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RESEARCH ARTICLE

Migration and erosion in tidal and river channels in Bangladesh

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ABSTRACT Environmental stressors and natural disasters are changing the physical landscapes in many countries worldwide. In this paper, we ask whether and how erosion affects internal and international migration in Bangladesh. Building on prior studies, we use data from 3,600 households in 18 research sites to investigate how erosion in tidal and river channels is related to the risk of making a first internal or international trip, net of extreme weather conditions and other relevant attributes. Findings reveal that the relationship between erosion and the likelihood of making a first domestic or international trip is moderated by livelihood type and landownership. As erosion worsens, the odds of making a first domestic trip rise for non-agricultural non-landowning household heads and decline for landowners working in agriculture. Estimated lifetime probabilities of making a first domestic trip are higher than those of making a first international trip, with non-agricultural non-landowners having the highest probabilities and agricultural landowners having the lowest. Together, the evidence suggests that shifts in physical landscapes, especially erosion, are tightly linked to out-migration through ties to land.

KEYWORDS Migration • Erosion • International migration • Internal migration • Bangladesh • River channels

Introduction

Over the last 20 years, there has been growing interest in the relationship between climate change and migration. Findings from this research show that shifts in precipitation and temperature are linked to migration decisions, although the patterns they identify vary and depend on the method, theory and geographic area of interest applied (Hunter et al., 2013). Migration itself has also changed, with the motives for leaving becoming more complex and the numbers of forced migrants, including refugees and internally displaced persons, growing (Donato and Ferris, 2020; Sharpe, 2018). Thus, international migration has become

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increasingly associated with evading threats related to war, conflict, natural disasters and environmental degradation (Donato and Massey, 2016; Betts, 2010).

Studies have suggested that agricultural productivity is a primary pathway through which climate change influences the likelihood of migration (Cai et al., 2016; Cattaneo and Peri, 2016). A recent macroeconomic study of 108 countries covering the period from 1960 to 2010 reported that the effects of weather shocks on migration occur mostly through changes to agricultural productivity (Falco et al., 2019). Such disruptions may directly affect households that cultivate crops, as well as agricultural laborers and those with businesses tied to the agricultural sector. Examining the effects of these disruptions on agriculture is central to understanding the migration-climate change relationship in low-lying rural Bangladesh, where, despite a shift away from agricultural employment, more than half of rural households remain engaged in agriculture (Lobell et al., 2011; Sen et al., 2021).

Building on prior studies, this paper examines whether and how tidal and river channel erosion (or land loss) intensifies or reduces the risks of making internal and international migrant trips. Bangladesh's location in the floodplain of the Ganges-Brahmaputra-Meghna river delta makes it prone to seasonal flooding, channel erosion and accretion as water and sediment move across the landscape (Rahman et al., 2020). Riverbank erosion is one of the most costly and disruptive environmental stressors Bangladeshi residents face each year (ICCHL, 2016). Sediment starvation from large infrastructure projects (e.g., dams, water diversions, embankments) is modifying natural sediment transport processes, intensifying erosion in some locations. Climate change further compounds these impacts through sea level rise and changes in rainfall, flooding and cyclone activity (Islam et al., 2021; Yang et al., 2017; Dewan et al., 2017; Moors et al., 2011). Although it is well-established that erosion often temporarily displaces families who lose their homes (Barua et al., 2019; Hutton and Haque, 2003), we know relatively little about the effects of erosion on individuals' decisions to migrate from their origin communities. Using data collected from 3,600 households in 18 communities in southwest Bangladesh, we investigate whether and how erosion is associated with the likelihood of making a first domestic or international migrant trip. Using an objective measure of erosion derived from Landsat satellite images and controlling for river and tidal flooding, we model the initial internal or international migrant trip as a process that unfolds over time, and consider whether and how the effects of erosion on household heads vary by agricultural landownership and livelihood.

Landscape change, migration and erosion in Bangladesh

It is widely known that Bangladesh experiences many natural disasters, including flooding, cyclones and riverbank erosion (Karim, 1995). Its flat topography, low-lying elevation, high population density and weak infrastructure combine to increase the exposure and the vulnerability of coastal Bangladesh to natural hazards.[1] Seasonal flooding along with

1 Cyclone Amphan, which made landfall in May 2020 and affected 10 million people in Bangladesh and India, damaged homes and agricultural production (UN News, 2020). Cyclone Mocha severely damaged shelters in southeastern Bangladesh near the Rohingya refugee camp in May 2023 (Vaidyanathan, 2023).

