), all stations in Chittagong, Barisal, Dhaka and northern Khulna have Yellow readings below 0.50 parts per thousand (ppt). Three stations on the Shibsa and Rupsa-Pasur Rivers in central Khulna have Tan readings (0.5 - 2.2 ppt) and one is Red (3.9 - 6.2). By 2008, rapid salinization has begun: Nine stations (8 in Barisal) are Yellow; 8 (scattered across all four regions)

Figure 3a: Mean salinity seasures for river stations (ppt): 2000

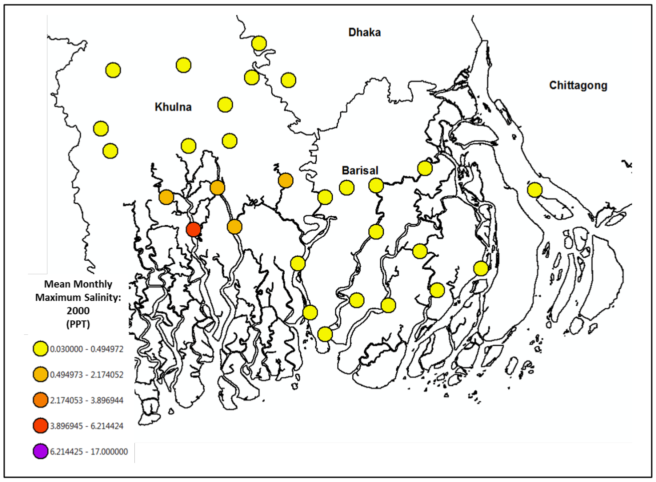


Figure 3b: Mean salinity measures for river stations (ppt): 2008

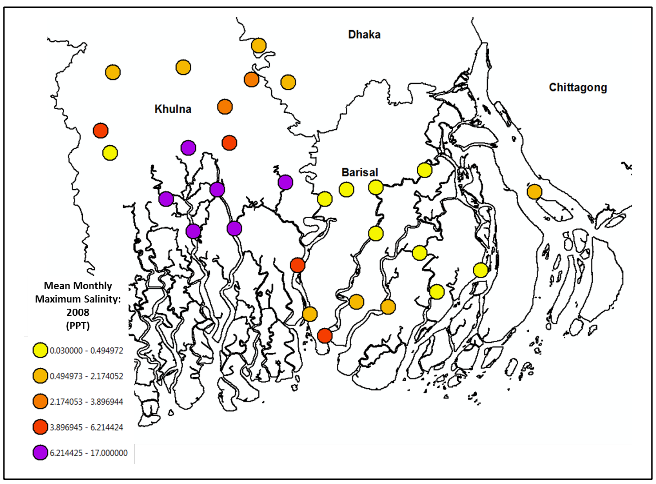
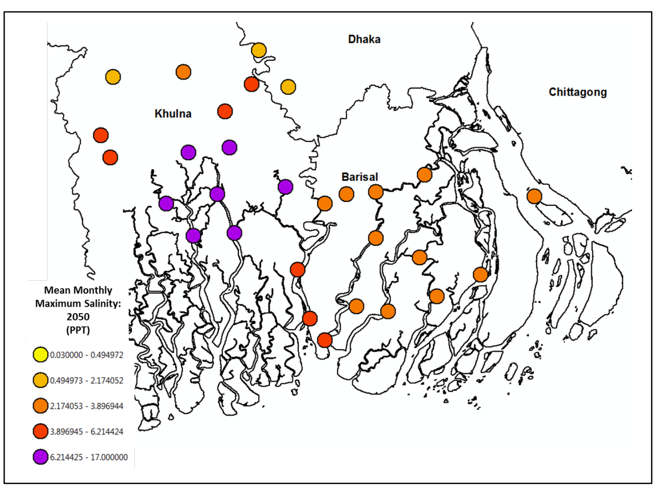


Figure 3c: Projected mean salinity seasures for river stations (ppt): 2050



are Tan; 2 (in Khulna) are Orange (2.2 - 3.9 ppt); 4 (in Khulna and Barisal) are Red; and 6 (all in central Khulna) are Purple (6.2 - 17.0 ppt). In the 2050 projection, the coastal river system has undergone a dramatic change: No stations are Yellow, 3 are Tan, 12 are Orange; 7 are Red, and 7 are Purple.

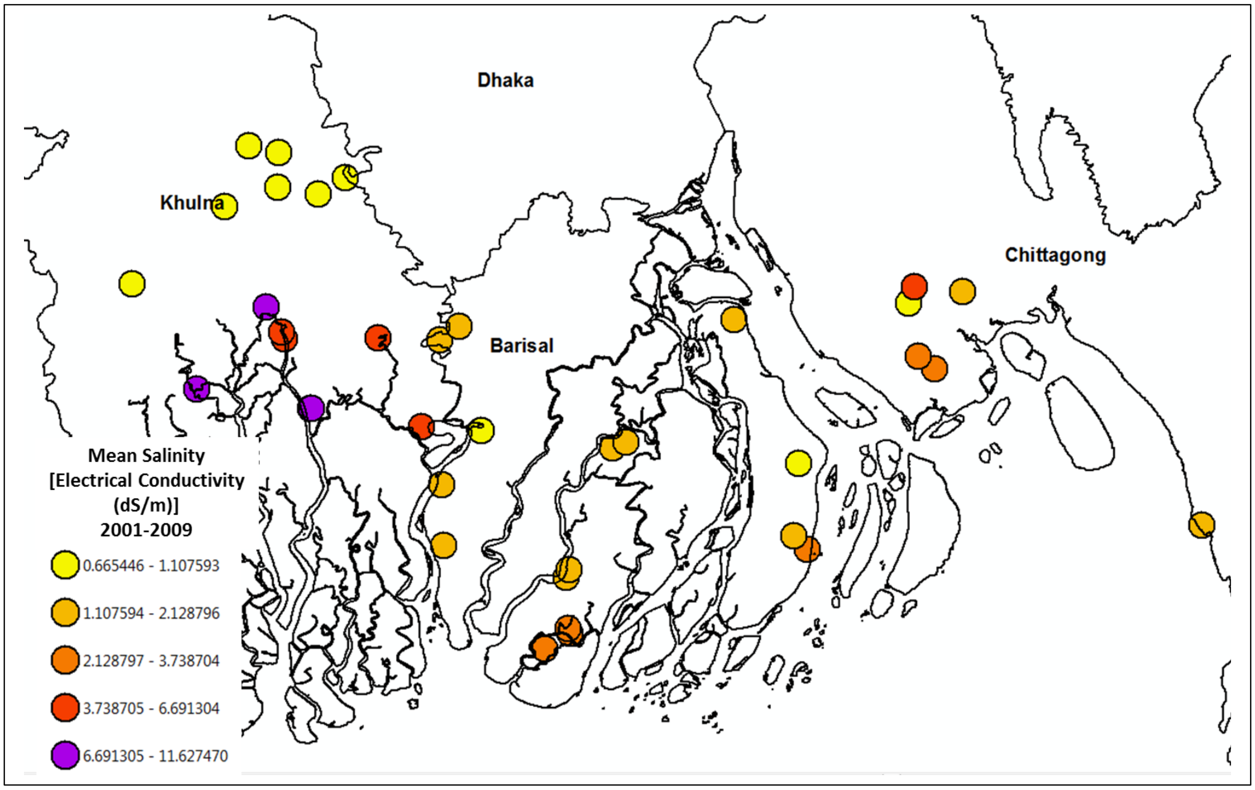
4.2 Soil Salinity

While the Dasgupta study provides a trove of new evidence on salinity change in Bangladesh's coastal rivers, no comparable assessment of soil salinity has been undertaken until now. For this study, the Bangladesh Soil Research Development Institute has provided measures from 41 soil salinity monitoring stations for the period 2001-2009. Figure 4 presents average monthly station measures for 2001-2009, color-coded in five groups for visual comparison with the distribution of readings from the river stations. The distribution of soil salinity measures bears some resemblance to the riverine distribution, particularly in the concentration of high salinity in central Khulna. However, Figure 4 reveals some marked differences as well. For example, the soil salinity measures in Barisal are relatively higher than their riverine counterparts.

4.3 Determinants of Soil Salinity

As we noted in the Introduction, one major objective of this study is an econometrically-estimated model that can be used to project soil salinity for HYV rice production areas in the coastal region of Bangladesh through 2050. In our model, land-based measures of soil salinity are related to salinity measures from nearby river stations via annual flooding and water table infusion. Logically, infusion effects and salinity should decline with elevation. In addition, dilution from precipitation should produce a negative relationship between soil salinity and rainfall. Finally, measured soil salinity rises with temperature because our soil salinity measure is based on electrical conductivity, which is greater at higher temperatures (Rhoades et al. 1999).

Figure 4: Mean salinity measures for land stations (dS/m): 2001-2009



We posit the following estimation model.

(1) $S_{Lit} = \beta_0 + \beta_1 E_i + \beta_2 S_{Rit} + \beta_3 R_{it} + \beta_3 T_{it} + \varepsilon_{it}$

Prior expectations: $\beta_1, \beta_3 < 0$; $\beta_2, \beta_4 > 0$

where
- S_{Lit} = Measured soil salinity (dS/m) at land station i, period t
- E_i = Elevation (m) of station i
- S_{Rit} = Distance-weighted mean measured salinity (ppt) of river stations within 30 km of land station i, period t
- R_{it} = Measured rainfall (mm) at the Bangladesh Meterological Department (BMD) weather station nearest to land station i
- T_{it} = Maximum monthly temperature (° C) at the BMD weather station nearest to land station i
- ε_{it} = Random, spatially-autocorrelated error term with station and time components

4.4 Data

Our data set includes monthly soil salinity measures from 41 stations for the period 2001-2009, provided by the Bangladesh Soil Research Development Institute; water salinity measures from 29 stations for 2000-2008, provided by Dasgupta et al. (2014); elevation data from DIVA-GIS;[6] and monthly temperature and rainfall data from 20 BMD weather stations for 1990-2010.[7]

As Figures 3, 4 and 5 show, the monitoring stations for soil salinity, river salinity and weather are located in different places, at varying distances from one another. Estimation of equation (1) requires juxtaposition of soil salinity, river salinity, temperature and rainfall at soil monitoring locations. For river salinity, we incorporate measures for all river stations within 30 km of each soil salinity monitor. We capture relative diffusion impacts using weights for river stations that are inversely proportional to their squared distances from the soil stations. For weather stations, we use observations for the station that is closest to each soil salinity monitor.

4.5 Estimation and Results

To test the robustness of our model, we use six estimation methods: two basic estimators (OLS, with and without dummy variables for monitoring stations); two panel estimators (random (RE) and fixed effects (FE)) and two spatial econometric estimators (random and fixed effects). For panel estimation, we employ the standard xtreg estimator in Stata. For spatial econometric estimation, we use the recently-developed xsmle estimator in Stata. It has been developed by Belotti, Hughes and Mortari, who draw on Cameron et al. (2011), Elhorst (2010), Lee and Yu (2010), and earlier work by Anselin (2001, 2002), Barrios et al. (2010); Kapoor et al. (2007); and Kelejian et al. (1998, 2004, 2006).

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[6] CGIAR-SRTM data with 3 seconds resolution, aggregated to 30 seconds by DIVA-GIS. Available online at http://www.diva-gis.org/gdata

[7] BMD temperature and rainfall data have been provided by the Bangladesh Agricultural Research Council. Temperature data available online at http://www.barc.gov.bd/ym_temp.php; rainfall data at http://www.barc.gov.bd/ym_rainfall.php

Our results, presented in Table 1, are robust and stable across all six estimators. All parameters have the expected signs, and all estimates have very high levels of significance. Collinearity forces exclusion of elevation from the three fixed-effects estimators. In the other estimators ((1), (3) and (5)), the effect of elevation is clear. Across the 41 monitors in our data set, elevation varies from 3 to 11 meters. In the most theoretically-appropriate estimate (5), measured electrical conductivity (a standard proxy for salinity) declines by .665 dS/m with each 1-meter increase in elevation, ceteris paribus. We choose the spatial fixed-effects (FE) estimator (6) for projection, since it incorporates the most appropriate specification of the error term. In (6), measured soil salinity increases by .326 dS/m for each increase of 1 part per thousand (ppt) in distance-weighted salinity measured by nearby river monitors. Rainfall has the predicted dilution effect: Measured soil salinity decreases by .003 dS/m for each one-millimeter increase in monthly rainfall. The predicted impact of temperature on electrical conductivity is also strongly reflected in our results: Measured soil salinity increases by .249 dS/m for each 1° C. increase in maximum monthly temperature.

Table 1 : Regression results: soil salinity monitors

Dependent variable: land station measure of soil salinity

	(1) OLS	(2) FE	(3) Panel, RE	(4) Panel, FE	(5) Spatial Panel, RE	(6) Spatial Panel, FE
Elevation	-0.476		-0.584		-.665	
	(16.42)**		(4.68)**		(4.04)**	
River Salinity	0.682	0.323	0.339	0.323	.334	.326
	(29.90)**	(15.18)**	(15.92)**	(15.18)**	(13.34)**	(12.73)**
Rainfall	-0.002	-0.003	-0.003	-0.003	-.003	-.003
	(9.96)**	(13.80)**	(13.69)**	(13.80)**	(12.37)**	(15.36)**
Temperature	0.162	0.245	0.242	0.245	.249	.249
	(7.59)**	(13.83)**	(13.59)**	(13.83)**	(13.52)*	(12.74)**
Constant	0.922	-4.42	-0.387	-3.990		
	(1.38)	(7.44)	(0.40)	(7.43)**		
Obs	4428	4428	4428	4428	4428	4428
R^2	0.30	0.55	0.27	0.22	0.26	0.53
Stations	41	41	41	41	41	41

Absolute value of t statistics in parentheses
*** significant at 5%; ** significant at 1%**

4.6 Weather Projections

Employing model (1) for forecasting requires projected salinity measures for each river station and projected rainfall and temperature for each weather station. We have introduced the river salinity projections of Dasgupta et al. (2014) in Section 4.1. In this section, we develop long-term rainfall and temperature projections using data from 20 coastal region BMD weather stations for the period 1990-2012. For temperature, we estimate a time trend in a panel regression that includes both station fixed effects and station-specific monthly variations. For rainfall, we adopt the same approach but perform the estimation for log rainfall to ensure positive projections in drier months. We use robust regression to ensure against any additional outlier effects. We do not report full results here, since our regressions include 11 monthly dummies, 19 weather station dummies, and 209 interactions of the monthly and weather station dummies, as well as the time trend.[8] Table 2 presents the estimates of primary interest: monthly time trends for temperature and rainfall.

