Bangladesh and the Surging Sea

A Vulnerability Assessment with the Projections
for Sea Level Rise and Coastal Flood Risk

Contents

Summary

Due to its unique topography and high population density, Bangladesh is extremely vulnerable to rising sea levels this century. This report presents an assessment of sea level rise and coastal flood exposure at national, division and district levels, using new high-resolution elevation data plus local sea level rise projections, tidal heights, minor flood heights, and population maps to analyze land area and current population below a range of potential water levels. If global carbon emissions continue unabated, over 1,000 km2 of land in Bangladesh could be permanently under the new high tide line by 2100, on which more than 8 lakh people current live. Twice as much land and more than 20 lakh people are at risk of frequent flooding from storm surge plus tides. Barisal, Chittagong, and Khulna are the divisions holding most of the risk, while Chittagong and Cox's Bazar (both in Chittagong division) are the leading districts in potential exposure this century.

Introduction

Climbing global temperatures bring rising sea levels worldwide. Not only do melting glaciers and collapsing ice sheets add enormous amounts of extra water to the oceans, but growing ocean temperatures are also causing sea water to expand. While rising tides are a threat to all coastal countries, Bangladesh is one of the most vulnerable in the world, with its flat, low-lying topography, numerous water bodies and rivers, and over 48% of its large, dense population currently living less than 10 meters above sea level [1].

A number of studies have investigated the impact of sea level rise on coastal flood exposure in Bangladesh during the most devastating storms, such as tropical cyclones [1]–[4]. Such events are already catastrophic to lives and infrastructure in the low elevation coastal zone, and will become even more so with sea level rise adding to storm surge heights. However, rare extreme events are not the only coastal challenges Bangladesh will face in the coming decades. This report focuses on land at risk of falling permanently below the future high tide line, and on threats from common floods as they reach ever higher. The analysis employs a recently published high-resolution digital elevation model covering Bangladesh, advancing prior research that has used models 3 to 30 times coarser in resolution.

This study uses sea level rise projections, tidal models, flood models, and elevation data to compute a range of potential permanent or temporary inundation layers for all areas inside Bangladesh. The sea level component depends upon the carbon emission pathway global society follows this century. The area of the land covered by each inundation layer, and the total population currently occupying it, are used as indicators of exposure; these are tallied nationwide, by division, and by district.

Related threats such as freshwater salinization [5]–[7] are not explored here.

Climate Central has developed two interactive online tools that present results related to this report. The **Surging Seas Risk Zone Map** (ss2.climatecentral.org) shows local sea level projections and areas vulnerable to submergence or flooding at different water levels. The **Surging Seas Risk Finder** (riskfinder.org) presents land and population exposed at different levels, from district through national scales.

Approach

Sea Level Rise Projections

This report considers two possible futures of sea level rise this century, depending on whether global greenhouse gas emissions continue to rise unabated (Representative Concentration Pathway (RCP) 8.5), or if large and immediate cuts are made to global emissions (RCP 2.6) – a range that represents the full spectrum of likely outcomes. Local sea level rise projections at tide gauges along the Bangladeshi coast are taken from [8], and interpolated into a continuous surface across Bangladesh by using values from the nearest neighbor tide gauge for each location. The global projections on which these local estimates are based closely match those found by the Intergovernmental Panel on Climate Change (IPCC) [9], but also include full probability distributions (including the tails) of potential ice sheet loss and sea level rise. Furthermore, [8] includes a local component to sea level rise, accounting for land subsidence and local sea surface dynamics by extrapolating historical differences between local and global trends, into the future.

After applying nearest-neighbor interpolation, the estimates of land subsidence in this work agree reasonably well with other recent literature in the area, e.g., [10] compaction, sedimentation and anthropogenic causes. It can have severe impacts and needs to be quantified and where possible (for subsidence due to anthropogenic causes, which lists Dhaka experiencing 5.9 (0.4–22.0) mm/yr (Kopp: 1.07 mm/yr), Khulna experiencing 3.5 (1.0–10.0) mm/yr (Kopp: 5.67 mm/yr), and Kolkata experiencing 8.6 (0.5–43.8) mm/yr (Kopp: 15.84 mm/yr). However, land subsidence rates can change significantly over small areas, as suggested by [10], [11] compaction, sedimentation and anthropogenic causes. It can have severe impacts and needs to be quantified and where possible (for subsidence due to anthropogenic causes, and so both [8] and this analysis offer just a broad estimate of this problem and its impacts.

We also note that more recent studies [12] suggest that if the West Antarctic Ice Sheet destabilizes before 2100, global sea levels could rise much faster than [8] predicted. In this scenario, the exposure described in this report could be reached decades earlier than expected.

Tidal Water Heights

This report approaches water height – and therefore exposure – in two different ways. First, sea level rise elevates the local high tide line (mean higher high water, or MHHW),

and all land and population under a new high tide line are considered permanently inundated. Alternatively, sea level rise makes coastal flooding more frequent, as the height of the average highest water level each year grows (mean annual maximum water level, or MAM). Land and population under this level might expect to be flooded every few years or more frequently, all the way up to and including permanent inundation.

