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Climate Change, Groundwater Salinization and Road Maintenance Costs in Coastal Bangladesh

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Abstract

The potentially-adverse impact of salinity on paved roads is well-established in the engineering literature. The problem seems destined to grow, as climate-related changes in sea level and riverine flows drive future increases in groundwater salinity. However, data scarcity has prevented systematic analysis for poor countries. This paper assesses the impact of groundwater salinity on road maintenance expenditures in the coastal region of Bangladesh. The assessment draws on new panel measures of salinity from 41 stations in coastal Bangladesh, and road maintenance expenditures, income, road network length, and road surfaces from 20 coastal municipalities. In a model relating maintenance expenditure for paved roads to groundwater salinity, municipal income, and road network length, large and significant effects are found for salinity. The regression model is used to predict the effect of within-sample salinity variation on road maintenance expenditure share, holding municipal income and road length constant at sample mean values. Increasing salinity from its sample minimum to its sample maximum increases the predicted road maintenance expenditure share by 252 percent. The implied welfare impact may also be substantial, particularly for poor households, if diversion of expenditures to road maintenance reduces support for community sanitation, health, and other infrastructure related programs.

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Climate Change, Groundwater Salinization and Road Maintenance Costs 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 groundwater 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 groundwater salinity may also pose a significant threat to livelihoods and public health through its impacts on infrastructure, agriculture, aquaculture, 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 groundwater 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 Bangladesh Soil Resources Development Institute (SRDI 1998a,b; Peterson and Shireen 2001).

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 on the expected intensity and diffusion rate of groundwater salinization in different locations. This paper will attempt to contribute by assessing the implications for road maintenance, which is critical for rural development.

The remainder of the paper is organized as follows. In Section 2, we review existing work on climate change and salinity diffusion in Bangladesh, as well as engineering research on road damage from groundwater salinity. Section 3 develops a model of municipal road expenditure that incorporates the effect of salinity. In Section 4, we describe the construction of our database from new information on salinity, income, road networks and maintenance expenditures in a sample of coastal region municipalities. Section 5 specifies and estimates an econometric model of road maintenance that incorporates the effect of salinity, while Section

6 discusses the implications of our results. We summarize and conclude the paper in Section 7.

2. **Previous Research**

2.1 Salinity in Bangladesh

In Bangladesh, work on salinity has advanced rapidly in recent years. Sarwar (2005) and SRDI (1998a,b, 2000, 2010) have documented changes in salinity that have accompanied coastal subsidence and thermal expansion of the ocean. Detailed assessments of salinization have employed two principal methods. One approach focuses on simulation of salinity changes 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 salinity changes in local soil and groundwater, 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. (2014a) use new monitoring data to develop detailed projections of river salinity through 2050 in Bangladesh's coastal region. Dasgupta et al. (2014b, 2014c) extend the projections to groundwater salinity and study its impacts on agriculture and infant health.

2.2 Salinity and Road Maintenance

In this paper, we consider the impact of salinization on road infrastructure. The engineering literature has devoted considerable attention to road maintenance problems created by salinity (Gokhale and Pundhir 1985; Obika et al.1989; McRobert and Foley 1999; Wilson 1999; O'Flaherty 2003). In brief, penetration of a road surface by saline water leads to progressive blistering, cracking and pulverization, as dissolved salt reacts with road materials to form enlarged crystals that expand openings for further saline penetration. The speed and severity of the process depend on the height of the saline water table, the degree of salinity, and the age and composition of road construction materials. These factors vary by location, so realistic threat assessment for an area requires local information. Data scarcity has hampered such analyses in poor countries and, to our knowledge, this study is the first assessment for Bangladesh. We focus on the implications for road maintenance expenditures that are required to offset the impact of groundwater salinization.

3. A Model of Road Maintenance Expenditure

To motivate our empirical work, we develop a model of municipality-level road maintenance expenditure that incorporates groundwater salinity. We posit that municipalities have a standard demand function for road transport quality:

(1) $Q_T = \alpha_0 C_Q^{\alpha_1} Y^{\alpha_2}$

Expectations: $\alpha_1 < 0$; $\alpha_2 > 0$

where

Q_T = Aggregate road network quality level
C_Q = Unit cost of maintaining that quality level
Y = Municipality income

The cost elasticity of road quality demand (α_1) should be negative, and the income elasticity (α_2) should be positive. In this context, we are agnostic about whether α_2 is greater than, equal to or less than one.

The unit cost function for paved (*pucca*) road quality is given by:

(2) $C_P = \delta_0 S^{\delta_1} L^{\delta_2}$

Expectations: $\delta_1 > 0$

where

C_P = Unit cost of maintaining *pucca* road quality
S = Groundwater salinity in the municipality
L = Muncipality *pucca* road network length

The maintenance cost elasticity of salinity (δ_1) should be positive, since penetration of a road surface by saline water leads to crystallization, blistering, cracking and progressive deterioration. We are agnostic about the sign of δ_2, since we have no prior information about scale economies in this context.