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erosion and land deposition are natural processes in the Ganges-Brahmaputra-Meghna delta that have long shaped local practices and livelihoods in the region. To protect and expand agricultural production, embankments were constructed in many coastal communities from the 1960s through the 1990s. Originally designed to provide flood control, the embankments (also known as polders) have weakened in recent decades because of lack of maintenance. These polders have altered the natural fluid dynamics and sedimentation processes, intensifying erosion in some areas (Brammer, 2014; Auerbach et al., 2015; Valentine et al., 2021; Valentine and Wilson, 2023). Evidence suggests that upstream damming also impacts sediment processes, exacerbating land loss downstream (Syvitski and Milliman, 2007). Climate change compounds these risks through changes in the amount and the intensity of rainfall, as well as in the water levels and flows in river and tidal channels (Islam et al., 2021; Yang et al., 2017; Dewan et al., 2017). Land lost to erosion frequently causes loss of and damage to homes, road infrastructure, agricultural land, buildings and other community infrastructure (e.g., irrigation works).

These natural and human forces combine to create to a dynamic and complex physical landscape in Bangladesh (Arefin et al., 2021; Edmunds et al., 2015). Using GIS and remote sensing imagery, Arefin et al. (2021) assessed changes in land use/land cover along Bangladesh's Padma River between 1955 and 2016. They found that, during this period, rates of riverbank erosion and vegetation loss related to settlement expansion increased, as did oscillations in the ratio of cultivated land to sand bars and water. Moreover, in recent decades, salinity intrusion has increased along the coast as higher water levels expand tidal inundation and groundwater reservoirs become more saline (Edmunds et al., 2015). Higher salinity in the soil and the water affects agricultural yields (Islam et al., 2021), raising food prices and poverty risks, especially for those with agricultural livelihoods (Ahmed et al., 2009). In addition, surface flooding is associated with exposure to drinking water from wells with high arsenic concentrations (Connolly et al., 2022).[2]

Specific environmental conditions are differentially associated with out-migration in Bangladesh. For example, Chen et al. (2017) reported that extreme flooding is negatively associated with out-migration. In addition to identifying effects of weather, Chen and Mueller (2018) found that gradual increases in soil salinity reduce agricultural income, which is associated with more internal migration. Carrico and Donato (2019) reported that dry spells are most consistently associated with increased migration of household heads with agricultural livelihoods, whereas heavy rainfall is less robustly related to out-migration.[3] However, warm spells were also found to be strongly associated with internal migration for those employed in agricultural livelihoods – signaling that some environmental conditions influence migration by disrupting agricultural livelihoods (Call et al., 2017; Nawrotzki et al., 2015).

2 Arsenic, which naturally occurs in sediment, leaches into water supplies in shallow tube wells. Bangladesh has the highest risk of environmental arsenic poisoning globally (Ahamad et al., 2018), which has a direct effect on health (Edmunds et al., 2015). Using prospective longitudinal data from 12,000 Bangladeshis, Argos et al. (2010) found that one in five deaths in Bangladesh (population of 125M) is associated with exposure to water from wells with high arsenic concentrations.

3 The findings for Mexico are comparable. In rural communities, declining precipitation and drought were positively associated with U.S. migration (Nawrotzki et al., 2013, 2015; Hunter et al., 2013). Changes in precipitation were also associated with Mexican internal and international migration (Leyk et al., 2017).

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Erosion and migration

Given that riverine Bangladesh is prone to tidal channel and riverbank erosion, it is not surprising that the country, along with India, has been the focus of many studies analyzing the relationship between human migration and erosion (Zaman, 1989; Das et al., 2014, 2017; Mili et al., 2013; Majumdar et al., 2023). In an early publication, Zaman (1989) described patterns of dislocation and resettlement related to riverbank erosion and accretion by Bangladeshi residents living in the Brahmaputra-Jamuna floodplain. Zaber et al.'s (2018) ethnographic study of four districts of Bangladesh described how riverbank erosion leads to forced migration and social displacement. Analyzing data collected from 420 internally displaced persons residing in two sub-districts in southwest Bangladesh, Chowdhury et al. (2020) found that approximately 40 percent of respondents reported riverbank erosion as the most significant reason for their displacement. Islam et al. (2020) looked at internal migration from the coast to the upland areas in the Chittagong Hill Tracts, and showed how erosion and climate events are associated with decisions to migrate.

Relying on survey data from 4,456 residents in 1,188 households in rural embanked communities in five districts in coastal Bangladesh, Bernzen et al. (2019) examined whether and how erosion and other measures of environmental stress are related to out-migration. They found that erosion, measured by self-reports of arable land, was positively associated with internal migration but not with international migration, controlling for other relevant factors. In addition, human capital variables, such as not being employed in core agricultural/aquaculture industries, were both shown to be positively associated with migration and more important covariates than erosion and environmental stressors. Ali et al. (2021) analyzed a study area in Sirajganj Sadar, an upazila in North Bengal prone to erosion, and reported that after 10 years, more than 20 percent of the area's population had migrated (mostly internally) as a result of river bank erosion. Islam et al. (2021), who collected survey and focus group data in a small administrative unit in the district of Bhola, concluded that river bank erosion leads to successive and gradual losses among the affected population and serves as a push factor for migration. Abdullah Kaiser (2023) also described how riverbank erosion negatively affects internally displaced persons in Lakshmipur, where they face physical and psychological risks due to displacement.