Table 2: Robust panel regression estimates: temperature and rainfall at 20 BMD weather stations, 1990-2010

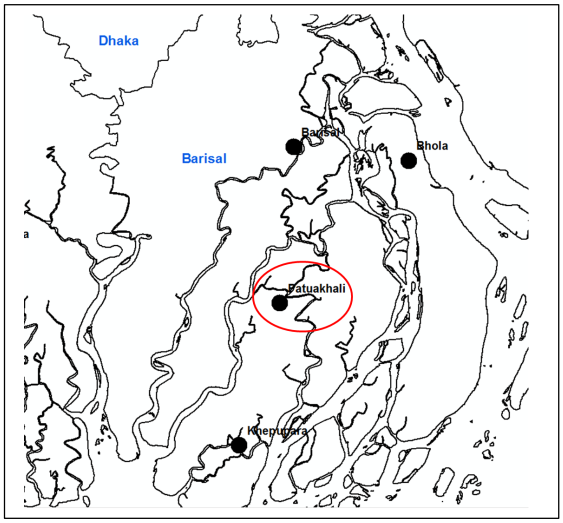
	Trend	t-Statistic	Regression F-Statistic	BMD Weather Stations	Monthly Observations
Temperature	0.0034	21.93**	F(240, 4799) = 197.15	20	5040
Log Rainfall	-0.00058	4.50**	F(240, 4775) = 379.89	20	5016

To illustrate the implications, Figures 5b-5c present annual means for monthly temperature and rainfall at the Bangladesh Meteorological Department's Patuakhali station in central Barisal (displayed on the map in Figure 5a). The projections for Patuakhali are representative of projections for all 20 BMD stations in our database. Appendix Table A4 presents monthly mean rainfall and

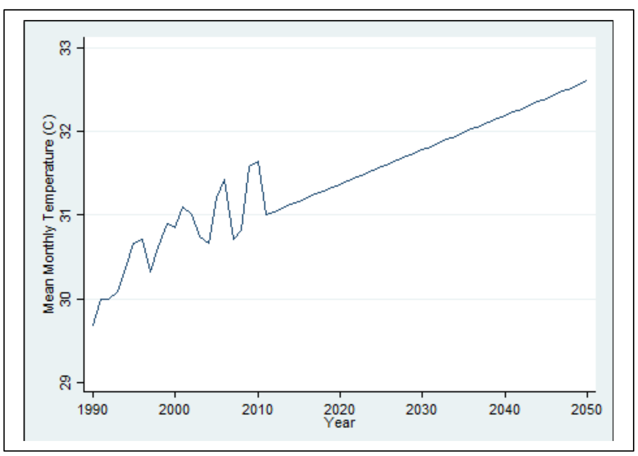
[8] Full results are available from the authors on request.

Figure 5: Recorded and projected temperature and rainfall, BMD Patuakhali station

5a: Station Location



5b: Temperature, 1990 - 2050



5c: Rainfall, 1990 - 2050

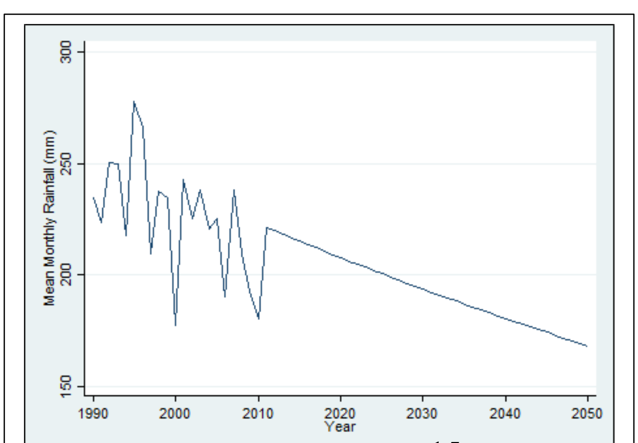


Table 3: Projections from global climate models, 2000 - 2050

a: Temperature

		Change, 2000-2050			
Division	Normal Daily Maximum Temp. (C) 2000	CNRM	CSIRO	ECHAM5	MIROC3.2
Barisal	34.1	1.8	1.5	1.7	-0.9
Chittagong	32.5	2.6	1.4	1.9	0.3
Dhaka	34.0	2.7	1.5	1.7	-0.2
Khulna	35.2	2.4	1.5	1.8	-0.4

b. Rainfall

		Change, 2000-2050			
Division	Mean Annual Precipitation (mm) 2000	CNRM	CSIRO	ECHAM5	MIROC3.2
Barisal	2,437	33	-62	99	212
Chittagong	2,644	-28	-51	88	212
Dhaka	2,085	31	-50	77	276
Khulna	1,717	48	-39	102	220

maximum temperature in 1990 and 2001 for all 20 stations, as well as projections for 2030 and 2050. For comparison, Table 3 provides downscaled estimates from four global climate models (GCMs) computed by Thomas et al. (2013).[9] It is important to note that the GCM estimates are global modeling results that do not reflect observed temperature and rainfall trends in Bangladesh. In Figure 5b, the projected temperature increase from our trend estimate for Patuakhali is about 2.0 ° C. from 2000 to 2050. As Table 3a shows, this falls within the midrange for the three GCMs with projected increases (CNRM, CSIRO, ECHAM5) and closest to the projections from ECHAM5.

In the case of rainfall (Table 3b) our trend estimate differs substantially from the GCM results. Of the four GCMs, only CSIRO projects a decline in annual rainfall for the four coastal regions in our study. As Figure 5c shows, our trend estimate yields a decline in average *monthly* rainfall of about 50

[9] The GCM results reflect the A1B scenario of the Intergovernmental Panel on Climate Change (Thomas et al. 2013).

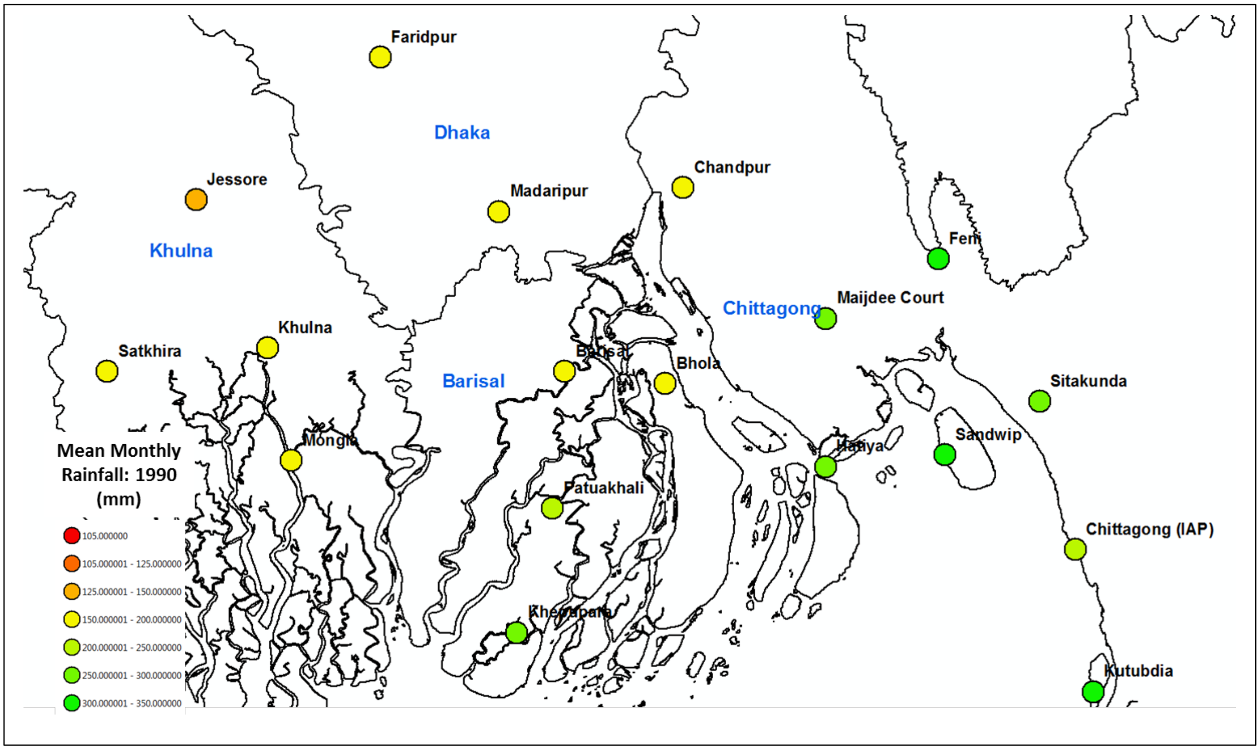
mm from 2000 to 2050, while the CSIRO estimate is a decline of 50 mm *annually*. For the CSIRO estimate to be correct (not to mention the positive estimates from the other GCMs), the sharply-declining trend in rainfall during 1990-2010 will have to moderate significantly or reverse itself. Perhaps this will happen, but the GCM rainfall results do not synchronize with actual observations.

In this research project, the temperature and rainfall results are important for two reasons. First, per our estimates for model (1) in Table 1, they are necessary for projecting future soil salinity. Second, they figure among the exogenous determinants of agricultural activity that are considered in Section 5. Later in the project, we will incorporate a range of temperature and rainfall projections into our analysis of options for agricultural adaptation to future salinity increases. For the present, however, we employ the temperature and rainfall projections that have emerged from our trend analyses.

Figure 6 displays the overall implications of our rainfall trend analysis for BMD weather stations in the coastal districts of Bangladesh. The figure provides color-coded mean monthly rainfall measures by station for 1990 and 2011, as well as our station-specific trend projections for 2030 and 2050. We have used the same color-coding in all four figures to highlight the strength of the estimated trend. The color code is Green for the highest observed and projected range (200-350 mm/month), Yellow for the intermediate range (150-200 mm/month) and Orange/Red for the low range (100-150 mm/month). In 1990, all stations in Chittagong except Chandpur are green, while most stations in Barisal, Dhaka and Kulna are Yellow. By 2030, a major shift toward lower rainfall is apparent in all three western districts, while stations in Chittagong are beginning to shift from Green to Yellow. By 2050, almost all stations in Kulna and Dhaka are Orange or Red, stations in Barisal

Figure 6: Recorded and predicted rainfall at 20 BMD weather stations, 1990 - 2050