In an all-*pucca* road system, equation (2) would specify the unit cost function for the entire network. However, each municipality maintains both *pucca* and *kutcha* (unpaved) roads. We have no prior information about differences in normal maintenance costs, so we introduce an adjustment factor that is proportional to the *pucca* share of the road network. In a similar vein, since the salinity factor only applies to *pucca* roads, we multiply the salinity cost elasticity by the *pucca* road share. After these adjustments, the fully-specified unit cost function is:

(3) $C_Q = \delta_0 e^{\gamma p} S^{p\delta_1} L^{\delta_2}$

where p = the *pucca* share of total road network length.

In this formulation, the cost functions for homogeneous road networks are:

Pucca (p = 1): (4) $C_P = \delta_0 e^{\gamma} S^{\delta_1} L^{\delta_2}$

Kutcha (p = 0): (5) $C_K = \delta_0 L^{\delta_2}$

Combining equations (1) and (3), we obtain the municipality maintenance expenditure function:

(6) $C_Q Q_T = \alpha_0 [\delta_0 e^{\gamma p} S^{p\delta_1} L^{\delta_2}]^{\alpha_1+1} Y^{\alpha_2}$

Converting to logarithmic form:

(7) $\log(C_Q Q_T) = \{\log(\alpha_0)+(\alpha_1+1)\log(\delta_0)\} + (\alpha_1+1)\gamma p + (\alpha_1+1)\delta_1\, p \log(S) + (\alpha_1+1)\delta_2 \log(L) + \alpha_2 \log(Y)$

This expenditure function provides the basis for the regression equation specified in Section 5.

4. Research Database

Figure 1 displays the four regions that comprise our study area in southern Bangladesh: Barisal, Chittagong, Dhaka and Khulna. The study area spans the coastal regions, with extensions to permit assessment of current and future salinity further inland. Our research combines spatially-formatted salinity information with municipality-level data on revenue, development income, road networks and road maintenance expenditures. Our study teams have collected time series data from the 20 municipalities highlighted in Figure 1, which provide a sampling from all parts of the coastal region.