Therefore, prior studies offer empirical evidence that riverbank erosion is associated with human suffering, material loss, displacement and migration. Many of these studies are based on small samples that focus on one or two areas of the country, illustrating how the relationship between land loss and migration is complex, difficult to measure and not well understood. Yet, this is not surprising given that the country's physical landscape is highly dynamic and not uniform (Brammer, 2014). Across space, land loss occurs at different rates and human interventions contribute to these processes.

Analysis plan and expectations

In this paper, we integrate data from remotely sensed imagery and household migration histories between 1998 and 2017 to assess the extent to which land loss and migration occur

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over time at a fine spatial scale. Thus, our analysis differs from prior studies in three important ways. First, we measure erosion using objective indicators derived from satellite data, rather than relying on subjective measures about perceptions of erosion obtained from survey respondents. Second, we capture erosion as a process that unfolds over time, rather than examining the effects of self-reported arable land loss on migration at a single point in time. To do this, we estimate net land loss on an annual time-step and integrate the data with household migration histories from 1998 to 2017. Third, in contrast to Bernzen et al. (2019), we use a household sample that includes randomly selected households in coastal and non-coastal communities, which may reveal more variation than has been observed to date.

Expectations

Given the physical landscape dynamics related to tidal and river channels in the southwest Bangladesh communities of origin, we expect to observe substantial variation in patterns of erosion and migration. In general, we expect erosion to be positively associated with the propensity to make a first domestic or international migrant trip. We anticipate that in response to land loss and other impacts on household and community assets, community members will seek livelihoods elsewhere, and thus many will migrate. In addition, given the observed relationship between erosion and migration in rural Bangladesh communities, we expect that agricultural landownership and livelihood moderate the relationship between erosion and migration. Specifically, we expect that among non-agricultural workers who do not own land, erosion will be positively associated with making a first trip. However, among agricultural and non-agricultural workers who own land, it is unclear a priori exactly how erosion will be related to migration. Given that non-agricultural workers who own land are wealthier than agricultural workers who own land (see Table 1), the former may have more resources to adapt locally when physical landscapes shift, leading to a lower likelihood of making a first migrant trip. In contrast, agricultural workers who are landowners typically have fewer resources, which may translate into a stronger relationship between erosion and migration among this group than that observed among non-agricultural workers who own land.

Data and methods

For this analysis, we use data collected as part of the 2019 Bangladesh Environment and Migration Survey (BEMS) in the country's southwest region. Building on a pilot study of 1,695 households in 2014 (Donato et al., 2016; Carrico and Donato 2019), the 2019 BEMS collected detailed migration history data, including information about the first, last and second-to-last trips to internal and international destinations of household heads, their spouses and other adults. We use these data to estimate discrete-time event history models that assess relationships between livelihood and agricultural land in a given person-year and the risk of making a first internal or international migration trip in the subsequent year.

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Table 1 Descriptive statistics for full sample and agricultural (AG) livelihood/landowning groups

		Non-agricultural (Non-AG)		Agricultural (AG)	
	Full sample	**Non-landowner**	**Landowner**	**Non-landowner**	**Landowner**
Erosion (km^2)	0.22	0.18	0.19	0.31	0.29
Livelihood & landownership					
% Non-AG/non-LO	48.9	100.0	–	–	–
% Non-AG/LO	17.4	–	100.0	–	–
% AG/non-LO	15.6	–	–	100.0	–
% AG/LO	18.1	–	–	–	100.0
% Owns > 2 acres of agricultural land	3.8	0.0	11.5	0.0	9.9
% Head/family member works on land*	34.8	13.1	37.8	47.8	79.4
% Family migrated internally	32.7	31.3	39.6	30.5	31.6
% Family migrated internationally	8.6	9.4	10.2	6.2	6.9
Age (%)					
11–20	15.5	26.2	6.1	8.7	1.6
21–34	36.9	44.3	32.2	39.4	19.5
35–49	29.3	20.6	39.1	33.7	39.7
Over 50	18.2	8.9	22.6	18.2	39.2
Education (%)					
Less than primary	45.0	36.0	35.0	70.0	56.0
Completed primary	33.1	35.3	33.3	25.6	33.5
Completed secondary	8.3	9.9	10.9	2.6	6.4
Higher than secondary	14.0	18.9	21.2	2.1	4.0
% Female	17.6	24.1	27.8	4.1	2.2
% Muslim	94.8	93.8	94.4	97.3	95.8
% Currently married	74.0	60.7	84.9	81.1	93.5
Household wealth score	−.07	.11	.24	−.64	−.37
N (person years)	40939	20012	7107	6406	7414

*Note: Members of households that do not own agricultural land may work on leased and borrowed landholdings for agricultural purposes.

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We separately model initial internal and international migration trips, following King and Skeldon (2010).