1990



2011

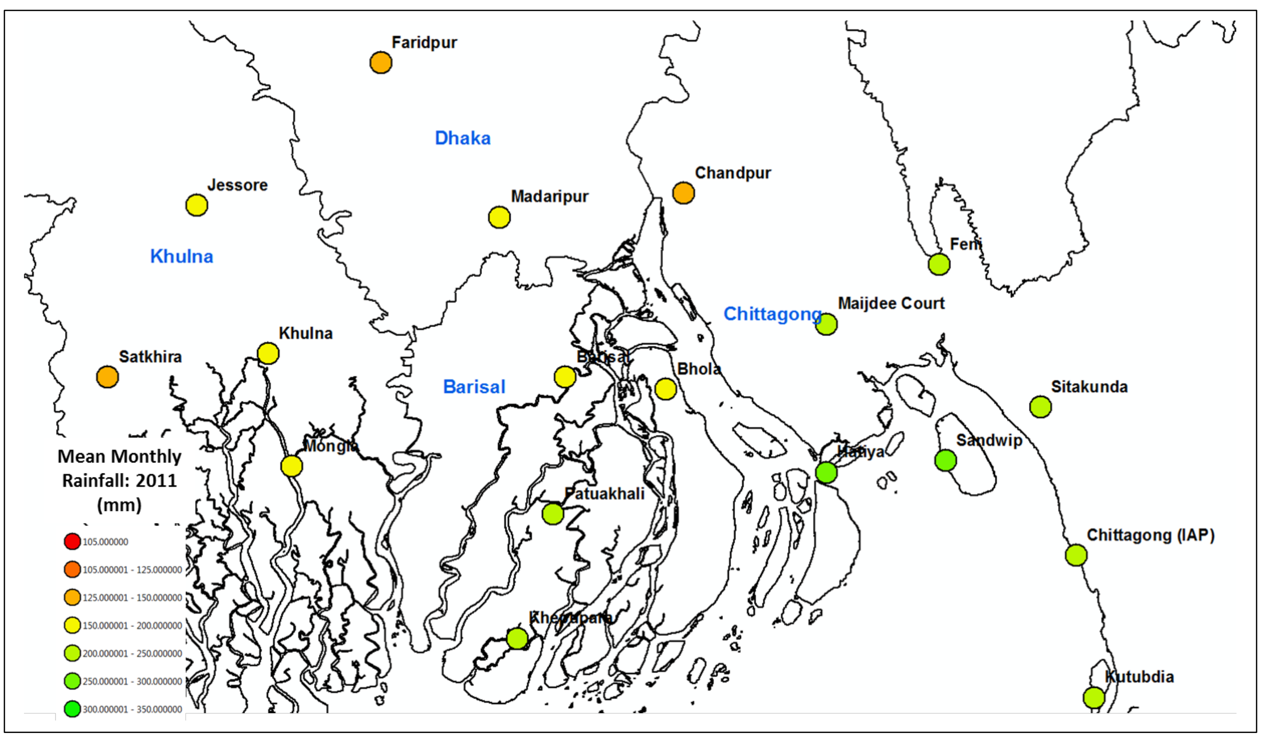
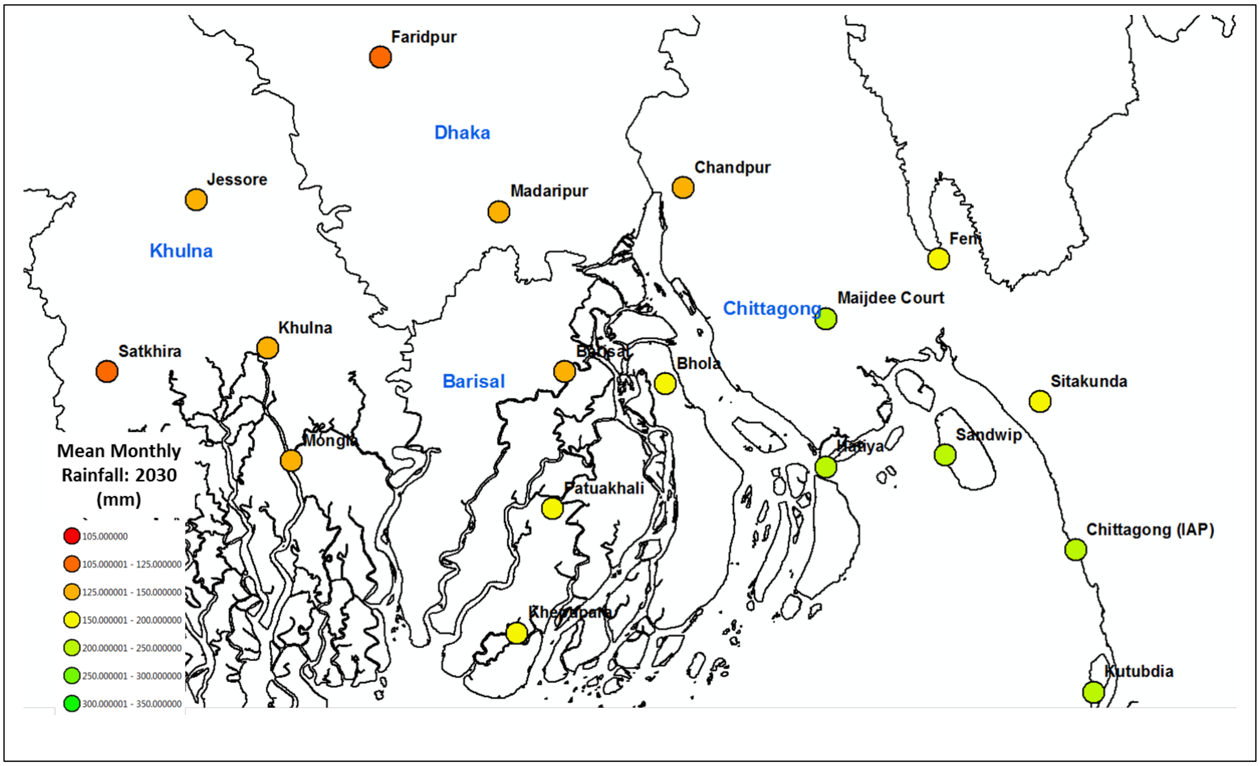
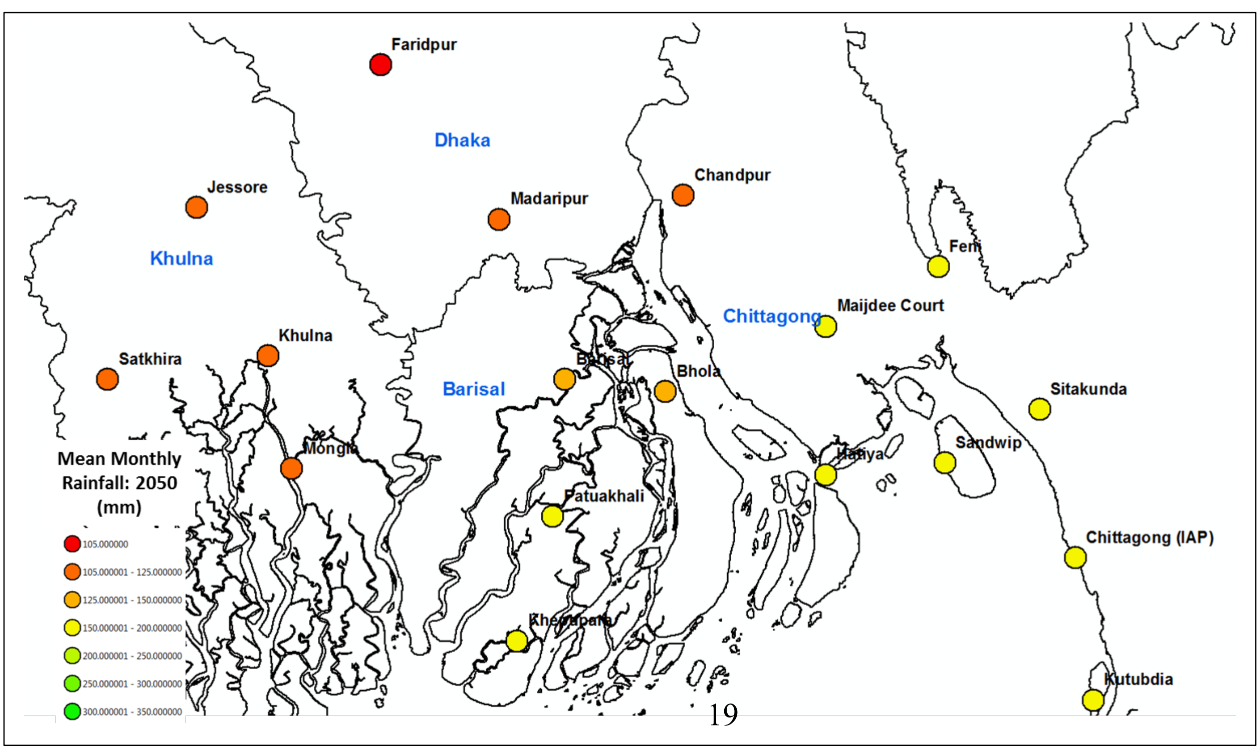


Figure 6 (cont'd): Recorded and predicted rainfall at 20 BMD weather stations, 1990 - 2050

2030



2050



are divided between Orange and Yellow, and all the formerly-Green stations in Chittagong have become Yellow.

4.7 Soil Salinity Projections

We develop projections for soil salinity measures at each of 41 monitoring stations by combining our estimates for model (1) with our projections for river salinity, temperature and rainfall. As we noted previously, inclusion of temperature provides a correction for the effect of temperature on electrical conductivity. Inclusion of rainfall provides a correction for the diluting effect of precipitation on measured salinity. To illustrate the implications of our estimates, we use the fixed-effects spatial estimates in Table 1, column (6). We adjust the series for all 41 monitoring stations by calculating their soil salinity at constant temperature and rainfall. We use 41-station means for both variables: 31.1 ° C for temperature and 178.2 mm for rainfall.

Appendix Table A5 presents the adjusted estimates for 2001, 2009 and (using projected exogenous variables) 2050. The last column of Table A5 presents percent changes from 2009 to 2050, using the high-salinity river case developed by Dasgupta et al. (2014). Table 4 provides summary statistics for the 41 stations.

Table 4: Distribution of projected percent changes: 41 soil monitoring stations, 2009-2050

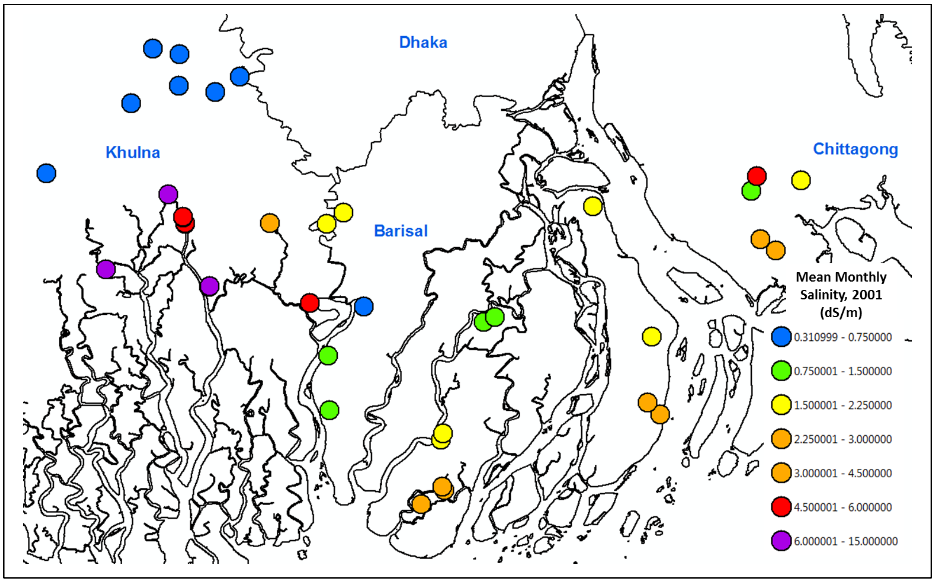
Min	P10	P25	P50	P75	P90	Max
0.3	6.8	14.2	26.2	41.8	55.7	69.1

Our results indicate that many areas in the coastal region of Bangladesh will have very significant increases in soil salinity during the coming decades. Across 41 monitoring stations, the median projected change is 26.2%. Above the median, 25% of the stations have changes of 41.8% or higher, and 10% have projected changes greater than 55.7%.

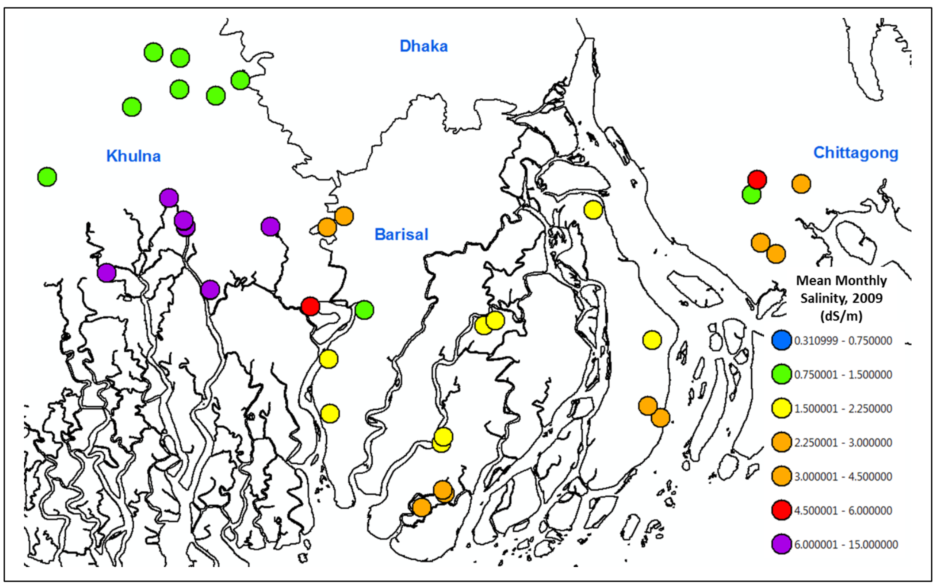
Figure 7 adds a geographic dimension to the projections. Monitoring stations are color-coded using standardized ranges for soil salinity in 2001, 2009 and 2050: Blue (0-0.75 dS/m); Green (0.75-

Figure 7: Observed and projected soil salinity measures: 2001, 2009, 2050

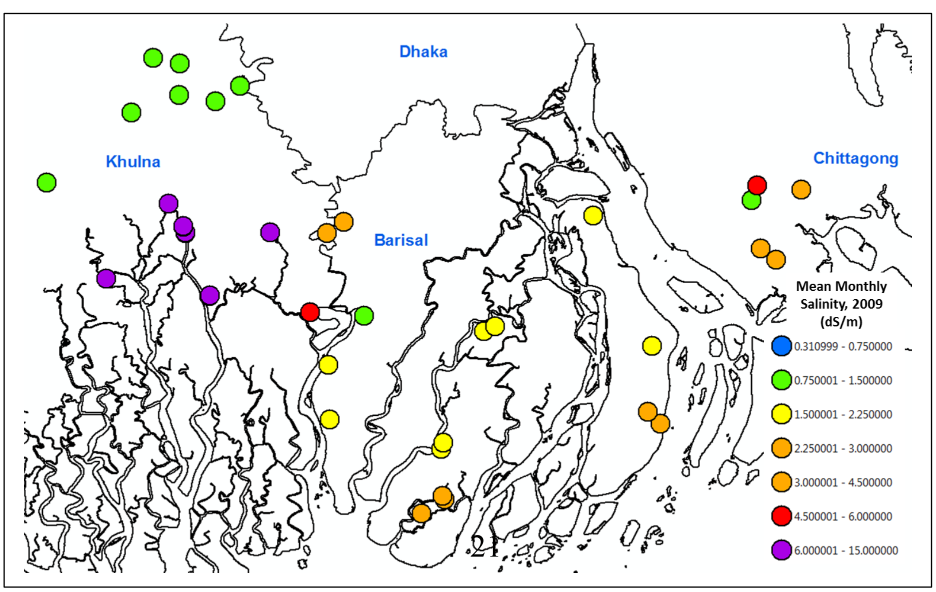
2001



2009



2050



1.50); Yellow (1.50-2.25); Orange (2.25-4.50); Red (4.50-6.00) and Purple (6.00+). In 2001, Khulna has the greatest variance among the four regions, with northern stations uniformly Blue and central stations heavily Red and Purple. Stations in Barisal vary from Blue to Orange, while stations in Chittagong vary from Green to Red.

By 2009, a general pattern of salinity increase is already apparent: All stations in northern Khulna have increased from Blue to Green; nearly all stations in Barisal (one exception) are Yellow or Orange; and stations in Chittagong have become heavily Orange as well. The shift continues through 2050, with some stations in north Khulna changing to Yellow; most stations becoming Purple in central Khulna, most stations in Barisal becoming Orange (and one changing to Red), and the sole Green station in Chittagong becoming Yellow.[10]

5. Salinity and HYV Rice Production

5.1 Potential Effects of Soil Salinity

As we noted previously, local research in Bangladesh has documented cases that are consistent with technical studies linking soil salinity to lower agricultural yields. In this paper, we expand the domain of inquiry by considering evidence from a large number of upazilas during the past decade. We focus on the relationship between increased soil salinity and four key variables: the physical productivity of paddy land, the market price of HYV rice, the extent of paddy planting, and the demand for paddy labor. Our econometric analysis seeks to determine whether these variables have been significantly affected by variations in soil salinity across upazilas and over time. Once the results are in hand, we will use them to investigate the impact of the future salinity increases that have been documented in Section 4.

[10] We have excluded one geographically-isolated station from Figure 7 to make the clustered icons easier to view. This station, Patenga, is further south on the coast of Chittagong. It is Yellow in 2001 and 2009, and changes to Orange in 2050.

5.2 Data

In preparation for this research, we have assembled a large panel database that includes previously-unavailable information on the economics of HYV rice production in the upazilas of coastal Bangladesh. Figure 1 identifies the 140 upazilas incorporated in the study, and Appendix Table A2 provides a complete accounting of the data collected from local offices. To summarize briefly, these data include annual information for 2000-2012 on HYV rice production and prices, as well as the quantities and prices of inputs (land, labor, seeds, fertilizer, pesticide and power tillage). The database also includes our measures of soil salinity, temperature and rainfall for upazilas. We calculate these measures for upazila centroids, using data from proximate monitoring stations. For soil salinity, we calculate the weighted mean of measures from stations within 30 km of the upazila centroid, using weights that are inversely proportional to squared distances. We calculate weighted mean temperature and rainfall at the upazila centroid using the same distance-weighting approach for GDM weather stations within 50 km.