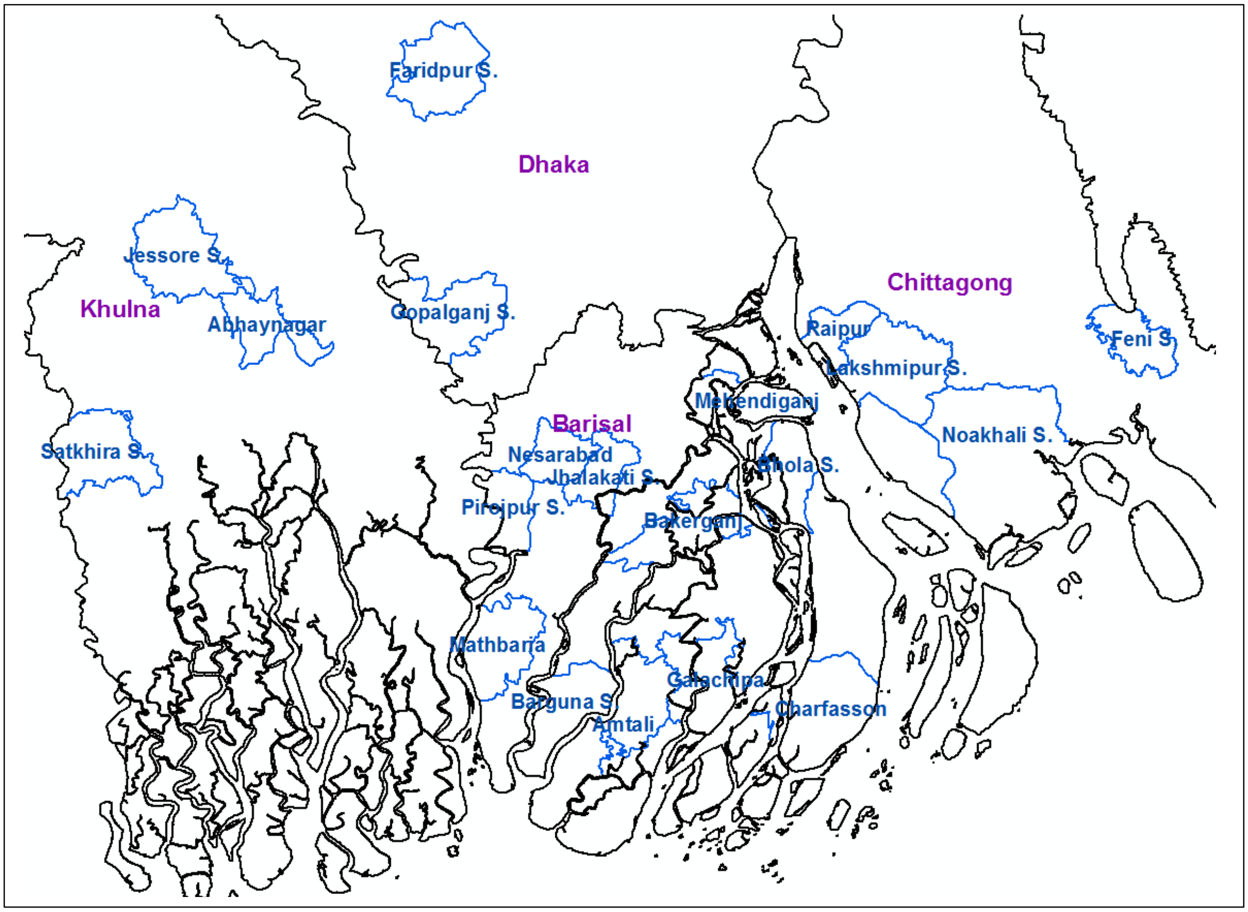
4.1 Salinity Measures

The Bangladesh Soil Research Development Institute has published monthly measures from 41 soil salinity monitoring stations for the period 2001-2009. In Dasgupta et al. (2014b), we extend these measures using projections of river salinization, temperature and rainfall through 2050. Our results (Figure 2) indicate that many areas in the coastal region of Bangladesh will have very significant increases in soil salinity during the coming decades. Monitoring stations are color-coded using standardized ranges for soil salinity in 2001, 2009 and 2050:[5] Blue (0-0.75 dS/m); Green (0.75-1.50); 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

[5] The standard sample-based measure for soil salinity is electrical conductivity (in dS/m -- deciSiemens per meter).

Figure 1: Study municipalities and regions in Bangladesh



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 (one changes to Red), and the sole Green station in Chittagong becoming Yellow.[6]

4.2 Groundwater Salinity Estimates for Municipalities

For this study, we assume that the soil salinity measure for an area provides a proxy indicator for groundwater salinity. This seems reasonable on two grounds. First, runoff from fields and subsurface diffusion produce higher groundwater salinity in areas with more saline

[6] We have excluded one geographically-isolated station from Figure 2 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.

soils. As Yu (2010) shows, soil composition in coastal Bangladesh is particularly conducive to vertical diffusion of salinity from the surface to groundwater. Second, in cases where soil monitors are near more scattered river monitors, Dasgupta et al. (2011b) show that neighboring soil and water salinity readings are highly correlated.[7] This provides further evidence of diffusion from runoff. Although we believe that local soil salinity provides a useful proxy indicator for groundwater salinity, we recognize that this assumption introduces random measurement error of unknown magnitude.

To derive municipality groundwater salinity measures, we spatially interpolate salinity measures from the 41 soil salinity monitors.[8] We adopt the interpolated salinity measure at the geographic centroid of each municipality as its groundwater salinity estimate. Then we calculate annual salinity means for matching with annual municipality-level data on income, road networks and road maintenance expenditures.

4.3 Municipality Data

The 20 municipalities displayed in Figure 1 have provided annual data on local revenue, development income and maintenance expenditures, as well as the lengths of the *pucca* (paved) and *kutcha* (unpaved) roads under their jurisdiction. As Table 1 shows, *pucca* road shares in total network lengths vary widely across municipalities -- from a minimum of 15.0% to a maximum of 93.3%.

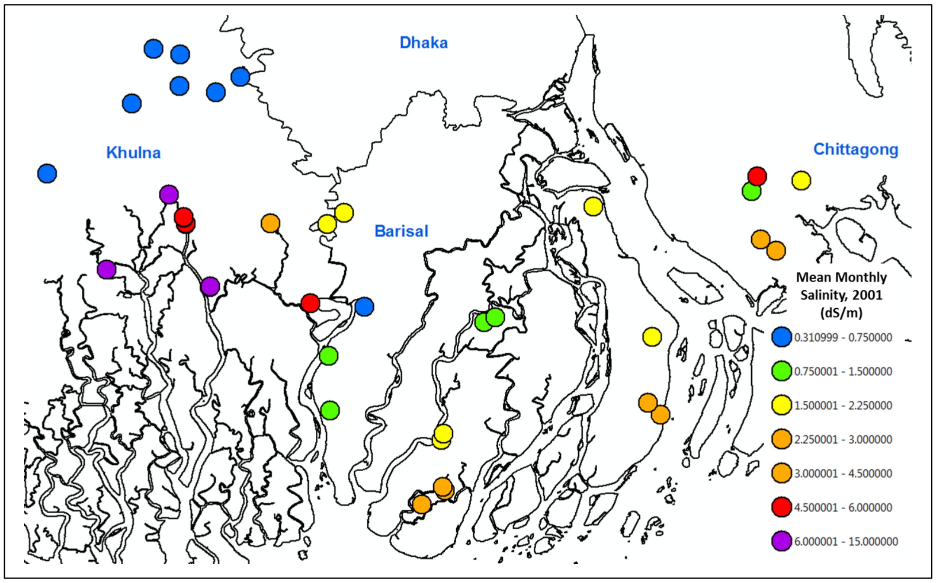
Table 1: *Pucca* (paved) road share of municipality network