The BEMS was collected in 20 mouzas, which are small administrative areas that usually contain 1–3 villages that vary in size from a few hundred to thousands of households.[4] In each mouza, we conducted a census of all households and then randomly selected a sample of 200 households. The 2019 BEMS data include a total of 4,000 households in communities that broadly cover the southwest region. From household heads and their spouses, we obtained information about the current and prior migrant trips they and other adults living in the household had taken. Thus, the BEMS data include information on prior and current migrants and non-migrants, even if the household members had not yet returned to the surveyed communities.[5] Another strength of these data is that, consistent with findings from the 2014 pilot and other surveys (see, for example, the Bangladesh Multiple Indicator Cluster Survey 2012–13, 2015; NIPORT, 2017), the BEMS had a very high completion rate (95%). Most of the non-complete households were unavailable during the time of data collection, and these households were replaced with a randomly selected alternate to meet the targeted sample size.[6]

The analytic sample focuses on household heads because they play an especially important role. Compared to other adult household members, heads are more likely to migrate; to send money to their origin household; and to remit larger amounts (Tonassi and Donato, 2023). Other adult household members are not included in the analysis because we lack data about the extent to which they had engaged with or supported the origin household.[7]

Finally, the analysis below relies on data from 18 of the 20 research sites that are in close proximity to a river or tidal channel,[8] and it is restricted to the years 1998 to 2017, for which we have consistent satellite imagery to construct measures of erosion. The final analytical sample includes 40,939 person-years generated from 2,717 respondents in 18 of the 20 research sites.

4 To select the 20 research sites, we constructed a sampling frame of all mouzas in the southwestern districts. We then stratified the sampling frame by district to capture variation in proximity to the Indian border (west), to Dhaka (east) and to the coast (south). We also stratified by economic development using an index summing adult literacy rates and household shares with access to electricity in each mouza, based on Bangladesh census data (Bangladesh Bureau of Statistics, 2011). We divided the sampling frame of mouzas into high and low economic development strata using a median split. Within each district, we selected one mouza from each stratum, resulting in two study sites in each district.

5 In a small number of households, there were no spouses or heads currently in the household. In such cases, we gathered migration history data about them from other adult residents.

6 Note that we refer to BEMS research sites without using mouza names to protect the confidentiality of respondents.

7 We performed robustness checks to assess whether processes differ for first and subsequent trips. Supplementary Table S.2 (available online at https://doi.org/10.1553/p-d9pb-hh22j) presents models for domestic and international trips controlling for a prior trip. In contrast to the first trip models discussed below in Table 3, the models in Table S.2 follow subjects from birth to the survey year. In addition to having more person-years (and more statistical power), these models include an additional variable that controls for whether a prior trip occurred in a prior person-year. Findings suggest that the erosion and livelihood/landownership effects for first trips are not much different from those for subsequent trips; thus, the odds ratios are largely similar in Table 3 and Table S.2. However, one difference emerges. Compared to non-agricultural non-landowners, agricultural non-landowners are less likely to make a first internal or international trip, but, when considering all trips, they are more likely to make a domestic trip and are less likely to make an international trip. This suggests that some non-agricultural non-landowners migrate more than once, whereas agricultural non-landowners migrate multiple times.

8 We excluded one site because it did not contain river channels, and a second site because estimates of erosion for it varied too widely from year to year, suggesting measurement error.

Variable definitions

In the analysis, we distinguish between the odds of making a first internal trip and a first international trip. We focus on household heads and use their year-by-year life histories up to the date of the first internal or international trip. The resulting discrete-time person-year files follow each subject from birth to the survey year, or to the year of the first trip, whichever came first. Internal migration equals one if a household head reported taking a first internal trip in a given person year, and otherwise equals zero. Similarly, international migration equals one if a household head reported taking a first international trip, and otherwise equals zero. We use robust clustered standard errors to account for within-individual clustering and include fixed effects for origin community. We operationalize a migrant trip as one that occurs outside of the upazila (subdistrict) in a domestic or international destination where a migrant has set up and lived in a household for three months or longer. This definition is more conservative than that used by Bernzen et al. (2019, p. 6), who defined migration "as any move from the household in which a person no longer ate meals at the household table, including moves both within the same union and outside the union."

One key objective of the analysis is to determine whether and how tidal and river channel shifts – as reflected in a measure of erosion – are associated with out-migration. To do this, we use images from LandSat remotely sensed imagery at low tide and in dry seasons for each year to calculate changes in tidal and river channels. Using ArcGIS, we calculate the area under water along river and tidal channels within five kilometers of the center of each research site.[9] Thus, for each year between 1998 and 2017, we estimate the total area along river channels in a research site that is water vs. land. From the estimates, we calculate continuous erosion variables to capture one-year and five-year shifts in absolute water area in square kilometers (km^2).[10] Across all research sites, Table 1 shows that average annual erosion is .222 km^2. Given that one square kilometer is approximately equal to 247 acres, an average annual erosion rate of .222 km^2 reflects total annual land loss of roughly 55 acres across all sites.[11]

To examine the moderating roles of agricultural landownership and livelihood, our analysis differentiates among four subsets of household heads. We use two BEMS variables to account for whether the heads' main livelihood activity is in the agricultural sector and whether they own or lease any type of agricultural land. We combine these variables to create four variables, lagged one year. The first group, which is the reference category in the models, includes non-agricultural non-landowners, i.e., heads whose main source of livelihood is from the non-agricultural sector and who do not own land. The second group contains heads whose main livelihood is also not in agriculture, but who own land. The third group includes heads whose main livelihood is the agricultural sector and who do not own land. The final group consists of heads whose main livelihood is in agriculture and

9 Using ArcMap/ArcGIS, we created polygon layers outlining river channels for each research site in each year from 1998 to 2017. For sites with multiple river channels, we created multiple polygons.