Although our data provide a new view of local production, the records obtained from many upazilas have significant gaps in coverage. Table 5 summarizes the availability of information for output and input prices and quantities, as well as our measures of soil salinity, rainfall and temperature. All upazila centroids fall within 50 km of at least one BMD weather station, so our coverage is complete for rainfall and temperature. For soil salinity, a binding constraint is imposed by the need for observations from monitors within 30 km of upazila centroids. This limits our soil salinity measures to 69 upazilas.

Table 5: Non-missing upazila observations for database variables, by year

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
All Variables	14	14	14	14	14	14	14	14	14	14	13	14
Upazila Sources												
Paddy Price	84	84	84	85	86	97	98	100	100	103	103	103
Paddy Production	88	88	89	93	95	105	106	109	108	111	111	112
Paddy Acreage	88	88	89	93	95	105	106	109	108	111	111	112
Land Rent	41	41	42	46	46	46	46	46	46	47	47	47
Labor Quantity	89	91	95	101	102	103	104	104	105	107	107	108
Mean Wage	89	91	95	97	98	100	102	102	103	105	105	106
Seed Quantity	85	85	85	90	94	98	101	101	101	102	103	104
Seed Price	71	71	71	76	80	84	87	87	89	90	91	90
Urea Fertilizer Quantity	85	85	85	95	99	103	105	105	105	106	107	109
Urea Price	82	82	82	87	89	95	97	98	99	100	102	103
Pesticide Cost	83	84	84	91	95	101	105	105	105	107	107	108
Power Tillage Cost	87	87	87	93	97	103	106	106	106	108	108	109
Mean Observations	76	76	77	82	84	89	91	91	91	93	93	94
Other Sources												
Soil Salinity	69	69	69	69	69	69	69	69	69	69	69	69
Temperature	140	140	140	140	140	140	140	140	140	140	140	140
Rainfall	140	140	140	140	140	140	140	140	140	140	140	140

For the upazila-supplied variables, mean observations increase by year, from 76 in 2001 to 94 in 2012. The dominant constraint is imposed by land rent, which has far fewer observations than the other variables. Overall, as the first row of Table 5 shows, a critical constraint for multivariate estimation is imposed by the requirement of availability for all variables. Complete data are available for only 14 upazilas for eleven years, and 13 in 2011. This limitation has strongly affected the estimation strategy that we describe in the following subsections.

5.3 Soil Salinity and HYV Paddy Yield

To test the relationship between soil salinity and HYV paddy yield, we maximize degrees of freedom by estimating a reduced-form model that links yield per acre to soil salinity, temperature and rainfall.[11] We estimate the effect of soil salinity using both continuous and threshold specifications.[12] Table 6 presents our estimates for five cases: OLS, two panel estimators (RE, FE) and two spatial panel estimators (Sp,RE; Sp,FE). Prior experimentation has determined that threshold effects are most pronounced for upazilas with soil salinity measures above 4.0 dS/m.

In both continuous and threshold cases, we find highly significant spatial autocorrelation for the 39 upazilas in the sample. Inspection of the continuous and threshold results for the spatial estimators shows that the threshold specification is clearly stronger. Results for the two threshold spatial estimators are nearly identical, so we choose random effects as the preferred estimator. Our results suggest that, ceteris paribus, the log of yield per acre is lower by 0.169 in upazilas with soil salinity

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[11] To preserve full observational variation in Section 5, we use soil salinity measures that are not adjusted for the effects of temperature and rainfall. Both weather variables are included in all regressions, so our estimates incorporate the collinear components in any case.

[12] With plentiful data, a full exercise could incorporate capital and labor into the yield model using instrumental variables estimation. An equivalent test of salinity's impact would augment the reduced form with the available instruments themselves -- price measures for labor and other inputs. In this case, as we note later in Section 5, incorporation of the appropriate instruments would radically reduce degrees of freedom because exclusion of missing values would yield a small data set. Our sparse reduced form strategy maximizes degrees of freedom and minimizes standard errors, but we recognize the possibility of estimation bias if excluded instruments are significantly correlated with salinity. We have used the available data to calculate separate correlation coefficients for salinity and each exogenous price measure: All correlations are negative and lie between -0.25 and -0.05. Although these correlations are modest, we cannot exclude the possibility of some bias in our estimate of salinity's impact.

Table 6: Soil salinity and yield per acre in HYV paddy production

All variables in logs except for threshold salinity dummy variables in (6)-(10)

Dependent varable: Paddy yield (metric tons/acre)

	Salinity Measure									
	Continuous					Threshold (>4 dS/m)				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	OLS	RE	FE	Sp,RE	Sp,FE	OLS	RE	FE	Sp,RE	Sp,FE
Mean Max Temp,	1.997	1.265	1.082	1.436	1.638	2.165	1.131	0.939	0.942	0.979
Highest 4 Months	(3.98)**	(2.89)**	(2.35)*	(1.72)	(1.47)	(4.34)	(2.64)**	(2.10)*	(1.24)	(1.00)
Mean Rainfall,	-0.123	-0.079	-0.073	-0.084	-0.099	-0.122	-0.078	-0.073	-0.076	-0.087
Highest 4 Months	(2.41)*	(2.28)*	(2.09)*	(1.01)*	(0.98)	(2.39)*	(2.28)*	(2.09)*	(0.99)	(0.93)
Mean Soil Salinity	-0.037	-0.023	-0.017	-0.090	-0.096	-0.084	-0.078	-0.079	-0.169	-0.169
Highest 4 Months	(3.37)**	(1.46)	(0.93)	(1.90)	(1.52)	(4.02)**	(2.96)**	(2.77)**	(2.45)**	(1.99)*
Constant	-5.654	-3.359	-2.757			-6.266	-2.887	-2.247		
	(2.84)**	(2.07)*	(1.63)			(3.18)**	(1.81)	(1.36)		
Observations	468	468	468	468	468	468	468	468	468	468
R-squared	0.14	0.14	0.14	0.14	0.06	0.15	0.14	0.13	0.11	0.06
Upzilas	39	39	39	39	39	39	39	39	39	39

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

measures above 4 dS/m.[13] This is equivalent to a reduction of 15.55%.

Our results for temperature and rainfall illustrate the effect of adjusting for spatial autocorrelation in this context. In the continuous and threshold cases, both weather variables are statistically significant in most of the OLS and panel estimates. In the FE panel estimate (8) for threshold salinity, for example, each 1% increase in temperature is associated with a 0.94% increase in paddy yield; each 1% increase in rainfall lowers yield by 0.07%. After adjustment for spatial autocorrelation in (9) and (10), the estimated impacts of temperature and rainfall remain virtually identical to the panel estimates (7 and 8). The estimated standard errors are larger, however, so both variables lose classical significance.

5.4 Soil Salinity and the Market Price of HYV Rice

Elevated soil salinity is believed to degrade the quality of HYV rice, with a consequent negative impact on its market price. We test for this effect while controlling for transport cost, which we proxy using high-resolution spatial estimates of travel time to the nearest major market developed by Uchida and Nelson (2009). We compute Uchida/Nelson time-to-market for the centroid of each upazila. Our HYV price model is specified as follows: [14]

[13] Our econometric result coincides with the salinity threshold established by technical experimentation (Suryanarayanan, 2010).

[14] This reduced form equation excludes total HYV output as a demand variable because it is jointly determined with HYV price and our upazila database does not include an appropriate time series variable to use as an instrument. In our model an exogenous shift in demand would have an impact similar to the incorporated impact of transport cost. This can be interpreted as an exogenously-induced shift in average price, with salinity-related quality differences inducing proportionate variations from the average.

(2) $ln\, P_{it} = \beta_0 + \beta_1\, lnD_i + \beta_2\, ln\, S_{it} + \varepsilon_{it}$

Expectations: $\beta_1, \beta_2 < 0$

where, for upazila i in year t:

P_{it} = Harvest time market price of HYV paddy (taka)
D_{it} = Travel time to nearest city with 50,000+ population (hours)
S_{it} = Mean soil salinity during the four most saline months, measured by sample electrical conductivity (dS/m)[15]
ε_{it} = Random error term with upazila and yearly components

Table 7 presents our results for OLS (1) and two panel estimators: random effects (2) and random effects with an adjustment for spatial autocorrelation (3). We employ random effects in this case to explicitly incorporate Uchida/Nelson time-to-market, which would be excluded from a fixed-effects estimate because it is constant for each upazila. In all cases, our results are strong and consistent with prior expectations. For OLS (1) and RE (2), the estimated elasticity of HYV price with respect to travel time is -0.11: Price declines .11% with each 1% increase in travel time. However, the estimated elasticity declines to -.07 and loses significance in Sp,RE (3), which adjusts for spatial autocorrelation across upazilas.

In all three estimates, we find a negative, significant effect for soil salinity. Estimated elasticities vary from -.061 (OLS) to -.079 (Sp,RE): HYV rice price declines .06% - .08% with each 1% increase in salinity. We have tested variable-slope models for the panel estimators, and we find that the estimated marginal effect of soil salinity remains constant as salinity increases.

[15] We have also tested for the impact of mean salinity during the four middle months. These results are significant, but the effect is stronger for the four highest months.

Table 7: Impact of soil salinity on the market price of HYV rice

All variables in log form

Dependent variable: Harvest time market price of HYV rice

	(1) OLS	(2) RE	(3) Sp,RE
Travel time to nearest city with 50,000+ population	-0.107 (6.45)**	-0.109 (2.65)**	-0.070 (1.08)
Mean soil salinity in the four most saline months	-0.061 (3.99)**	-0.064 (2.91)**	-0.079 (2.32)*
Constant	2.752 (33.14)**	2.764 (14.29)**	
Observations	468	468	468
R-squared	0.09	0.08	0.02
Number of upzilas	39	39	39

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

The spatial autocorrelation parameter is marginally significant in this case and technical problems have hindered prediction with our Sp,RE results, so we predict the effect of salinity on price using the standard panel estimator (2). The estimated price elasticity of soil salinity in (2) is somewhat lower than the Sp,RE estimate (3), so our prediction is conservative. Table 8 displays the results, using mean time-to-market for our sample and grouping upazila salinity measures by decile. The table shows a decline in mean predicted price from 9.7 taka/kg at a soil salinity measure of 0.6 dS/m to 8.0 taka/kg at 14.7 dS/m. By implication, farmers in the highest-salinity upazilas receive market prices 17.5% lower than their counterparts in the lowest-salinity upazilas, ceteris paribus.

Table 8: Soil salinity and HYV rice price at mean distance to market

Mean Salinity, Highest Four Months (dS/m)	Paddy Price (taka/kg)
0.7	9.7
0.9	9.6
1.4	9.3
1.9	9.1
2.4	9.0
2.9	8.9
3.7	8.7
5.7	8.5
9.3	8.2
14.7	8.0

5.5 Soil Salinity and Input Use

In the preceding sections, we find that soil salinity has significant negative impacts on HYV prices and yields in the coastal region of Bangladesh. Before drawing any summary conclusions, however, we need to explore the links between soil salinity and the use of inputs, particularly land and labor. Farmers may respond to the threat of yield and price reductions with expansion at the extensive margin (more land in production) and the intensive margin (more labor per acre). If this happens, modeling the full impact of salinity becomes more complex. On one side of the economic benefit calculation, negative impacts from yield and price declines may be at least partly offset by greater production and higher employment. On the other side, input costs will also increase.

Unfortunately, missing observations in our panel database create significant problems for testing these relationships with fully-specified models. As Table 5 shows, only 13 upazilas have data sufficient for full panel estimation of input use equations for labor, land, seeds and fertilizer. Given this limitation, we have confined ourselves to two exercises. First, we maximize degrees of freedom and upazila representation by estimating sparse reduced-form input use equations for labor and land. Then, in a subsidiary exercise, we estimate full input use functions for the 13 upazilas that have complete data. We present separate estimates for these functions without trying to impose standard restrictions from microeconomic theory, since our data are for entire upazilas, not farm households.

5.5.1 Sparse Reduced-Form Estimates for Land and Labor

We estimate reduced-form input use functions for land and labor, using fixed effects to control for scale differences across upazilas. The basic functional form incorporates own- and cross-price effects for the two inputs, as well as temperature, rainfall and soil salinity. As Table 5 shows, land rent is much sparser than most variables in the data set, so we begin the exercise by testing its own-price effect on land use in the restricted sample. We find no significance for this variable, so we exclude it and estimate the following fixed-effects equation for land and labor:

$$(3)\ \ ln\, N_{hit} = \beta_0 + \beta_1\, ln\, W_{it} + \beta_2 \ln T_{it} + \beta_3 \ln R_{it} + \beta_4 \ln S_{it} + \varepsilon_{it}$$

where, for upazila i in year t:

Inputs are defined as follows:

N_{1it} = Area planted in HYV paddy (acres)
N_{2it} = Total labor for paddy production (man-days/acre)

Exogenous variables are defined as follows

W_{it} = Average wage rate of agricultural labor without food (Nov to June) (taka/day)
T_{it} = Mean maximum temperature during the four hottest months (° C)
R_{it} = Mean rainfall during the four wettest months (mm)
S_{it} = Mean soil salinity during the four most saline months, measured by sample electrical conductivity (dS/m)[16]
ε_{it} = Random error term with upazila and yearly components

Table 9 presents fixed-effects results for a large number of upazilas (37 for land, 41 for labor), with and without adjustment for spatial autocorrelation. We find significant spatial autocorrelation for land, but not for labor. Only the temperature effect is significant in Sp,FE for land, and estimated wage elasticities in both labor equations have perverse signs. In all four results, the estimated effect of soil salinity is negative and insignificant. From this large-sample result, we tentatively conclude

[16] We have also tested for the impact of mean salinity during the four middle months; these results are also significant, but the effect is stronger for the four highest months.

that soil salinity has no impact on labor and land use that would partially offset salinity's direct impacts on yield and price.[17]

Table 9: Input use functions: land and labor

All variables in log form

Dependent variables: Logs of HYV paddy acreage and paddy labor/acre

Spatial Autocorrelation:	Significant		Insignificant	
	Paddy Acreage		Paddy Labor/Acre	
	(1)	(2)	(3)	(4)
	FE	Sp,FE	FE	Sp,FE
Mean Wage	0.436	0.252	0.037	.039
	(3.50)**	(0.95)	(2.52)*	(2.90)**
Mean max. temperature, hottest four months	9.343	12.520	-0.028	-0.027
	(6.12)**	(2.94)**	(0.16)	(0.13)
Mean rainfall, wettest four months	-0.104	-0.138	-0.007	-0.007
	(0.95)	(0.45)	(0.58)	(0.47)
Mean soil salinity, four more saline months	-0.031	-0.278	-0.007	-0.008
	(0.57)	(1.74)	(1.05)	(1.12)
Constant	-25.400		3.640	
	(4.70)**		(5.87)**	
Observations	444	444	492	492
Number of upazilas	37	37	41	41
R-squared	0.18	0.18	0.02	0.02

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

[17] In the following section, we present small-sample results in Table 10a that suggest some substitution toward labor under saline conditions. If compensating labor substitution does occur (we remain doubtful, given the small sample size and our opposing results in Table 9), then the fully-accounted impact of salinity on output and income would be lower than our estimate in this paper. To assess the potential magnitude of the adjustment, we use the results in Table 10a: The random- and fixed-effects elasticities for labor wrt salinity are about .02, indicating that labor input increases by .02% for each 1% increase in salinity. Drawing on the findings of Harrison (2002) for low- and middle-income countries, we assume that the elasticity of output wrt labor is 0.60%. By implication, compensating labor substitution from a 1% increase in salinity increases output by .012% (0.02 x 0.60). Our preferred threshold-based estimates in Table 6 are not directly comparable, but we can draw a suggestive inference from the continuous random- and fixed-effects estimates in Columns (4) and (5): The estimated elasticity of output wrt salinity is around -0.09. Accounting for the labor-compensating effect on output, the adjusted estimate is -.078 (-0.09+0.012) and the estimated total impact of salinity on yield falls by 13.3%. In addition, it is entirely possible that farmers attempt to compensate for increased salinity by increasing the use of inputs that are not included in our database. For example, Tahir et al. (2013) report yield-enhancing effects from composting for rice production under saline conditions. We have no empirical evidence on the relevant elasticities, so we cannot judge whether such exclusions would have significant implications for our results.