Min	p10	p25	p50	p75	p90	Max
15.0	46.1	51.1	63.6	76.1	86.9	93.3

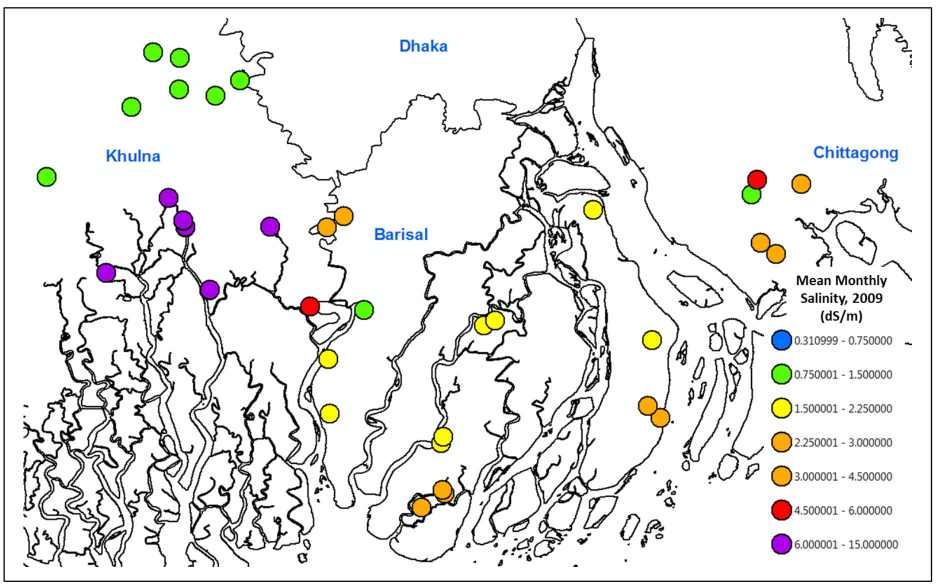
[7] This study uses the soil salinity monitors because they provide more observations for estimation. Soil monitors substantially outnumber river monitors in the databases available for this study. The soil monitors are also more widely scattered geographically, so they are relatively close to more municipalities than the river monitors.
[8] Our spatial interpolation method employs the geonear package in Stata. Salinity at each point on the surface is a weighted combination of monitor measures; weights decline with the square of the distance from the point to each monitor.

Figure 2: Observed and projected soil salinity measures: 2001, 2009, 2050

2001



2009



2050

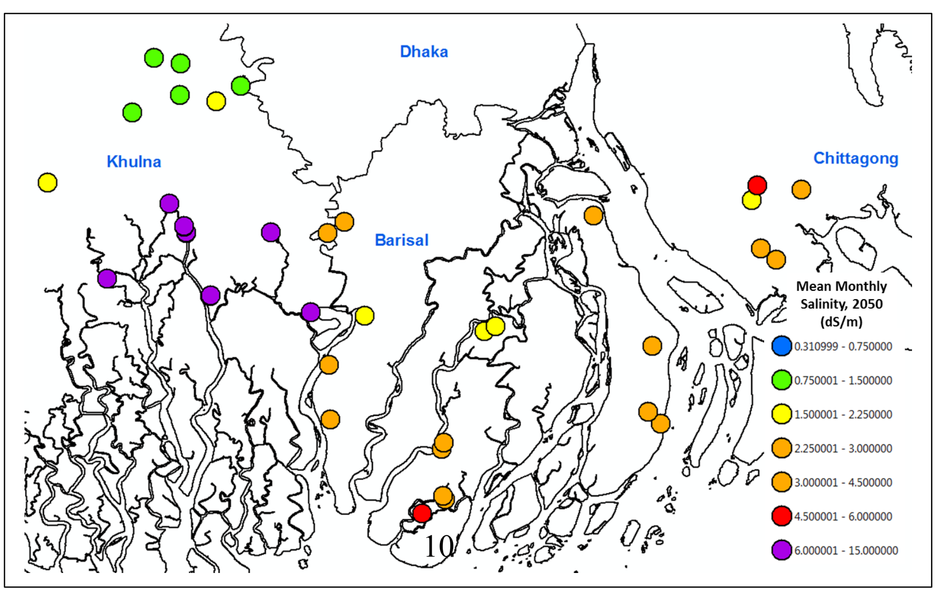


Table 2 shows that the available data comprise an unbalanced panel: Among the 20 municipalities sampled, 4 have observations for 4 years, while 9 have observations for only 1 year.[9] Yearly representation is also uneven, with 10 observations recorded for 2013, no observations for 2010 and 2011, and 4 for 2009.