10 In a separate analysis not presented here, we included a measure that reflects five-year changes in absolute water area (km^2). The findings presented below for one-year shifts are comparable to those from models with the five-year change measure.

11 Supplementary Table S.1 presents descriptive statistics for livelihoods and agricultural landownership among domestic and international migrants.

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who own land. Table 1 indicates that approximately 49 percent of the sample are non-agricultural, non-landowning household heads; 17 percent are non-agricultural but own land; 18 percent have an agricultural livelihood but do not own land; and 16 percent have an agricultural livelihood and own land.

Among the other variables, we include a 0,1 dummy variable for whether the head or members of the head's family work on land for agricultural purposes. We also include dummy variables that represent whether the household head reported having ties to siblings or parents with prior internal or international experience. Age appears in four dummy variables: 11–19 (reference category), 20–34, 35–49 and 50+ years. Education is included in four dummy variables: less than primary school (reference), completed primary, more than primary up through completion of secondary school and more than secondary school. For gender, being a woman equals one and being a man equals zero. In addition, being Muslim equals one, and being non-Muslim equals zero; and being currently married equals one, and not being married equals zero.

We also include an index for household wealth at the time of the survey. Following Córdova (2009), we construct a relative asset-based wealth index that yields a more valid and reliable measure of economic well-being than income- or expenditure-based measures (Deaton, 1997). The approach avoids the non-response bias associated with income-based questions. Specifically, we ascertain whether the heads own or lease a variety of household and transportation assets, and then construct a relative wealth index using the Principal Components Analysis (PCA) approach used in prior studies (Filmer and Pritchett, 2001).

Because rainfall patterns are correlated with both erosion and migration in Bangladesh (Carrico and Donato, 2019), we add two measures of rainfall extremes: dry and wet spells. To daily meteorological data gathered at 29 southwest Bangladesh stations within close proximity of the 18 BEMS research sites, we apply two indicators developed by the Expert Team on Climate Change Detection Indices (Peterson and Manton, 2008). These include, for each site and year, the duration of dry spells (measured by the maximum number of consecutive days within a year with less than one mm of rainfall) and wet spells (measured by the maximum number of consecutive days within a year with more than one mm of rainfall).[12] Finally, in all models, we include community and year fixed effects.

Findings

We begin by describing the variation among household heads in the probability of taking a first internal or international migration trip. We then present findings from the discrete-time event history models to assess whether and how tidal and river channel erosion are associated with the risk of taking a first internal or international migration trip in the subsequent year.

Table 2 describes the spatial variation in the household heads' internal and international migration experiences. Across the entire sample, approximately 42.1 percent of household

12 We purchased and use daily precipitation and temperature data from the Bangladesh Agricultural Research Council.

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Table 2 First domestic and international trips by household heads

Site	% of household heads: Migrated domestically	% of household heads: Migrated internationally
201	31.5	1.5
202	45.5	22.5
203	32.6	10.7
204	39.0	16.0
205	46.9	9.4
206	43.7	8.6
207	49.1	18.6
209	30.3	12.4
210	51.2	9.0
211	33.2	3.5
212	43.3	27.9
213	33.2	5.0
214	63.2	6.5
215	46.9	3.4
216	43.1	0.5
217	49.5	6.4
218	48.0	6.0
220	28.5	3.5
Overall	42.1	9.6

heads reported having made a first domestic trip, and 9.6 percent reported having taken a first international trip. However, substantial variation exists in patterns of first trip migration across the research sites. With respect to domestic migration, the share of household heads who reported having made a first trip range from 2.5 percent in community 220 to 63.2 percent in community 214. Although the variation is smaller for initial international migration trips, it is still sizeable, ranging from approximately zero in community 216 to 27.9 percent in community 212.

Event history models

Results from baseline logistic regression models that predict the likelihood of taking a first domestic or international trip are presented in Table 3 (see columns referred to as model A). The models include the one-year water change variable capturing tidal and river channel erosion, the household head's livelihood and agricultural landownership, and other relevant variables.