5.5.2 Sparse-Sample Estimates for Land, Labor, Seeds and Fertilizer

With much lower confidence, we use the available data from only 14 upazilas to explore the potential impact of soil salinity in more fully-specified input use functions. The general form of our estimating equations:

$$(4)\ \ ln\, N_{hit} = \beta_0 + \beta_1\, lnP_{it} + \beta_2\, ln\, W_{it} + \beta_3 \ln L_{it} + \beta_4 \ln G_{it} + \beta_5 \ln F_{it} + \beta_6 \ln K_{it} + \beta_7 \ln M_{it} + \beta_8 \ln T_{it} + \beta_9 \ln R_{it} + \beta_{10} \ln S_{it} + \varepsilon_{it}$$

where, for upazila i in year t:

Inputs are defined as follows:

N_{1it} = Total labor for HYV paddy production (man-days/acre)
N_{2it} = Area planted in HYV paddy (acres)
N_{3it} = Seed used for HYV paddy production (kg/acre)
N_{4it} = Urea fertilizer used for HYV paddy production (kg/acre)

Exogenous variables are defined as follows

P_{it} = Harvest time market price of HYV paddy (taka)
W_{it} = Average wage rate of agricultural labor without food (Nov to June) (taka/day)
L_{it} = Land rent (taka/acre/year)
G_{it} = Price of seed used for paddy production (taka/kg)
F_{it} = Price of urea fertilizer used for paddy producation (taka/kg)
K_{it} = Cost of pesticide for paddy production (taka/acre)
M_{it} = Cost of tractors/power tillers used for paddy production (taka/acre)
T_{it} = Mean maximum temperature during the four hottest months (° C)
R_{it} = Mean rainfall during the four wettest months (mm)
S_{it} = Mean soil salinity during the four most saline months, measured by sample electrical conductivity (dS/m)
ε_{it} = Random error term with upazila and yearly components

Tables 10a and 10b present our results for the four inputs. The 13 upazilas in our sparse sample are scattered across the coastal region, and we find that spatial autocorrelation is not significant in this case.[18] We have therefore estimated each input equation using OLS and two standard panel estimators (random effects (RE) and fixed effects (FE)). Missing data have significantly restricted

[18] We confirmed this in a preliminary estimation exercise using the Stata xsmle estimator.

Table 10a: Soil salinity in labor and land use functions (all variables in logs)

	Labor			Land		
	(1) OLS	(2) RE	(3) FE	(4) OLS	(5) RE	(6) FE
HYV Rice Price	-0.061	0.008	0.006	-0.680	0.136	0.121
	(0.59)	(0.44)	(0.46)	(1.13)	(0.72)	(0.63)
Wage	0.220	-0.044	-0.063	0.878	1.229	1.236
	(1.30)	(1.56)	(2.98)**	(0.90)	(4.11)**	(4.10)**
Land Rent	0.002	0.084	0.101	0.832	0.320	0.373
	(0.03)	(2.22)*	(3.41)**	(2.42)*	(0.82)	(0.89)
Seed Price	-0.306	-0.040	-0.010	-1.906	-0.757	-0.753
	(2.72)**	(1.03)	(0.33)	(2.95)**	(1.87)	(1.82)
Fertilizer Price	0.152	0.012	0.014	0.032	0.025	0.021
	(1.64)	(0.77)	(1.21)	(0.06)	(0.15)	(0.13)
Pesticide Cost	0.685	0.053	-0.003	1.433	0.910	0.831
	(8.95)**	(1.74)	(0.13)	(3.26)**	(2.87)**	(2.49)*
Power Tiller Cost	0.005	-0.055	-0.043	-0.169	-0.398	-0.320
	(0.08)	(1.76)	(1.80)	(0.46)	(1.21)	(0.94)
Temperature	-6.393	-0.078	0.036	-7.972	8.658	8.557
	(4.19)**	(0.30)	(0.18)	(0.91)	(3.18)**	(3.11)**
Rainfall	-0.040	-0.006	-0.008	-0.685	0.082	0.088
	(0.33)	(0.34)	(0.55)	(0.99)	(0.42)	(0.45)
Soil Salinity	0.154	0.026	0.019	1.265	-0.319	-0.363
	(2.69)**	(2.04)*	(2.01)*	(3.85)**	(2.39)*	(2.65)**
Constant	21.392	3.415	3.136	26.826	-31.889	-32.070
	(3.69)**	(3.54)**	(4.38)**	(0.81)	(3.15)**	(3.16)**
Observations	156	156	156	156	156	156
R-squared	0.68	0.21	0.24	0.33	.37	0.37
Upzilas	13	13	13	13	13	13

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

Table 10b: Soil salinity in seed and fertilizer use functions (all variables in logs)

	Seed			Fertilizer		
	(1) OLS	(2) RE	(3) FE	(4) OLS	(5) RE	(6) FE
HYV Rice Price	-0.038	-0.021	0.032	0.058	0.051	0.016
	(1.12)	(0.64)	(1.36)	(1.18)	(1.37)	(0.53)
Wage	0.051	0.075	0.098	0.004	-0.120	-0.206
	(0.95)	(1.43)	(2.62)**	(0.05)	(2.00)*	(4.34)**
Land Rent	0.276	0.250	-0.168	0.296	0.381	0.329
	(14.33)**	(11.60)**	(3.22)**	(10.60)**	(10.61)**	(4.98)**
Seed Price	-0.261	-0.217	-0.003	0.605	0.290	0.004
	(7.25)**	(5.41)**	(0.05)	(11.58)**	(4.77)**	(0.06)
Fertilizer Price	-0.098	-0.093	-0.081	0.236	0.141	0.066
	(3.28)**	(3.26)**	(3.89)**	(5.47)**	(4.28)**	(2.49)*
Pesticide Cost	0.074	0.067	-0.042	0.169	0.121	0.033
	(3.00)**	(2.65)**	(1.00)	(4.74)**	(3.36)**	(0.64)
Power Tiller Cost	0.031	0.014	-0.077	-0.089	-0.057	-0.013
	(1.51)	(0.61)	(1.82)	(2.95)**	(1.45)	(0.23)
Temperature	-0.662	-0.763	-0.081	-1.403	-0.149	0.316
	(1.35)	(1.60)	(0.24)	(1.98)	(0.27)	(0.73)
Reainfall	0.016	0.011	-0.012	-0.043	-0.024	-0.010
	(0.41)	(0.28)	(0.48)	(0.77)	(0.58)	(0.33)
Soil Salinity	0.048	0.034	-0.022	-0.012	0.016	0.027
	(2.62)**	(1.88)	(1.30)	(0.46)	(0.72)	(1.27)
Constant	2.633	3.128	4.930	4.176	0.714	1.139
	(1.42)	(1.72)	(3.91)**	(1.55)	(0.34)	(0.71)
Observations	156	156	156	156	156	156
R-squared	0.72	0.02	0.26	0.79	0.20	0.34
Number of Upazilas	13	13	13	13	13	13

Absolute value of t statistics in parentheses
* significant at 5%; ** significant at 1%

the degrees of freedom available for estimation of a balanced panel, so each equation is estimated with 156 observations.

We are primarily interested in the estimated effect of soil salinity on input demands, since this is the innovative part of the exercise. Our most robust results are for the labor elasticity of salinity (Table 10a), which is positive and significant in all three estimates, but much smaller in the panel estimates than in OLS. Panel estimation also has a clear impact on the land elasticity of salinity, which appears positive and significant in OLS but becomes negative and significant in both panel estimates. In Table 10b, only the OLS estimate for the seed elasticity of salinity appears positive and significant. The panel estimates for seeds and all estimates for fertilizer are insignificant.

At this point, we should note that the significant results for land and labor in this small sample may be spurious, because they are not confirmed by our previously-reported large-sample estimates for the two variables. With this strong caveat, we interpret the results in Table 10 as weakly consistent with salinity effects that ameliorate negative impacts on yields and prices in the case of labor (labor demand rises with salinity) and reinforce them in the case of land (land demand falls as salinity rises). Overall, our panel estimates suggest net reinforcement of the negative impacts. The negative land elasticity of salinity [RE(-0.312);FE(-.363)] is much greater than the offsetting labor elasticity [RE(.026);FE(.019)]. Even if we accepted these results as valid for the region, we would have to conclude that the net impact of salinity is employment-reducing because, ceteris paribus, the slight increase in labor intensity (labor/acre) is more than offset by the reduction in paddy land.

Since the data employed for this exercise are new, our other results are also of some interest. We find that HYV price elasticity is insignificant for all four inputs.[19] Among the own-price results, only labor exhibits an appropriately-signed, significant result in the FE estimate, and the estimated

[19] Technically, this implies that the sum of paddy price coefficients is not significantly different from zero in a log-log demand system where all other input prices are normalized by the price of paddy.

wage elasticity is small (-.063). For land, both panel estimates of land rent elasticity are insignificant. The OLS and RE estimates of own-price elasticity for seeds are negative and highly significant, but the FE estimate is insignificant. For fertilizer, all three estimates are significant, but with perverse signs.

Among the panel estimates of cross-price effects, only labor and land elasticities have a strong, symmetric substitution relationship (i.e. both cross-price elasticities are positive and significant).
We have also included available information on unit costs for pesticide and power equipment in the equations, although we do not have information on input quantities for these two variables. Our panel estimates for pesticide suggest that it has significant substitution relationships with land, seeds and fertilizer, although the results are much stronger for RE than FE. In contrast, our panel estimates for power equipment are uniformly weak. Finally, our panel results for temperature and rainfall display significance only for land, whose temperature elasticity is positive and highly significant in both panel estimates.

6. Future Salinity, Productivity, Prices and Incomes

In Section 4, we developed an econometric model that links soil salinity to proximate river salinity, rainfall and temperature. Using projections of river salinity from Dasgupta et al. (2014) and our own projections for temperature and rainfall, we have used the econometric results to develop projections of soil salinity for 69 upazilas in the coastal region through 2050. In Section 5, our investigation of the relationships linking soil salinity to the economics of HYV rice production have yielded three key findings: (1) The best-fit relationship between yield and soil salinity is a threshold model in which upazilas whose soil salinity exceeds 4 dS/m have about 16% lower yield than their counterparts. (2) The price of HYV rice declines continuously as soil salinity increases, with an elasticity of -.064 (price declines .064% with each 1 % increase in salinity). (3) Our best evidence suggests that the demand for labor and land in HYV rice production is not that sensitive to salinity, so yields fall even with potential adjustments in inputs.

In summary, our results suggest that yield per acre and price decline with salinity, while inputs of labor and land remain stable. With constant acreage, declining yield and declining price, income from paddy production declines with salinity. The magnitude of the impact can be expected to vary by upazila, according to local conditions.

In this section, we explore the potential consequences of increased soil salinity with a projection exercise for yields and prices. Our sample comprises 69 upazilas with the requisite data in Khulna (29), Barisal (27), Chittagong (9) and Dhaka (4).

6.1 Paddy Yields

To project yields, we use the identical spatial random- and fixed-effects estimate (from (9) and (10)) in Table 6. We use the results from Section 5 to project mean soil salinity in the four most saline months from 2012 to 2050. For the 56 upazilas with observations for paddy output and acreage in 2012, we calculate initial yield for our projection directly. The remaining 13 upazilas have no yield observations for 2000-2012, so we use mean 2012 yield in their respective regions.

Our exercise sets baseline yield equal to yield in 2012 for the entire projection period. For comparison, we identify upazilas that have salinity measures lower than 4 dS/m in 2012 and higher than this threshold in 2050. We apply our econometric result to these upazilas, reducing baseline yield by 15.55% in each year after the 4 dS/m threshold is exceeded.

Table 11 provides information on the threshold status of our sample upazilas. By 2012, 18 have already exceeded the threshold (17 in Khulna and 1 in Barisal). Since the yield-reducing effects have already occurred for these upazilas, their baseline and comparative yields are both set at their 2012 yields for the projection. During the period 2013-2050, soil salinity goes past the threshold value of 4 dS/m in 9 upazilas (Barisal (6), Chittagong (2), Dhaka(1)). For these areas, we reduce baseline yield by 15.55% for each year after the threshold is exceeded.

Table 11 : Upazila salinity threshold dtatus by period

Region	2012 or Earlier	2013 - 2050	After 2050
Barisal	1	6	20
Chittagong	0	2	7
Dhaka	0	1	3
Khulna	17	0	12

The remaining 42 upazilas remain below the threshold in 2050, so their baseline and comparative yields are set at their 2012 levels.

6.2 HYV Rice Prices

To project prices, we use the random effects estimates (2) in Table 7. For each of the 69 sample upazilas, we use projected soil salinity (and upazila time to market) to forecast the annual price through 2050. We divide the forecast for each year by the forecast value in 2012 to form a ratio with value 1.0 in 2012 that declines as salinity increases through 2050. We set the baseline price at the observed price in 2012 and multiply it by the forecast ratio to generate the projected price series for each upazila. This procedure is straightforward for the 49 upazilas that have price observations for 2012. The remaining 20 have no price information, so we set their baseline prices at mean prices for their regions in 2012.