Table 2: Panel statistics for Bangladesh municipality data

Year	Count	Pct	Cum. Pct
2007	7	17.07	17.07
2008	8	19.51	36.59
2009	4	9.76	46.34
2012	12	29.27	75.61
2013	10	24.39	100
Total	41	100	

Municipalities: Years Recorded	Count	Pct	Cum. Pct
1	9	45	45
2	5	25	70
3	2	10	80
4	4	20	100
Total	20	100	

5. Road Maintenance Regression Model

5.1 Specification

Following equation (7) above, our regression model relates road maintenance expenditure to groundwater salinity, municipal income, road network length, and the network share of *pucca* roads. We specify the model in log-log form, so that estimated coefficients can be interpreted as response elasticities.

[9] Prior to estimation, we removed two problematic observations from the data provided by the 20 municipalities. The first, a single annual observation for Paikgachha municipality, Khulna, has an outlier measure for salinity so extreme that it would dominate all other observations in the regressions. The second, for Satkhira municipality, Khulna, has reported road maintenance expenditure for 2008 that differs by more than an order or magnitude from reported expenditures for 2012 and 2013. Believing the 2008 report to be a transcription error, we have removed it while retaining the other two observations for Satkhira..

$$(8)\quad \ln(M_{it}) = \beta_0 + \beta_1 P_i + \beta_2 P_i \ln(S_{it}) + \beta_3 \ln(L_i) + \beta_4 \ln(R_{it}) + \beta_5 \ln(D_{it}) + \varepsilon_{it}$$

Coefficient interpretation from equation (7)

β_0	$\log(\alpha_0)+(\alpha_1+1)\log(\delta_0)$
β_1	$(\alpha_1+1)\,\gamma$
β_2	$(\alpha_1+1)\,\delta_1$
β_3	$(\alpha_1+1)\,\delta_2$
β_4	$\alpha_{2(1)}$
β_5	$\alpha_{2(2)}$

where, for municipality i in year t:

M_{it}	=	Road maintenance expenditure (taka)
P_i	=	*Pucca* (paved) road share
S_{it}	=	Mean annual groundwater salinity (dS/m)
L_i	=	Total municipality road length (km)
R_{it}	=	Municipality-based revenue (taka)
D_{it}	=	Development income (taka)
ε_{it}	=	Random error term

Municipality income is determined by local revenues and development funds provided by outside agencies.[10] Although development funds are formally earmarked for investments, they are fungible to some degree because their availability enables municipality administrators to allocate fewer local resources to investment and more to recurrent expenses such as road maintenance. We introduce revenue (R) and development income (D) separately in (8) to allow for less-than-complete fungibility. A priori, we would expect the estimated coefficient of D to be less than or equal to the coefficient of R. Full fungibility implies statistically-indistinguishable coefficients.

5.2 Estimation

The unbalanced nature of our panel (Table 2) precludes spatial panel estimation in Stata[11] but, in any case, Figure 1 suggests that spatial autocorrelation is not likely to be a

[10] International donors provide a significant share of Bangladesh's development funds, but municipalities generally receive the funds from the central government.
[11] A balanced panel is required for the xsmle estimator developed by Belotti, Hughes and Mortari (2013).

serious problem for our geographically-scattered municipality sample. To test for robustness, we fit the model using two versions of equation (8) (with separate and composite municipality incomes) and three estimation techniques: robust regression, GLS (which incorporates non-uniform error variances across municipalities), and fixed effects estimation. We reproduce the full regression database in the Appendix.

Table 3 summarizes our estimation results.[12] Parameter estimates for the *pucca* share, salinity and road network length are the products of the underlying cost function parameters (γ, δ_1, δ_2) and ($1 + \alpha_1$), where α_1 is the elasticity of road quality demand w.r.t. unit maintenance cost. The upper bound of α_1 is zero, but it might be less than -1. Our results for groundwater salinity in Table 3, which are uniformly positive and significant, imply that [$-1 < \alpha_1 < 0$]. Since δ_1 (the cost elasticity of salinity) is unambiguously positive, β_2 (= $(\alpha_1+1)\delta_1$) is positive only if α_1 is greater than -1.

5.3 Robust and GLS Results

5.3.1 Salinity

To clarify our interpretation of the implied cost elasticity of salinity, consider possible values of (α_1+1), rounded to two decimal places within the admissible range: [.01 , .99]. The upper bound (.99) reflects a quality demand elasticity w.r.t. unit maintenance cost that is near zero. In that case, the estimated parameter β_2 (= 0.99 δ_1) is extremely close to the underlying unit maintenance cost elasticity of salinity. Since all four GLS and Robust estimates in Table 3 are effectively 1.86, the implication is that unit maintenance cost increases by *at least* 1.86% for each 1% increase in groundwater salinity.