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Table 3 Logistic regressions predicting first domestic and international trips

	Domestic trip		International trip	
	Model A	Model B	Model A	Model B
	OR	OR	OR	OR
Erosion (km^2)	1.056	–	1.002	–
Livelihood & landownership (ref = non-AG/non-LO)				
Non-AG/LO	.634***	.639***	.567***	.605***
AG/non-LO	.649***	.646***	.480***	.576**
AG/LO	.385***	.427***	.414***	.322***
> 2 acres of agricultural land	.531**	.534**	.906	.852
Head/family member works on land	.569***	.566***	.447***	.462***
Family migrated internally	1.102	1.102	–	–
Family migrated internationally	–	–	1.602***	1.580***
Age (ref = under 20)				
20–34	.978	.982	3.875***	3.875***
35–49	.298***	.299***	1.902	1.896
50 or older	.163***	.163***	.546	.562
Education (ref = less than primary)				
Completed primary	1.079	1.079	1.511*	1.496
Some/completed secondary	1.127	1.129	1.501	1.492
More than secondary	1.307	1.311	.675	.668
Female (ref = male)	.446***	.447***	.133***	.133***
Muslim (ref = non-Muslim)	1.182	1.183	9.273**	9.204**
Married (ref = not married)	1.036	1.036	.955	.958
Wealth index score	1.208***	1.206***	2.114***	2.127***
Dry spells (CDD)	.999	.999	1.011**	1.012**
Wet spells (CWD)	1.010	1.010	.961	.962
Interactions[a]				
Erosion*Non-AG/non-LO	–	1.075**	–	.987
Erosion*Non-AG/LO	–	1.042	–	.676***
Erosion*AG/non-LO	–	1.085	–	.257
Erosion*AG/LO	–	.742*	–	1.349***
Constant	.020***	.019***	.000***	.000***
Observations	39033	39033	33183	33183
Pseudo R-squared	.087	.088	.192	.197
Year fixed effects	Yes	Yes	Yes	Yes
Site fixed effects	Yes	Yes	Yes	Yes

[a]Note: Using the testparm command in STATA, the interaction terms predicting internal and international migration are jointly significant.
Standard errors clustered at the site level. *** $p < .01$, ** $p < .05$, * $p < .1$

Erosion appears to be positively associated with the odds of taking a first internal or international trip, although the coefficients underlying the odds ratios are not significant. However, we see robust effects for the livelihood/landownership variables. Relative to household heads whose livelihoods are not in agriculture and who do not own land, the three other groups – all of whom have a stronger attachment to agricultural land – have significantly lower odds of making a first domestic or international trip. For example, the odds of taking a first domestic trip among non-agricultural landowners is .634, meaning that for household heads in this category, the odds of taking a first domestic trip are 37 percent lower. Moreover, the odds of these household heads taking a first international trip are approximately 44 percent lower. Among heads who have agricultural livelihoods and who are also landowners, the odds of taking a first domestic or international trip are even lower (62 and 59 percent lower, respectively, than those of non-agricultural, non-landowning household heads).

With respect to other covariates in the domestic migration model, the results indicate if a head or another member of the family works on household land for agricultural purposes, they have a lower likelihood of making a first migration trip of either type, relative to those who do not. In addition, in contrast to the domestic migration model, the findings show that having ties to parents or siblings with international migration experience increases the likelihood of making a first international trip. For heads with such ties, the odds of making a first international trip rise by approximately 60 percent.

Effects for age also vary in models predicting the likelihood of taking a first domestic or international trip. Relative to heads under age 20, the odds ratio of making a first international trip is significantly higher for heads aged 20–34. However, the odds of making a first domestic trip do not differ between these two age groups. Moreover, consistent with a declining age-migration profile, we see that the likelihood of making a first domestic trip is lower for heads aged 35 and older (although these effects are not significant for international trips). Interestingly, education appears to be largely unrelated to the odds of making a first domestic or international trip. However, in both models, women are significantly less likely than men to make a first domestic or international trip. In addition, being Muslim is associated with a higher likelihood of making a first international trip, but not a first domestic trip.

We also see that household wealth matters; as wealth increases, the odds of making a first trip rise. In addition, as we might expect, the wealth index odds ratio is larger for international first trips than for domestic trips, reflecting the greater costs associated with leaving home, crossing an international border and establishing oneself in a foreign location. Finally, extreme weather in the form of dry spells increases the likelihood of making a first international (but not a domestic) migrant trip, but wet spells have no effect.

Effects vary for agricultural landowners and workers

The second set of columns for domestic and international migration in Table 3 (see columns labeled Model B) presents odds ratios from interaction models that consider whether and how the effects of erosion vary by agricultural livelihood and landownership. For domestic