6.3 Incomes

To explore the implications of our results for income (projected price times projected output), we must estimate paddy acreage as well as yield. In our database, 56 upazilas have paddy acreage observations for 2012 and 13 have no observations for any year. In the latter case, we develop baseline acreage estimates with a two-step procedure. First, we calculate the median ratio of paddy acreage to total area for upazilas in each coastal region (Barisal, Chittagong, Dhaka, Khulna). Then, for each of the 13 cases with missing observations, we multiply the upazila's area by the median acreage/area ratio for its region to obtain an estimate of paddy acreage. We use this estimate as our baseline for the income projection.

We calculate future incomes in two scenarios. The first scenario multiplies baseline yields and acreages to produce baseline outputs, and multiplies the results by the baseline paddy prices to calculate (constant) baseline incomes for each year from 2013 to 2050. The second scenario employs our projections for yields and prices that incorporate the effects of rising soil salinity. We multiply projected yields by baseline paddy acreages to produce projected outputs, and multiply these by projected prices to calculate projected incomes.

Table 12 (on the following two pages) presents complete results for upazilas, and Table 13 below provides summary statistics. Our output results are skew-distributed, with large declines confined to upazilas that pass the 4 dS/m threshold during the projection period. On the other hand, all upazilas encounter price declines that vary from 0.2% to 3.9%, with a median of 2.0%.

Table 13: Summary statistics for sample upazilas

	Percent Change, 2012-2050		
	Paddy Output	Paddy Price	Income
Minimum	-15.5	-3.9	-17.1
P25	0.0	-2.9	-3.2
Median	0.0	-2.0	-2.4
P75	0.0	-1.5	-1.5
Max	0.0	-0.2	-0.2

Table 12: Projected changes in HYV rice outputs, prices and incomes, 2012-2050

				Percent Change, 2012-2050			Change Share	
Region	District	Sub-District	Upazila	Paddy Output	Paddy Price	Income	Paddy Output	Paddy Price
Barisal	Barisal	Barisal	Bakerganj	0.0	-3.1	-3.1	0.0	100.0
Barisal	Barisal	Barisal	Banaripara	-15.5	-1.7	-17.0	89.9	10.1
Barisal	Barisal	Barisal	Mehendiganj	0.0	-2.9	-2.9	0.0	100.0
Barisal	Barisal	Jhalakati	Kathalia	0.0	-3.3	-3.3	0.0	100.0
Barisal	Barisal	Jhalakati	Nalchity	0.0	-3.1	-3.1	0.0	100.0
Barisal	Barisal	Jhalakati	Rajapur	0.0	-3.3	-3.3	0.0	100.0
Barisal	Barisal	Pirojpur	Bhandaria	0.0	-2.8	-2.8	0.0	100.0
Barisal	Barisal	Pirojpur	Kawkhali	0.0	-2.1	-2.1	0.0	100.0
Barisal	Barisal	Pirojpur	Mathbaria	0.0	-1.9	-1.9	0.0	100.0
Barisal	Barisal	Pirojpur	Nazirpur	-15.5	-1.7	-17.0	90.2	9.8
Barisal	Barisal	Pirojpur	Nesarabad	-15.5	-1.6	-16.9	90.5	9.5
Barisal	Barisal	Pirojpur	Pirojpur S.	-15.5	-1.6	-16.9	90.8	9.2
Barisal	Patuakhali	Bhola	Bhola S.	0.0	-2.9	-2.9	0.0	100.0
Barisal	Patuakhali	Bhola	Burhanuddin	0.0	-2.7	-2.7	0.0	100.0
Barisal	Patuakhali	Bhola	Charfasson	-15.5	-1.8	-17.0	89.8	10.2
Barisal	Patuakhali	Bhola	Daulatkhan	0.0	-2.9	-2.9	0.0	100.0
Barisal	Patuakhali	Bhola	Lalmohan	0.0	-2.1	-2.1	0.0	100.0
Barisal	Patuakhali	Bhola	Manpura	-15.5	-1.7	-17.0	90.0	10.0
Barisal	Patuakhali	Bhola	Tazumuddin	0.0	-2.7	-2.7	0.0	100.0
Barisal	Patuakhali	Borgona	Amtali	0.0	-2.1	-2.1	0.0	100.0
Barisal	Patuakhali	Borgona	Bamna	0.0	-1.9	-1.9	0.0	100.0
Barisal	Patuakhali	Borgona	Barguna S.	0.0	-2.2	-2.2	0.0	100.0
Barisal	Patuakhali	Borgona	Patharghata	0.0	-1.9	-1.9	0.0	100.0
Barisal	Patuakhali	Patuakhali	Bauphal	0.0	-3.0	-3.0	0.0	100.0
Barisal	Patuakhali	Patuakhali	Kalapara	0.0	-1.4	-1.4	0.0	100.0
Barisal	Patuakhali	Patuakhali	Mirzaganj	0.0	-3.1	-3.1	0.0	100.0
Barisal	Patuakhali	Patuakhali	Patuakhali S.	0.0	-3.1	-3.1	0.0	100.0
Chittagong	Chittagong	Chittagong	Anwara	0.0	-2.4	-2.4	0.0	100.0
Chittagong	Chittagong	Chittagong	Kotwali	0.0	-2.4	-2.4	0.0	100.0
Chittagong	Chittagong	Chittagong	Patiya	0.0	-2.4	-2.4	0.0	100.0
Chittagong	Noakhali	Feni	Daganbhuiyan	0.0	-2.4	-2.4	0.0	100.0
Chittagong	Noakhali	Lakshmipur	Ramgati	0.0	-3.4	-3.4	0.0	100.0
Chittagong	Noakhali	Noakhali	Begumganj	-15.5	-1.8	-17.1	89.7	10.3
Chittagong	Noakhali	Noakhali	Companiganj	0.0	-2.4	-2.4	0.0	100.0
Chittagong	Noakhali	Noakhali	Noakhali S.	-15.5	-1.9	-17.1	89.3	10.7
Chittagong	Noakhali	Noakhali	Senbagh	0.0	-2.4	-2.4	0.0	100.0
Dhaka	Faridpur	Faridpur	Alfadanga	0.0	-3.8	-3.8	0.0	100.0
Dhaka	Faridpur	Gopalgonj	Gopalganj S.	0.0	-3.8	-3.8	0.0	100.0

				Percent Change, 2012-2050			Change Share	
Region	District	Sub-District	Upazila	Paddy Output	Paddy Price	Income	Paddy Output	Paddy Price
Dhaka	Faridpur	Gopalgonj	Kashiani	0.0	-3.8	-3.8	0.0	100.0
Dhaka	Faridpur	Gopalgonj	Tungipara	-15.5	-1.7	-17.0	89.9	10.1
Khulna	Jessore	Jessore	Abhaynagar	0.0	-2.2	-2.2	0.0	100.0
Khulna	Jessore	Jessore	Bagherpara	0.0	-2.7	-2.7	0.0	100.0
Khulna	Jessore	Jessore	Keshabpur	0.0	-1.7	-1.7	0.0	100.0
Khulna	Jessore	Jessore	Manirampur	0.0	-2.0	-2.0	0.0	100.0
Khulna	Jessore	Magura	Shalikha	0.0	-2.7	-2.7	0.0	100.0
Khulna	Jessore	Narail	Kalia	0.0	-2.9	-2.9	0.0	100.0
Khulna	Jessore	Narail	Lohagara	0.0	-3.4	-3.4	0.0	100.0
Khulna	Jessore	Narail	Narail S.	0.0	-3.9	-3.9	0.0	100.0
Khulna	Khulna	Bagerhat	Bagerhat S.	0.0	-1.5	-1.5	0.0	100.0
Khulna	Khulna	Bagerhat	Chitalmari	0.0	-1.4	-1.4	0.0	100.0
Khulna	Khulna	Bagerhat	Fakirhat	0.0	-1.0	-1.0	0.0	100.0
Khulna	Khulna	Bagerhat	Kachua	0.0	-1.3	-1.3	0.0	100.0
Khulna	Khulna	Bagerhat	Mollahat	0.0	-1.5	-1.5	0.0	100.0
Khulna	Khulna	Bagerhat	Morrelganj	0.0	-0.9	-0.9	0.0	100.0
Khulna	Khulna	Bagerhat	Rampal	0.0	-0.7	-0.7	0.0	100.0
Khulna	Khulna	Khulna	Batiaghata	0.0	-0.7	-0.7	0.0	100.0
Khulna	Khulna	Khulna	Dacope	0.0	-0.5	-0.5	0.0	100.0
Khulna	Khulna	Khulna	Dighalia	0.0	-0.6	-0.6	0.0	100.0
Khulna	Khulna	Khulna	Dumuria	0.0	-0.6	-0.6	0.0	100.0
Khulna	Khulna	Khulna	Kotwali	0.0	-0.6	-0.6	0.0	100.0
Khulna	Khulna	Khulna	Paikgachha	0.0	-0.2	-0.2	0.0	100.0
Khulna	Khulna	Khulna	Phultala	0.0	-1.0	-1.0	0.0	100.0
Khulna	Khulna	Khulna	Rupsa	0.0	-0.8	-0.8	0.0	100.0
Khulna	Khulna	Khulna	Terokhada	0.0	-2.9	-2.9	0.0	100.0
Khulna	Khulna	Shatkhira	Assasuni	0.0	-0.2	-0.2	0.0	100.0
Khulna	Khulna	Shatkhira	Kalaroa	0.0	-1.7	-1.7	0.0	100.0
Khulna	Khulna	Shatkhira	Satkhira S.	0.0	-1.7	-1.7	0.0	100.0
Khulna	Khulna	Shatkhira	Tala	0.0	-0.7	-0.7	0.0	100.0

In Table 14, we consolidate the upazila projections into projections at the regional level. In Barisal, where 6 upazilas reach the threshold of 4 dS/m during the projection period, the impact on yields is sufficient to reduce output by 7.7%. Coupled with an overall price decline of 2.8%, this reduces income by 10.5%. In Chittagong, which has fewer upazilas in the sample, rising soil salinity in two upazilas exceeds the 4 dS/m threshold before 2050. The result is a 5.6% reduction in output which, coupled with the regional price decline of 1.9%, produces a decline of 7.5% in income. Dhaka has only one upazila that crosses the threshold during the projection period, so its income decline of 4.6% is mostly attributable to price decline (3.5%) rather than output decline (1.1%).

Table 14: Regional projection summary:
Impact of soil salinity increase on incomes, production and prices

	Percent Change, 2012-2050			Change Share	
Region	Income	Paddy Output	Paddy Price	Paddy Output	Paddy Price
Barisal	-10.5	-7.7	-2.8	73.4	26.7
Chittagong	-7.5	-5.6	-1.9	74.6	25.4
Dhaka	-4.6	-1.1	-3.5	23.7	76.3
Khulna	-1.9	0.0	-1.9	0.0	100.0

Finally, Khulna begins the projection period with several upazilas already beyond the salinity threshold. No upazila crosses the threshold during the projection period, so Kulna’s income decline of 1.9% is due entirely to the decline in prices.

Tables 15 and 16 highlight the potential magnitude of additional salinity problems after 2050. Table 15 presents soil salinity measures in 2012 and 2050, sorted in descending order of salinity in 2050. We also include information on changes to highlight the steady increases in salinity for all

Table 15: Soil salinity by upazila, 2012 and 2050

				Soil Salinity (dS/m)		
Region	District	Sub-District	Upazila	2012	2050	Change
Khulna	Khulna	Khulna	Paikgachha	15.8	16.2	0.5
Khulna	Khulna	Shatkhira	Assasuni	15.8	16.2	0.5
Khulna	Khulna	Bagerhat	Fakirhat	13.1	15.2	2.2
Khulna	Khulna	Khulna	Dacope	14.1	15.2	1.1
Khulna	Khulna	Khulna	Dighalia	13.4	14.7	1.3
Khulna	Khulna	Khulna	Dumuria	13.4	14.7	1.3
Khulna	Khulna	Bagerhat	Rampal	13.1	14.6	1.5
Khulna	Khulna	Khulna	Rupsa	12.6	14.2	1.6
Khulna	Khulna	Bagerhat	Mollahat	11.0	14.0	3.0
Khulna	Khulna	Bagerhat	Bagerhat S.	10.9	13.9	3.0
Khulna	Khulna	Khulna	Kotwali	12.5	13.8	1.3
Khulna	Khulna	Khulna	Batiaghata	10.9	12.2	1.3
Khulna	Khulna	Bagerhat	Chitalmari	7.3	9.1	1.7
Khulna	Khulna	Bagerhat	Kachua	6.8	8.3	1.6
Khulna	Khulna	Bagerhat	Morrelganj	6.8	7.8	1.1
Khulna	Khulna	Shatkhira	Tala	7.0	7.8	0.8
Khulna	Khulna	Khulna	Phultala	6.2	7.3	1.1
Barisal	Patuakhali	Patuakhali	Kalapara	4.3	5.4	1.1
Barisal	Patuakhali	Bhola	Manpura	3.6	4.7	1.1
Barisal	Barisal	Pirojpur	Pirojpur S.	3.7	4.7	1.0
Barisal	Patuakhali	Bhola	Charfasson	3.5	4.7	1.1
Chittagong	Noakhali	Noakhali	Begumganj	3.5	4.6	1.1
Barisal	Barisal	Pirojpur	Nesarabad	3.6	4.6	1.0
Chittagong	Noakhali	Noakhali	Noakhali S.	3.3	4.4	1.1
Barisal	Barisal	Pirojpur	Nazirpur	3.4	4.4	1.0
Dhaka	Faridpur	Gopalgonj	Tungipara	3.3	4.3	1.0
Barisal	Barisal	Barisal	Banaripara	3.3	4.3	1.0
Khulna	Khulna	Shatkhira	Kalaroa	3.0	4.0	0.9
Khulna	Khulna	Shatkhira	Satkhira S.	3.0	4.0	0.9
Khulna	Jessore	Jessore	Keshabpur	3.0	4.0	0.9
Barisal	Barisal	Pirojpur	Mathbaria	2.9	3.9	1.0
Barisal	Patuakhali	Bhola	Lalmohan	2.8	3.9	1.1
Barisal	Patuakhali	Borgona	Bamna	2.9	3.9	1.0
Khulna	Khulna	Pirojpur	Mathbaria	2.9	3.9	1.0
Barisal	Patuakhali	Borgona	Patharghata	2.9	3.9	1.0
Barisal	Patuakhali	Borgona	Amtali	2.8	3.9	1.1
Barisal	Barisal	Pirojpur	Kawkhali	2.7	3.7	1.0
Barisal	Patuakhali	Borgona	Barguna S.	2.6	3.7	1.1