[12] We have also tested for period effects using yearly dummy variables. They are uniformly insignificant, so we have excluded them from the final regressions.

As an alternative, consider a more cost-elastic case where α_1 = -0.5 and (1 + α_1) = 0.5. The implied value of δ_1 is now twice as high (3.72) and the multiples obviously increase further as α_1 approaches its lower bound of -1. Since a cost elasticity of 1.86 is already quite high, we believe (without empirical proof) that our result is consistent with relatively inelastic road quality demand w.r.t. unit maintenance cost. In any case, our overall result stands: For an all-*pucca* network (p = 1 in equation (8)), a 1% increase in groundwater salinity is associated with a 1.86% increase in road maintenance expenditures. As the *pucca* share declines, the composite elasticity declines proportionally. Our salinity result reflects the engineering literature by indicating that groundwater salinity has a large, significant impact on maintenance expenditures for *pucca* roads.

5.3.2 *Pucca* Share of Road Network Length

In equation (8), the estimated *pucca* share parameter tests the possibility that normal unit maintenance costs differ for *pucca* and *kutcha* roads. All four estimates for the *pucca* share parameter (β_1) in (8) are insignificant. By implication, only the salinity factor for *pucca* roads differentiates unit maintenance costs for the two road types in our results.

5.3.3 Road Network Length

Our estimates for the network length parameter (β_3) are the product of (1 + α_1) and δ_2, the network scale economy factor in the unit maintenance cost equation. Our prior result for salinity has established that (1 + α_1) is positive, so our negative result (-0.20) for the parameter estimates in Table 3 is consistent with scale economies in road network maintenance. However, the consistent insignificance of our results suggests that δ_2 is not significantly different from zero. This in turn implies constant returns to scale in road network maintenance.

5.3.4 Municipal Income

Our results for the Robust and GLS regressions provide a consistent view of income/expenditure relationships in the sample municipalities. The Robust estimates [(1) and (2)] indicate that road maintenance expenditure is significantly affected by local revenue and development income, both singly and combined. [13] The estimated coefficients for development income are marginally lower than the revenue coefficients, but overlaps in their 95% confidence intervals indicate that they are not statistically distinguishable. By implication development income is fully fungible, at least in the case of road maintenance.

The GLS elasticities [(3) and (4)] are identical to their Robust counterparts, but larger standard errors reduce significance levels. They fall below 95% for local revenue and development income separately, but the estimate for their combined effect remains highly significant. Overall, the Robust and GLS estimates indicate that the income elasticity of demand for road quality is about 0.74: Ceteris paribus, road maintenance increases by 0.74% for each 1% increase in municipal income from all sources.

5.4 Fixed Effects Results

Our fixed-effects results (regressions (5) and (6)) provide an additional robustness check,[14] subject to the caveat that, as Table 2 shows, 9 of the 20 sample municipalities have only one observation. Relatively sparse data clearly take their toll on the results for municipality income sources, which are insignificant both separately and combined. Salinity, on the other hand, is significant at 95% in both regressions. While this provides strong additional support for the importance of salinity, the estimated elasticities (10.0, 9.6) seem

[13] The combined income variable in regressions (2), (4) and (6) is the sum of log Revenue and log Development Income, so it can be interpreted as the log geometric mean of its two components.

[14] We cannot include *pucca* share or road network length in the fixed-effects regressions, since they do not vary across time-series observations for individual municipalities.

Table 3: Determinants of road maintenance expenditures
Coastal region municipalities in Bangladesh, 2007-2013

All variables except *Pucca* Share in logs

Dependent variable: Road maintenance expenditure

	Robust		GLS		Fixed Effects	
	(1)	(2)	(3)	(4)	(5)	(6)
***Pucca* Share**	-2.796	-2.801	-2.796	-2.801		
	(1.79)	(1.71)	(1.75)	(1.67)		
Groundwater Salinity x *Pucca* Share	1.859	1.862	1.859	1.862	10.014	9.617
	(2.81)**	(2.43)*	(2.85)*	(2.30)*	(2.09)*	(2.30)*
Road Network Length	-0.205	-0.203	-0.205	-0.203		
	(0.59)	(0.63)	(0.53)	(0.58)		
Local Revenue	0.741		0.741		0.049	
	(2.21)*		(1.92)		(0.08)	
Development Income	0.735		0.735		0.228	
	(2.21)*		(1.88)		(0.54)	
Local Revenue + Development Income		0.738		0.738		0.159
		(4.69)**		(4.41)**		(0.84)
Constant	-9.416	-9.428	-9.416	-9.428	2.728	2.278
	(2.56)*	(2.52)*	(2.46)*	(2.43)*	(0.46)	(0.43)
Observations	41	41	41	41	41	41
R-squared	0.66	0.66	0.66	0.66	0.40	0.40
Number of municipalities					20	20

t statistics in parentheses
*** significant at 5%; ** significant at 1%**

unreasonably high. On balance, we believe that the Robust and GLS estimates provide a much more plausible and complete quantification of model relationships.