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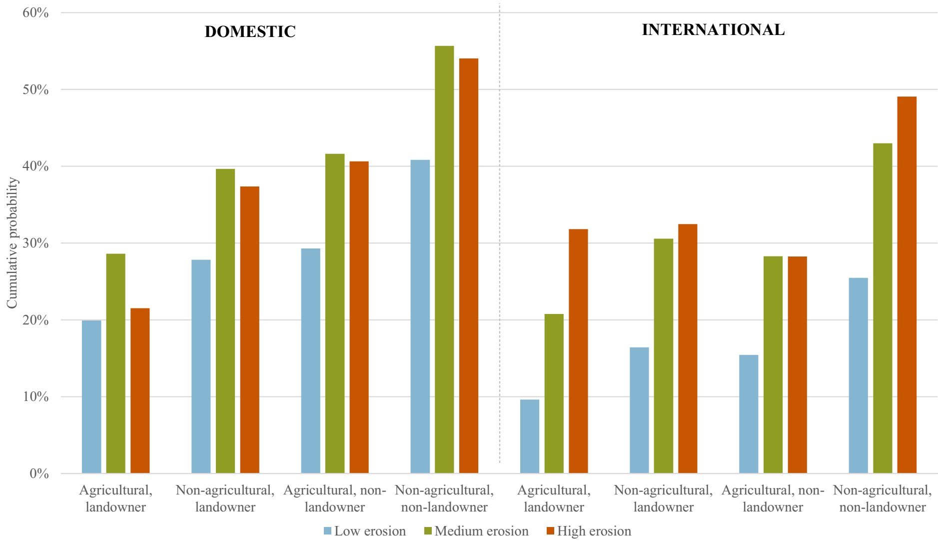
Figure 1 Cumulative probabilities of making a first domestic/international trip by age 43 by erosion, livelihood and landownership



Note: Lifetime probabilities are for single Muslim men, born in 1974, who have completed primary school and have no family with migration experience (derived from Table 3 coefficients – see Models B).

migration, the findings are consistent with our expectations. As erosion worsens, the odds of non-agricultural non-landowning household heads making a first domestic trip rise. By comparison, among landowners working in agriculture, the odds of making a first domestic trip are significantly lower. For the risk of taking a first international migration trip, the odds ratio for landowners whose livelihoods do not depend on agriculture is lower, whereas the odds ratio for landowners working in agriculture is approximately 35 percent higher. This latter finding is surprising, and we discuss it further in the last section of the paper.

Figure 1 presents the cumulative probabilities of making a first domestic or international trip by age 43 for single Muslim men born in 1974 who have completed primary school, but who have no relatives with migration experience. These cumulative probabilities are presented for those in the four livelihood/landownership groups in research sites categorized as having low, medium and high levels of erosion.[13]

Three findings are noteworthy. First, the overall lifetime probabilities of making a first domestic trip are higher than those of making a first international trip irrespective of livelihood and agricultural landownership. Second, the chances of taking a trip are considerably higher for some groups than for others. Consistent with expectations, the probabilities of

13 Based on the distribution of the erosion variable, we categorized the erosion level of a research site as low if its average annual erosion is less than .1 km^2; as medium if it is greater than .1 but less than .25 km^2; and as high if it is greater than or equal to .25 km^2. The lowest annual erosion of a research site was 0.01 km^2 and the highest was 1.21 km^2.

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making a first domestic or international trip by age 43 are highest among heads with non-agricultural livelihoods who do not own agricultural land. The lifetime chances of making a first domestic trip are 40 percent among heads in low erosion areas, and are even higher among heads in areas with medium or high levels of erosion. The lifetime chances of making a first international trip follow a similar low-to-high erosion pattern. Among heads with non-agricultural livelihoods who do not own agricultural land, the chances of taking such a trip range from 25 percent for those in low erosion areas to 49 percent for those in high erosion areas.

Third, although – for some groups – the cumulative probabilities of making a first trip increase incrementally as erosion levels rise, this pattern holds only for agricultural landowners and non-agricultural non-landowners making a first international trip. For agricultural landowners, the chances of making a first international trip ranges from 10 percent in low erosion areas to 20 percent in medium erosion areas and 30 percent in high erosion areas. However, for all four livelihood-landownership groups, the chances of making a first domestic trip are highest, and do not differ considerably for those living in medium and low erosion areas. For example, among agricultural landowners, the chances of making a first domestic trip begin at 20 percent in low erosion areas, rise to 29 percent in medium erosion areas and then drop to 21 percent in high erosion areas. We see a similar pattern for the chances of non-agricultural non-landowners making a first domestic trip: the chances rise from 40 to 55 percent and then drop to 53 percent across low, medium and high erosion areas, respectively.

Discussion

In this paper, we have combined household data collected in 2019 with data from remote sensing imagery to examine how erosion is associated with the likelihood making a first domestic or international migrant trip among Bangladeshi household heads. Findings from our models suggest that erosion is tied to internal out-migration, but the effect varies by livelihood and landownership. As expected, we observe that the effect of erosion on the likelihood of making a first domestic trip is strong and positive for non-agricultural non-landowners: high levels of erosion mean higher odds of making a first domestic trip. In contrast, with respect to the likelihood of making a first international trip, high levels of erosion are associated with lower odds for non-agricultural landowners, and, somewhat surprisingly, with higher odds for agricultural landowners.