				Soil Salinity (dS/m)		
Region	District	Sub-District	Upazila	2012	2050	Change
Chittagong	Noakhali	Feni	Daganbhuiyan	2.5	3.6	1.1
Chittagong	Noakhali	Noakhali	Senbagh	2.5	3.6	1.1
Chittagong	Noakhali	Noakhali	Companiganj	2.5	3.6	1.1
Chittagong	Chittagong	Chittagong	Kotwali	2.2	3.3	1.0
Chittagong	Chittagong	Chittagong	Anwara	2.2	3.3	1.0
Chittagong	Chittagong	Chittagong	Patiya	2.2	3.3	1.0
Khulna	Jessore	Jessore	Manirampur	2.4	3.3	0.9
Barisal	Patuakhali	Bhola	Tazumuddin	2.0	3.1	1.1
Barisal	Patuakhali	Bhola	Burhanuddin	2.0	3.1	1.1
Barisal	Patuakhali	Bhola	Daulatkhan	2.0	3.1	1.1
Barisal	Patuakhali	Bhola	Bhola S.	2.0	3.1	1.1
Barisal	Barisal	Barisal	Mehendiganj	2.0	3.1	1.1
Barisal	Patuakhali	Patuakhali	Bauphal	1.9	3.0	1.2
Barisal	Barisal	Pirojpur	Bhandaria	1.8	2.9	1.0
Khulna	Jessore	Jessore	Abhaynagar	2.0	2.9	0.8
Barisal	Barisal	Barisal	Bakerganj	1.7	2.8	1.1
Barisal	Barisal	Jhalakati	Nalchity	1.7	2.8	1.1
Barisal	Patuakhali	Patuakhali	Patuakhali S.	1.7	2.8	1.1
Barisal	Patuakhali	Patuakhali	Mirzaganj	1.7	2.8	1.1
Chittagong	Noakhali	Lakshmipur	Ramgati	1.6	2.7	1.1
Khulna	Khulna	Khulna	Terokhada	1.7	2.7	1.0
Khulna	Jessore	Narail	Kalia	1.7	2.7	1.0
Barisal	Barisal	Jhalakati	Kathalia	1.5	2.6	1.0
Barisal	Barisal	Jhalakati	Rajapur	1.5	2.6	1.0
Khulna	Jessore	Jessore	Bagherpara	1.6	2.5	0.9
Khulna	Jessore	Magura	Shalikha	1.6	2.4	0.9
Khulna	Jessore	Narail	Lohagara	1.4	2.4	1.0
Dhaka	Faridpur	Gopalgonj	Kashiani	1.3	2.3	1.0
Dhaka	Faridpur	Gopalgonj	Gopalganj S.	1.3	2.3	1.0
Dhaka	Faridpur	Faridpur	Alfadanga	1.3	2.3	1.0
Khulna	Jessore	Narail	Narail S.	1.0	1.9	0.9

upazilas that remain below 4 dS/m in 2050.

Potential future impacts are highlighted by Table 16, which tabulates upazilas by soil salinity group in 2012 and 2050. There are 21 upazilas with measures between 1.0 and 2.0 dS/m in 2012, but only 1 upazila remains in this group by 2050. The number of upazilas in the next group (2.0-3.0 dS/m) remains nearly constant during the projection period, but the population of the near-threshold group (3.0-4.0 dS/m) doubles, from 12 to 24. Although the period after 2050 is beyond our projection interval, these results strongly suggest that 24 more upazilas will cross the threshold within a few decades after 2050.

Table 16: Upazilas by Soil Salinity Class, 2012 and 2015

	Upazila Counts	
Soil Salinity (dS/m)	2012	2050
1.01-2.00	21	1
2.01-3.00	18	17
3.01-4.00	12	24
4.01+	18	27
Total	69	69

7. Summary and Conclusions

In this paper, we have developed, estimated and applied a system for projecting the impact of rising soil salinity on outputs and prices of HYV rice in the upazilas of coastal Bangladesh. Our soil salinity projections are based on spatial econometric estimation of a model that links soil salinity to proximate river salinity, temperature and rainfall. We project future soil salinity for 69 upazilas using new river salinity projections from Dasgupta et al. (2014) and our own projections of rainfall and temperature, based on trend estimates from a panel database for 20 BMD weather stations in the coastal region.

In the second part of the exercise, we estimate the impact of soil salinity on agriculture using spatial econometric estimates where appropriate, and standard panel estimates where spatially-scattered samples make spatial autocorrelation insignificant. Our estimation exercise yields three main findings. First, HYV paddy yield is significantly (15.6%) lower in upazilas where soil salinity is greater than 4 dS/m. Second, soil salinity has a significant, negative impact on paddy prices through the product quality effect. Finally, we find that rising salinity does not appear to have a significant effect on land and labor used for production.

In the projection section of the paper, we use our econometric yield and price equations to forecast the future impact of soil salinity on paddy outputs, prices and incomes. We project output declines of 15.6% in 9 upazilas that cross the 4 dS/m salinity threshold before 2050. We also project price declines in all upazilas that vary from 0.2% to 3.9%. The combined effect of rising soil salinity on outputs and prices produces substantial income losses in Barisal (10.5%) and Chittagong (7.5%).

In the final section of the paper, we consider the implications of projections through 2050 for soil salinity and economic losses in the post-2050 period. We find that they are likely to exceed the projected losses before 2050, since the number of upazilas crossing the 4 dS/m threshold after 2050 (24) greatly exceeds the number projected to cross the threshold between 2012 and 2050 (9).

Our results paint a sobering picture of the impact of rising soil salinity on HYV rice production in the coastal region of Bangladesh. Many upazilas have already suffered large yield losses and substantial price reductions from rising salinity, and the coastal region losses will be compounded by further salinity increases in the coming decades. This inexorable process will continue as long as the sea continues to rise and salinity increases in coastal rivers. We see no prospect for near-term relief, since rising global greenhouse gas emissions continue to propel rapid climate change and melting of the polar ice caps.

The government of Bangladesh is aware of the expected adverse effects of climate change on HYV rice production in the coastal region, and invested in promoting suitable adaptation measures. Bangladesh Rice Research Institute is conducting research on salt-resistant varieties of rice. Salt-resistant rice: BRRI Dhan 47 was released by the country's National Seed Board in 2007, and now can be found in a growing number of coastal community markets at the same price as conventional rice.[20] Another salt resistant variety of rice, BINA Dhan 10 was introduced by Bangladesh Institute of Nuclear Agriculture in 2012. Government agricultural extension officials are providing training on cultivation of salt resistant varieties of rice. However, the future of these initiatives will depend on relative profitability as well as on adaptability of farmers and acceptance by consumers. Compilation of location-specific adaptation alternatives and costing of adaptation is the subject of our ongoing research.

[20] BRRI Dhan 47 can withstand 12-14 dS/m salinity of land while they are tender, and 6 dS/m in their entire lifespan of 152-155 days., whereas salt tolerance capacities of other conventional high-yielding rice varieties are below 4 dS/m. http://www.irinnews.org/report/88426/bangladesh-salt-resistant-paddy-offers-hope-to-farmers

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Table A1: Study upazilas with mean HYV rice yields, 2000-2012

Region	District	Sub-District	Upazila	Mean Yield, 2000-2012
Barisal	Barisal	Barisal	Agailjhara	4.20
Barisal	Barisal	Barisal	Babuganj	5.35
Barisal	Barisal	Barisal	Bakerganj	5.17
Barisal	Barisal	Barisal	Banaripara	5.39
Barisal	Barisal	Barisal	Barisal S.	5.63
Barisal	Barisal	Barisal	Gaurnadi	2.33
Barisal	Barisal	Barisal	Hizla	5.43
Barisal	Barisal	Barisal	Mehendiganj	5.59
Barisal	Barisal	Barisal	Muladi	5.45
Barisal	Barisal	Barisal	Wazirpur	5.74
Barisal	Barisal	Jhalakati	Jhalakati S.	2.13
Barisal	Barisal	Jhalakati	Kathalia	1.95
Barisal	Barisal	Jhalakati	Nalchity	2.10
Barisal	Barisal	Jhalakati	Rajapur	1.57
Barisal	Barisal	Pirojpur	Bhandaria	2.56
Barisal	Barisal	Pirojpur	Kawkhali	2.10
Barisal	Barisal	Pirojpur	Mathbaria	1.91
Barisal	Barisal	Pirojpur	Nazirpur	2.10
Barisal	Barisal	Pirojpur	Nesarabad	2.15
Barisal	Barisal	Pirojpur	Pirojpur S.	2.17
Barisal	Patuakhali	Bhola	Bhola S.	3.01
Barisal	Patuakhali	Bhola	Burhanuddin	
Barisal	Patuakhali	Bhola	Charfasson	
Barisal	Patuakhali	Bhola	Daulatkhan	1.47
Barisal	Patuakhali	Bhola	Lalmohan	
Barisal	Patuakhali	Bhola	Manpura	
Barisal	Patuakhali	Bhola	Tazumuddin	
Barisal	Patuakhali	Borgona	Amtali	2.18
Barisal	Patuakhali	Borgona	Bamna	1.96
Barisal	Patuakhali	Borgona	Barguna S.	2.09
Barisal	Patuakhali	Borgona	Betagi	1.98
Barisal	Patuakhali	Borgona	Patharghata	2.06
Barisal	Patuakhali	Patuakhali	Bauphal	1.18
Barisal	Patuakhali	Patuakhali	Dashina	1.92
Barisal	Patuakhali	Patuakhali	Galachipa	4.09
Barisal	Patuakhali	Patuakhali	Kalapara	1.31
Barisal	Patuakhali	Patuakhali	Mirzaganj	1.75
Barisal	Patuakhali	Patuakhali	Patuakhali S.	1.19
Chittagong	Chittagong	Chittagong	Anwara	3.37
Chittagong	Chittagong	Chittagong	Banshkhali	2.00

Region	District	Sub-District	Upazila	Mean Yield, 2000-2012
Chittagong	Chittagong	Chittagong	Boalkhali	1.50
Chittagong	Chittagong	Chittagong	Chandanaish	2.14
Chittagong	Chittagong	Chittagong	Fatikchhari	
Chittagong	Chittagong	Chittagong	Hathazari	5.40
Chittagong	Chittagong	Chittagong	Kotwali	
Chittagong	Chittagong	Chittagong	Lohagara	1.85
Chittagong	Chittagong	Chittagong	Mirsharai	1.99
Chittagong	Chittagong	Chittagong	Patiya	1.91
Chittagong	Chittagong	Chittagong	Rangunia	1.46
Chittagong	Chittagong	Chittagong	Raozan	3.32
Chittagong	Chittagong	Chittagong	Sandwip	
Chittagong	Chittagong	Chittagong	Satkania	1.51
Chittagong	Chittagong	Chittagong	Sitakunda	1.89
Chittagong	Noakhali	Feni	Chhagalnaiya	2.23
Chittagong	Noakhali	Feni	Daganbhuiyan	1.22
Chittagong	Noakhali	Feni	Feni S.	1.42
Chittagong	Noakhali	Feni	Parshuram	1.43
Chittagong	Noakhali	Feni	Sonagazi	1.34
Chittagong	Noakhali	Lakshmipur	Lakshmipur S.	
Chittagong	Noakhali	Lakshmipur	Raipur	
Chittagong	Noakhali	Lakshmipur	Ramganj	
Chittagong	Noakhali	Lakshmipur	Ramgati	
Chittagong	Noakhali	Noakhali	Begumganj	1.62
Chittagong	Noakhali	Noakhali	Chatkhil	1.43
Chittagong	Noakhali	Noakhali	Companiganj	1.75
Chittagong	Noakhali	Noakhali	Hatiya	1.83
Chittagong	Noakhali	Noakhali	Noakhali S.	1.60
Chittagong	Noakhali	Noakhali	Senbagh	1.60
Dhaka	Faridpur	Faridpur	Alfadanga	
Dhaka	Faridpur	Faridpur	Bhanga	
Dhaka	Faridpur	Faridpur	Boalmari	
Dhaka	Faridpur	Faridpur	Char Bhadrasan	
Dhaka	Faridpur	Faridpur	Faridpur S.	
Dhaka	Faridpur	Faridpur	Madhukhali	
Dhaka	Faridpur	Faridpur	Nagarkanda	
Dhaka	Faridpur	Faridpur	Sadarpur	
Dhaka	Faridpur	Gopalgonj	Gopalganj S.	2.85
Dhaka	Faridpur	Gopalgonj	Kashiani	4.13
Dhaka	Faridpur	Gopalgonj	Kotalipara	1.93
Dhaka	Faridpur	Gopalgonj	Muksudpur	2.59
Dhaka	Faridpur	Gopalgonj	Tungipara	4.37

Region	District	Sub-District	Upazila	Mean Yield, 2000-2012
Khulna	Jessore	Jessore	Abhaynagar	5.40
Khulna	Jessore	Jessore	Bagherpara	5.18
Khulna	Jessore	Jessore	Chaugachha	2.21
Khulna	Jessore	Jessore	Jessore S.	2.35
Khulna	Jessore	Jessore	Jhikargachha	1.66
Khulna	Jessore	Jessore	Keshabpur	1.61
Khulna	Jessore	Jessore	Manirampur	2.45
Khulna	Jessore	Jessore	Sharsha	1.57
Khulna	Jessore	Jhenaidah	Harinakunda	
Khulna	Jessore	Jhenaidah	Jhenaidaha S.	
Khulna	Jessore	Jhenaidah	Kaliganj	
Khulna	Jessore	Jhenaidah	Kotchandpur	
Khulna	Jessore	Jhenaidah	Maheshpur	
Khulna	Jessore	Jhenaidah	Shailkupa	
Khulna	Jessore	Magura	Magura S.	
Khulna	Jessore	Magura	Mohammadpur	
Khulna	Jessore	Magura	Shalikha	
Khulna	Jessore	Magura	Sreepur	
Khulna	Jessore	Narail	Kalia	2.33
Khulna	Jessore	Narail	Lohagara	4.32
Khulna	Jessore	Narail	Narail S.	1.75
Khulna	Khulna	Bagerhat	Bagerhat S.	2.01
Khulna	Khulna	Bagerhat	Chitalmari	2.10
Khulna	Khulna	Bagerhat	Fakirhat	1.57
Khulna	Khulna	Bagerhat	Kachua	1.38
Khulna	Khulna	Bagerhat	Mollahat	
Khulna	Khulna	Bagerhat	Mongla	
Khulna	Khulna	Bagerhat	Morrelganj	1.81
Khulna	Khulna	Bagerhat	Rampal	
Khulna	Khulna	Khulna	Batiaghata	2.14
Khulna	Khulna	Khulna	Dacope	1.73
Khulna	Khulna	Khulna	Dighalia	1.53
Khulna	Khulna	Khulna	Dumuria	1.48
Khulna	Khulna	Khulna	Kotwali	1.70
Khulna	Khulna	Khulna	Koyra	1.50
Khulna	Khulna	Khulna	Paikgachha	4.39
Khulna	Khulna	Khulna	Phultala	2.20
Khulna	Khulna	Khulna	Rupsa	2.23
Khulna	Khulna	Khulna	Terokhada	1.59
Khulna	Khulna	Pirojpur	Mathbaria	
Khulna	Khulna	Shatkhira	Assasuni	2.00

Region	District	Sub-District	Upazila	Mean Yield, 2000-2012
Khulna	Khulna	Shatkhira	Debhata	1.45
Khulna	Khulna	Shatkhira	Kalaroa	5.43
Khulna	Khulna	Shatkhira	Kaliganj	2.11
Khulna	Khulna	Shatkhira	Satkhira S.	
Khulna	Khulna	Shatkhira	Shyamnagar	1.38
Khulna	Khulna	Shatkhira	Tala	1.64
Khulna	Kushtia	Choua Danga	Alamdanga	
Khulna	Kushtia	Choua Danga	Chuadanga S.	
Khulna	Kushtia	Choua Danga	Damurhula	
Khulna	Kushtia	Choua Danga	Jibannagar	
Khulna	Kushtia	Kustia	Bheramara	
Khulna	Kushtia	Kustia	Daulatpur	
Khulna	Kushtia	Kustia	Khoksa	
Khulna	Kushtia	Kustia	Kumarkhali	
Khulna	Kushtia	Kustia	Kushtia S.	
Khulna	Kushtia	Kustia	Mirpur	
Khulna	Kushtia	Meherpur	Gangni	
Khulna	Kushtia	Meherpur	Meherpur S.	