6. Implications of the Results

To assess the significance of the salinity results, we use model (1)[15] in Table 3 to generate regression predictions for the sample median *pucca* share (64%) and sample minimum and maximum values for groundwater salinity (2.00 and 5.76 dS/m, respectively), while holding municipality revenue, development income and network road length constant at their mean log-values. We divide predicted maintenance expenditure in each case by sample mean income (local revenue + development income) to obtain the predicted expenditure share. The predicted road maintenance expenditure shares are 1.86% and 6.55%, respectively: At the sample median for *pucca* road share, increasing groundwater salinity from sample minimum to maximum value increases the road maintenance expenditure share by 252%.

We conclude that existing variations in groundwater salinity play an important role in determining road maintenance expenditures in coastal Bangladesh. By diverting resources from community health and education programs, saline groundwater may have a particularly adverse impact on poor households. The problem seems likely to worsen significantly in Bangladesh's coastal regions, as groundwater salinity is increased by climate-related changes in the sea level and river flows.

7. Summary and Conclusions

This paper has used new monitoring and expenditure data to assess the impact of groundwater salinity on road maintenance expenditures in the coastal region of Bangladesh. The potentially-adverse impact of salinity on paved roads is well-established in the engineering literature, but its magnitude depends on local conditions (e.g., the level of groundwater salinity, the height of the water table, and the

[15] We select model (1) because it separates the effects of municipal revenue and development income. Model (3) yields identical estimates (only the standard errors are different), and predictions from the other models are not meaningfully different from the predictions reported here.

material composition of the affected infrastructure). Data scarcity has prevented systematic analysis for poor countries and, to our knowledge, this is the first such exercise for Bangladesh.

Our assessment draws on two new information sources: panel measures of salinity from 41 stations in coastal Bangladesh, provided by the Bangladesh Soil Research Development Institute, and information on road maintenance expenditure, income, road network length and road surfaces compiled by our project study team from the annual budget books of 20 coastal municipalities. We use spatial interpolation of station measurements to estimate groundwater salinity at the geographic centroids of the sample municipalities, and combine these with the municipality-level information to construct our estimation database.

Using this information, we estimate a log-log expenditure model that relates road maintenance expenditure to groundwater salinity interacted with the paved road share of the road network; the paved road share separately; the length of the road network; and two sources of municipal income (local revenue and development income from outside sources). To test robustness, we fit alternative models using robust regression, generalized least squares (allowing for variable error variances across municipalities) and fixed-effects panel regression. We find large and significant effects for salinity in all model specifications, including fixed effects, and significant effects for municipality income in the robust and GLS regressions.

To assess the overall impact of salinity, we use our regression model to predict the effect of within-sample salinity variation on road maintenance expenditure shares, holding municipal income and road length constant at sample mean values. For the median paved road share of municipality road networks, we find that increasing salinity from its sample minimum to its sample maximum increases the predicted road maintenance expenditure share by 252%.

We conclude that groundwater salinity has a large, significant impact on municipal expenditures for road maintenance in coastal Bangladesh. The implied welfare impact may also be substantial, particularly for poor households, since diversion of expenditures to compensate for salinity reduces budgetary support for community sanitation, health and other infrastructure related programs. This problem seems destined to grow, as climate-related changes in sea level and riverine flows drive future increases in groundwater salinity.

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Appendix Table: Regression Database