Our finding that for agricultural landowners in high erosion areas, the chances of making a first international trip are higher than the chances of making a first domestic trip is challenging to explain. Table 1 shows that landowners whose livelihoods depend on agriculture are less wealthy than landowners whose livelihoods do not depend on agriculture. Our models nonetheless reveal that, controlling for wealth differences, erosion is related to lower odds of making an international move for non-agricultural landowners and to higher odds for agricultural landowners. This suggests that the role of landownership is complicated. Thus, landowning heads without an agricultural livelihood may adapt by selling at least some of their land, or they may be supporting their land through migrant remittances

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sent from other household members – which are strategies that landowners with an agricultural livelihood may be unable to employ. This is a research question we will address in the future using BEMS data on remittances received in the last 12 months.

Similar to most studies, this study has limitations. One is that the BEMS data do not include entire households that have migrated from the sampled research sites and have not returned. Without these households in the analytic sample, we may underestimate migration and are unable to capture covariates leading to permanent out-migration (Hamilton and Savinar, 2015). In addition, the BEMS data may be selective in that in some households, certain individuals, such as the elder brother, may have migrated and not returned, leading the younger brother to assume the role of household head at the time of the interview. There are likely differences between migrants who have returned and migrants have not, especially in terms of livelihood characteristics and the effects of erosion. For example, for migrants who have returned, the effects of erosion may be more robust in facilitating additional migrant trips. We therefore urge readers to keep in mind that the findings reported here do not capture these types of household selectivity. However, our future work will do so. With new National Science Foundation funding, we recently returned to a subset of households to collect panel data that will enable us to investigate the extent to which entire households have left BEMS research sites since 2019 and the onset of the COVID-19 pandemic.

For some readers, another limitation of this study may be that the analysis does not permit a deeper consideration of the social underpinnings of migration. Our focus on household heads and on agro-ecological factors does not provide a deep understanding of intra-household dynamics, such as strategies that involve sending a child or a sibling to migrate domestically or abroad. Nonetheless, the analysis captures the livelihood and migration activities of heads, who play very important roles in their households. Thus, while it does not fully interrogate the social foundations of Bangladeshi migration, the paper's main purpose is to investigate whether and how erosion is related to the migration of household heads – a question that few studies have addressed up until now. In other work currently in development, we are using BEMS data to examine intra-household migration strategies. A final limitation of the analysis may be related to its emphasis on first, and not subsequent, migrant trips. Although preliminary evidence from robustness checks described in footnote 13 suggests that processes for first and later trips are similar, future research should explore how the processes for subsequent trips vary from those for first trips.

Despite these limitations, the findings presented here suggest that measuring a process such as erosion at a fine spatial scale offers new insights into how physical landscape changes are linked to migration. On the one hand, our findings are consistent with prior work that found a positive relationship between erosion and domestic (but not international) migration. On the other hand, the findings describe the different ways in which landownership and having an agricultural livelihood moderate the relationship between erosion and the risk of taking a first migrant trip. Thus, the analysis suggests that attachment to land moderates how erosion affects the risk of migration. That is, erosion increases the odds of making a domestic trip only among household heads who have a non-agricultural livelihood and do not own land. Among heads who own land but whose livelihood does not depend on agriculture, erosion lowers the likelihood of making an international trip; while among

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agricultural landowners whose livelihood depends on agriculture, erosion raises the likelihood.

Taken together, the results of the analysis point to a complex set of relationships. Although there are strong associations among shifting physical landscapes of migration and land attachment through agricultural livelihoods and landownership, the findings do not support causal interferences. Investigating the causal links among changing physical landscapes, differences in agricultural and land attachment and out-migration requires prospective panel data and enhanced research designs that can be used to disentangle the pathways among variables (Falco et al., 2019). However, it appears that landowners – whether agricultural or non-agricultural – are better able to finance migration. International migrants are diverse, and migration to some countries, such as those in the Middle East, may be lucrative enough to encourage people *both* to migrate more than once and to remain in Bangladesh after returning and thus not to migrate again. Therefore, it may be the case that erosion pushes households to send at least one household member to seek employment elsewhere and then eventually return. In addition, future studies must identify and disentangle the observed relationships reported in prior studies. For example, given our findings about the relationship between land erosion and migration, we call upon future studies to integrate migration history data with other physical landscape data, including data on the salinity of surface and ground water, as well as on the volumes of sediment and water discharge moving through the river channels.

The impacts of climate change on erosion have been documented for decades (Li and Fang, 2016). Among the direct impacts are shifts in the amounts and the intensity of rainfall. The indirect impacts include rising temperatures, which also affect erosion by changing vegetation cover. Alongside anthropogenic changes, such as upstream damming and the creation of polders, erosion influences people's agricultural landholdings and livelihoods, which, as we show, moderate the relationship between erosion and migration. Given the scale and the impacts of erosion in southwest Bangladesh and the growing threat of climate change in the region, there is an urgent need for more research on how households are impacted; how they are adapting; and how their well-being can be supported despite these risks.

Supplementary material

Available online at https://doi.org/10.1553/p-d9pb-h22j
Supplementary file 1. Tables S.1 and S.2.

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