Table A2: Database variables used for this research

Variable	Description	Period	Units
highh	mean river salinity monitor readings in highest 4 months.	2000-2008	Concentration (PPT)
highs	mean land salinity monitor readings in highest 4 months	2001-2009	Electrical conductivity (dS/m)
hightemp	mean maximum temperature in warmest 4 months	2001-2011	Degrees C.
highrain	mean rainfall in highest 4 months	2001-2012	Millimeters
hyvtons	production of HYV paddy	2000-2012	Metric tons
hyvprice	harvest time market price of HYV paddy	2000-2012	Taka/kg.
hyvacres	land planted in HYV paddy	2000-2012	Acres
landrent	land rent	2000-2012	Taka/acre/year
totlabor	total labor for paddy production	2000-2012	Man days per acre
avwage	daily average wage rate of agricultural labor without food (Nov to June)	2000-2012	Taka/day
seedkg	seed used for paddy production	2000-2012	Kg/acre
seedprice	price of seed used for paddy production	2000-2012	Taka/kg
ureakg	urea fertilizer used for paddy production	2000-2012	Kg/acre
ureaprice	price of urea fertilizer used for paddy production	2000-2012	Taka/kg
pestcost	pesticide cost for paddy production	2000-2012	Taka/acre
powertill	tractor/power tiller cost for paddy production	2000-2012	Taka/acre
nelson	travel time to major market (from Uchida and Nelson, 2009)	2009	Hours
elevation	mean elevation		Meters

Table A3: Mean monthly salinity measures (ppt): 2000, 2008, 2050

		Location		Mean Monthly Salinity (PPT)		
Station	River	latitude	longitude	2000	2008	2050
Bagerhat	Alaipur Khal Daraton	22.65	89.81	0.54	8.69	10.94
Bhatiapara	Gorai-Madhumoti	23.21	89.70	0.05	0.52	1.16
Pirojpur	Gorai-Madhumati-Haringhata-Baleswar	22.58	89.97	0.10	0.19	2.23
Rayanda	Gorai-Madhumati	22.31	89.86	0.25	4.08	5.40
Chardoani	Gorai-Madhumati-Haringhata-Baleswar	22.11	89.91	0.16	0.65	5.35
Kawkhali	Kacha	22.62	90.06	0.03	0.30	2.18
Jhikargacha	Kobadak	23.10	89.10	0.09	1.11	0.89
Barisal	Barisal-Buriswar	22.70	90.38	0.05	0.28	2.72
Patuakhali	Lohalia	22.36	90.36	0.05	0.26	2.78
Galachipa	Lohalia	22.20	90.43	0.10	0.22	2.75
Haridaspur	Madaripur Beel Route	23.06	89.82	0.04	0.50	0.95
Amtali	Barisal-Buriswar	22.14	90.23	0.03	0.67	3.20
Bardia	Nabaganga	23.07	89.67	0.08	2.41	3.94
Gazirhat	Nabaganga	22.96	89.56	0.08	2.73	5.23
Kalaroa	Betna-Kholpetua	22.86	89.05	0.23	5.47	5.27
Benarpota	Betna-kholpetua	22.77	89.09	0.49	0.49	4.48
Khulna	Rupsa-Pasur	22.81	89.58	0.28	5.84	9.28
Chalna	Rupsa-Pasur	22.62	89.53	1.90	9.34	12.73
Mongla	Rupsa-Pasur	22.46	89.60	1.11	11.40	12.69
Paikgacha	Shibsa	22.58	89.32	1.00	13.15	11.55
Nalianala	Shibsa	22.45	89.43	5.33	16.23	15.79
Daulatkhan	Surma-Meghna	22.61	90.83	0.09	0.56	2.93
Dumuria	Bhadra	22.79	89.41	0.36	8.42	10.78
Dasmunia	Tentulia	22.29	90.61	0.05	0.22	2.96
Afraghat	Bhairab	23.12	89.39	0.09	1.90	2.72
Jhalokati	Bishkhali	22.63	90.18	0.03	0.30	2.49
Betagi	Bishkhali	22.44	90.18	0.04	0.29	2.56
Barguna	Bishkhali	22.16	90.10	0.07	0.61	3.37
Patharghata	Bishkhali	22.02	89.97	0.22	4.89	4.28

Table A4: BMD Weather stations: rainfall and temperature, 1990 - 2050

				Mean Monthly Rainfall (mm)				Mean Maximum Monthly Temperature (°C)			
No.	Name	Latitude	Longitude	1990	2011	2030	2050	1990	2011	2030	2050
1	Barisal	22.7167	90.3667	198.2	168.6	147.5	128.2	30.0	31.1	31.8	32.7
2	Bhola	22.6833	90.6500	184.9	188.7	165.2	143.5	30.1	30.8	31.5	32.4
4	Chandpur	23.2333	90.7000	163.0	148.3	129.8	112.8	30.0	30.9	31.6	32.5
6	Chittagong (IAP)	22.2167	91.8000	237.7	234.0	204.8	178.0	30.0	31.2	32.0	32.8
9	Cox's Bazar	21.4500	91.9667	345.0	300.7	263.2	228.8	30.1	31.2	32.0	32.8
12	Faridpur	23.6000	89.8500	165.4	138.1	120.8	105.0	30.0	31.0	31.8	32.6
13	Feni	23.0333	91.4167	331.7	216.6	189.6	164.7	30.0	30.7	31.5	32.3
14	Hatiya	22.4500	91.1000	250.8	262.0	229.3	199.3	29.4	29.9	30.7	31.5
16	Jessore	23.2000	89.3333	140.5	154.3	135.1	117.4	31.0	32.2	33.0	33.8
17	Khepupara	21.9833	90.2333	267.7	221.4	193.8	168.4	29.7	30.7	31.5	32.3
18	Khulna	22.7833	89.5333	161.5	151.3	132.4	115.1	30.9	31.6	32.4	33.2
19	Kutubdia	21.8167	91.8500	322.2	250.0	218.8	190.2	29.4	30.3	31.1	31.9
21	Maijdee Court	22.8667	91.1000	292.7	238.4	208.7	181.4	29.5	30.7	31.5	32.3
20	Madaripur	23.1667	90.1833	180.8	152.7	133.6	116.1	30.8	31.3	32.1	32.9
22	Mongla	22.4667	89.6000	155.3	157.0	137.4	119.4	30.5	31.4	32.1	33.0
24	Patuakhali	22.3333	90.3333	234.8	221.3	193.7	168.4	29.7	31.0	31.8	32.6
29	Sandwip	22.4833	91.4333	301.2	254.8	223.0	193.8	29.1	30.2	31.0	31.8
30	Satkhira	22.7167	89.0833	151.8	141.0	123.4	107.3	31.2	31.7	32.5	33.3
31	Sitakunda	22.6333	91.7000	279.6	217.0	189.9	165.1	30.1	31.1	31.9	32.7
35	Teknaf	20.8667	92.3000	299.7	340.2	297.8	258.8	29.7	30.7	31.5	32.3

Table A5: Adjusted soil salinity measures: 2001, 2009, 2050

						Monthly Average Salinity (dS/m)				
No.	District	Upazila	Union	Latitude	Longitude	(1) 2001	(2) 2009	(3) 2050 (Low)	(4) 2050 (High)	% Change (2)→(4)
1	Patuakhali	Kalapara	Nilganj	21.9458	90.1705	3.93	4.23	4.51	4.92	16.3
2	Patuakhali	Kalapara	Kalapara Paurashava	21.9833	90.2333	3.45	3.71	3.99	4.42	19.3
3	Patuakhali	Kalapara	Kalapara Paurashava	21.9939	90.2268	2.96	3.22	3.50	3.93	22.3
4	Barguna	Amtali	Amtali Paurashava	22.1214	90.2229	1.81	2.03	2.31	2.74	35.3
5	Barguna	Amtali	Amtali Paurashava	22.1391	90.2292	1.59	1.81	2.09	2.52	39.4
6	Bhola	Charfesson	Betua	22.1905	90.8182	3.66	3.74	4.08	4.50	20.4
7	Pirojpur	Mathbaria	Sapleza	22.2004	89.9211	1.40	2.12	2.40	2.74	29.4
8	Bhola	Charfesson	Aslampur	22.2223	90.7843	2.68	2.76	3.11	3.53	27.7
9	Chittagong	Sadar	Patenga	22.2499	91.7909	1.93	2.04	2.39	2.74	34.4
10	Pirojpur	Mathbaria	Tushkhali	22.3491	89.9158	1.22	2.00	2.30	2.62	30.8
11	Bhola	Tazumuddin	Shambhupur	22.4018	90.7963	1.66	1.75	2.10	2.49	41.8
12	Patuakhali	Dumki	Lebukhali	22.4402	90.3381	1.43	1.52	1.80	2.21	45.5
13	Patuakhali	Dumki	Lebukhali	22.4545	90.3704	1.44	1.52	1.80	2.21	45.5
14	Pirojpur	Bhandaria	Nudmulla	22.4838	90.0134	0.74	1.01	1.30	1.62	60.4
15	Bagerhat	Morrelganj	Boloibunia	22.4915	89.8662	5.14	5.96	6.32	6.61	10.8
16	Bagerhat	Mongla	Burirdanga	22.5371	89.5926	9.91	12.14	12.62	12.83	5.7
17	Bagerhat	Mongla	Burirdanga	22.5376	89.5945	9.50	11.72	12.21	12.42	6.0
18	Khulna	Paikgacha	Paikgacha Paurshava	22.5845	89.3124	9.96	12.83	12.86	12.87	0.3
19	Noakhali	Sadar		22.6351	91.1319	2.97	3.08	3.44	3.79	22.8
20	Noakhali	Subarnachar	Char Jubilee	22.6657	91.0914	3.09	3.20	3.56	3.91	22.0
21	Pirojpur	Nazirpur	sekhmatia	22.7074	89.9124	1.74	2.58	2.94	3.25	26.1
22	Khulna	Batiaghata	Batiaghata	22.7076	89.5287	5.50	7.81	8.45	8.70	11.5
23	Khulna	Batiaghata	Batiaghata	22.7085	89.5288	5.48	7.79	8.43	8.69	11.5
24	Khulna	Batiaghata	Jalma	22.7101	89.7583	3.61	8.18	9.52	10.25	25.4
25	Khulna	Batiaghata	Jalma	22.7102	89.7583	3.38	7.94	9.29	10.02	26.2

Table A5 (cont'd): Adjusted soil salinity measures: 2001, 2009, 2050

						Monthly Average Salinity (dS/m)				
No.	District	Upazila	Union	Latitude	Longitude	(1) 2001	(2) 2009	(3) 2050 (Low)	(4) 2050 (High)	% Change (2)→(4)
26	Khulna	Batiaghata	Batiaghata	22.7251	89.5216	4.35	6.61	7.27	7.52	13.7
27	Khulna	Batiaghata	Batiaghata	22.7259	89.5215	4.81	7.06	7.72	7.97	12.9
28	Pirojpur	Nazirpur	Nazirpur	22.7385	89.9581	1.88	2.43	2.76	3.07	26.2
29	Bhola	Bhola Sadar	Illisha	22.7557	90.6365	1.68	1.73	2.04	2.44	40.7
30	Khulna	Dumuria	Gutudia	22.7870	89.4822	10.01	12.21	12.82	13.04	6.8
31	Khulna	Dumuria	Gutudia	22.7879	89.4830	10.43	12.62	13.24	13.46	6.6
32	Noakhali	Sadar		22.7969	91.0669	1.27	1.38	1.74	2.09	50.9
33	Noakhali	Sadar	Noakhali Paurashava	22.8250	91.2009	2.18	2.29	2.65	3.00	30.6
34	Noakhali	Subarnachar	Char Bata	22.8372	91.0810	4.85	4.96	5.31	5.66	14.2
35	Jessore	Keshabpur	Sagardari	22.8443	89.1514	0.48	1.33	1.82	1.86	39.7
36	Jessore	Abhoynagar	Noapara Paurshava	23.0354	89.3807	0.31	0.89	1.22	1.34	50.0
37	Narail	Kalia	Babra Hachla	23.0658	89.6108	0.40	0.90	1.35	1.53	69.1
38	Narail	Sadar	Singasolpur	23.0816	89.5114	0.38	0.86	1.27	1.43	66.0
39	Narail	Lohagara	Kotakul	23.1068	89.6774	0.43	0.87	1.29	1.45	66.9
40	Narail	Sadar		23.1689	89.5130	0.41	0.83	1.16	1.29	55.7
41	Narail	Sadar	Tularampur	23.1843	89.4406	0.41	0.84	1.14	1.25	50.1