Region	District	Sub-District	Municipality	Year	Mean Salinity (dS/m)	Road Maintenance Expenditure (taka)	Local Revenue (taka)	Development Income (taka)	Road Network Length (km)	Pucca Share of Road Network
Barisal	Barisal	Barisal	Bakerganj	2013	2.2797	3,084,415	7,175,531	15,530,056	35	57.1
Barisal	Barisal	Barisal	Mehendiganj	2013	2.2135	3,026,289	7,960,834	15,451,613	85	60.0
Barisal	Barisal	Jhalakati	Jhalakati S.	2007	3.3839	1,668,450	36,580,123	14,623,858	67	76.1
Barisal	Barisal	Jhalakati	Jhalakati S.	2008	3.6671	4,844,629	60,522,208	26,864,408	67	76.1
Barisal	Barisal	Jhalakati	Jhalakati S.	2012	3.7697	6,485,270	50,983,699	12,850,482	67	76.1
Barisal	Barisal	Jhalakati	Jhalakati S.	2013	3.7988	9,585,875	56,580,207	16,415,875	67	76.1
Barisal	Barisal	Pirojpur	Mathbaria	2012	2.9210	7,466,321	24,288,247	32,726,155	55	63.6
Barisal	Barisal	Pirojpur	Mathbaria	2013	2.9465	4,311,548	24,675,599	44,433,761	55	63.6
Barisal	Barisal	Pirojpur	Nesarabad	2012	3.9497	222,022	6,779,983	7,500,000	91	52.7
Barisal	Barisal	Pirojpur	Nesarabad	2013	3.9791	212,771	8,476,400	7,400,000	91	52.7
Barisal	Barisal	Pirojpur	Pirojpur S.	2007	3.5980	2,506,643	21,189,382	18,382,537	84	86.9
Barisal	Barisal	Pirojpur	Pirojpur S.	2008	3.9098	3,526,718	41,907,200	34,611,332	84	86.9
Barisal	Barisal	Pirojpur	Pirojpur S.	2012	3.9859	3,146,506	43,581,881	35,380,013	84	86.9
Barisal	Patuakhali	Bhola	Bhola S.	2013	1.9967	2,686,364	63,469,842	40,788,548	75	93.3
Barisal	Patuakhali	Bhola	Charfasson	2007	2.3774	175,000	9,823,014	10,715,916	50	70.0
Barisal	Patuakhali	Bhola	Charfasson	2008	2.4399	220,000	12,076,074	15,014,525	50	70.0
Barisal	Patuakhali	Bhola	Charfasson	2009	2.7373	550,230	10,863,909	8,642,159	50	70.0
Barisal	Patuakhali	Bhola	Charfasson	2012	2.6023	500,000	15,964,176	28,152,860	50	70.0
Barisal	Patuakhali	Borgona	Amtali	2007	2.0183	41,604	6,321,778	19,637,669	33	90.9
Barisal	Patuakhali	Borgona	Barguna S.	2007	2.5512	280,312	15,239,077	7,150,000	154	46.1
Barisal	Patuakhali	Borgona	Barguna S.	2008	2.5903	774,150	12,211,564	12,000,000	154	46.1
Barisal	Patuakhali	Borgona	Barguna S.	2012	2.7776	1,000,000	42,490,324	17,000,000	154	46.1
Barisal	Patuakhali	Borgona	Barguna S.	2013	2.8037	3,416,000	40,187,605	23,416,935	154	46.1
Barisal	Patuakhali	Patuakhali	Galachipa	2007	2.4390	175,673	5,761,813	4,575,157	22	54.5
Barisal	Patuakhali	Patuakhali	Galachipa	2008	2.5285	131,222	8,206,400	11,866,899	22	54.5
Chittagong	Noakhali	Feni	Feni S.	2007	2.3558	5,035,228	78,466,571	60,004,322	215	86.0
Chittagong	Noakhali	Feni	Feni S.	2008	2.4460	5,000,000	87,410,446	57,122,629	215	86.0
Chittagong	Noakhali	Feni	Feni S.	2012	2.5730	5,917,335	182,235,064	134,993,155	215	86.0
Chittagong	Noakhali	Lakshmipur	Lakshmipur S.	2009	2.6746	1,000,000	51,453,246	13,055,704	115	60.9
Chittagong	Noakhali	Lakshmipur	Raipur	2008	2.1736	500,000	16,253,929	10,584,653	147	15.0
Chittagong	Noakhali	Lakshmipur	Raipur	2009	2.3969	500,000	14,663,308	6,020,507	147	15.0
Chittagong	Noakhali	Noakhali	Noakhali S.	2013	2.8364	1,200,000	91,456,984	9,185,655	720	30.6
Dhaka	Faridpur	Faridpur	Faridpur S.	2012	3.2256	9,551,298	208,614,027	43,830,187	183	78.7
Dhaka	Faridpur	Gopalgonj	Gopalganj S.	2012	4.1006	4,567,318	88,385,184	60,982,128	108	66.7
Khulna	Jessore	Jessore	Abhaynagar	2008	2.2026	1,408,751	23,249,254	12,350,231	176	51.1
Khulna	Jessore	Jessore	Abhaynagar	2009	2.4022	1,520,000	28,423,951	21,085,000	176	51.1
Khulna	Jessore	Jessore	Abhaynagar	2012	2.2413	1,275,000	24,723,586	12,980,831	176	51.1
Khulna	Jessore	Jessore	Abhaynagar	2013	2.2648	479,526	27,046,718	12,636,069	176	51.1
Khulna	Jessore	Jessore	Jessore S.	2012	3.5682	3,541,778	103,521,117	20,887,644	230	52.2
Khulna	Khulna	Shatkhira	Satkhira S.	2012	5.7332	2,462,670	59,394,429	21,885,614	281	58.7
Khulna	Khulna	Shatkhira	Satkhira S.	2013	5.7603	7,917,686	62,318,353	29,673,771	281	58.7