Elevation Analysis

This analysis uses elevation data on a roughly 30-meter horizontal resolution grid derived from NASA's Shuttle Radar Topography Mission (SRTM). This is the highest resolution digital elevation model publically available in Bangladesh, and this analysis is the first Bengali coastal flood exposure assessment developed using this detailed model. However, SRTM provides surface elevations, not bare earth elevations, causing it to commonly overestimate elevations, especially in areas with dense and tall buildings [13] or vegetation [14]. Consequently, exposure estimates presented here could be interpreted as lower bounds of actual potential exposure, and true exposure could be twice as great or greater [15]. Furthermore, SRTM elevations, as distributed by NASA, are all rounded to the nearest meter (1-meter vertical resolution), making comparisons between similar water levels more challenging. For example, two water levels differing by 0.30 m might or might not show a difference in exposure when using unmodified SRTM, depending upon whether or not a 1-meter jump is crossed. That said, the use of a spatially and continuously varying zero-elevation reference based on local water height metrics, MHHW and MAM, as opposed to the standard SRTM zero-elevation reference, mitigates this issue to some extent, as does this report's focus on highly contrasting sea level rise scenarios.

Exposure Analysis

Using population density estimates with 1-km^2 resolution [16], this report assesses the total number of people today living on land at risk of permanent and/or frequent flooding by 2100 under each warming scenario. Place boundaries, defined by the Global Administrative Boundaries 2.0 dataset [17], delineate administrative areas at a number of levels, including the nation, divisions, districts, and subdistricts of Bangladesh. Analysis at very small spatial scales, such as in subdistricts, has been shown to perform poorly when using SRTM [15], and so this report will focus on the former (larger) three administrative levels.

Results do not account for present or future shoreline defenses, such as levees, that might be built, nor for future population growth, decline, or relocation. See Appendix for additional detail on methods.

Results

Global mean sea level rise is projected to reach 0.25m (0.18–0.33, 90% confidence interval) by 2050 and 0.50 m (0.29–0.82) by 2100 under RCP 2.6, or 0.29 m (21–38) by 2050 and 0.79 m (0.52–1.21) by 2100 under RCP 8.5, above a 2000 baseline [8]. However, other factors, such as land subsidence, will add to local relative sea level rise, in some locations dramatically. West of the Ganges Delta, relative rise could reach as high as 2.37m by 2100 under RCP 8.5, triple global SLR alone. Subsidence rates gradually drop to nearly zero east of the delta. Heights of the mean annual maximum water level also vary considerably along the coast – height ranges in each division are listed in Table 1.

Table 1. The ranges of mean annual maximum water level heights (MAM) above the high tide line (relative to MHHW) in each Bangladesh division.

DIVISION	MAM HEIGHT (M)
Barisal	0.20–1.03
Chittagong	0.71–1.40
Dhaka	0.46–0.91
Khulna	0.54–1.26
Rajshahi	0.87–1.27
Sylhet	0.80–1.40

By 2100, if carbon emissions this century continue to rise unabated, over 1,000 km2 of land area in Bangladesh could be permanently under the new high tide line, on which 8.6 lakh people currently live (Table 2). This corresponds to about 0.7% of Bangladesh's total area and 0.6% of the nation's total population. These numbers more than double when considering land and people exposed at least to frequent flooding below the mean annual maximum water level. If extreme cuts to emissions are enacted, the number of people and land area exposed during routine storm surge and tides could both drop by about 18%. However, even in the low emissions scenario, population exposure under the mean annual maximum water level is more than twice that of the present-day estimate (8.2 lakh people).

Table 2. Projected nationwide land and population exposure in 2050 and 2100, below the high tide line (MHHW) or the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP 2.6) vs. continued rising emissions (RCP 8.5). 90% confidence intervals in parentheses. The total national land area is roughly 136,000 km2, and the total population is about 1,561 lakh.

SCENARIO/ WATER REFERENCE	LAND (THOUSANDS KM²)		POPULATION (LAKH PEOPLE)	
	2050	2100	2050	2100
RCP 2.6, MHHW	0.6 (0.5–0.6)	0.8 (0.6–1.2)	4.7 (3.9–5.5)	7.2 (5.1–9.9)
RCP 8.5, MHHW	0.6 (0.5–0.7)	1.0 (0.8–1.8)	4.9 (4.1–5.7)	8.6 (6.4–15.6)
RCP 2.6, MAM	1.1 (1–1.4)	1.8 (1.2–2.3)	11.2 (9.5–13.9)	17.0 (11.0–22.2)
RCP 8.5, MAM	1.2 (1–1.4)	2.2 (1.5–3.1)	11.9 (9.9–14.4)	20.7 (15–31.6)

At the division level, Barisal, Chittagong, and Khulna are of similar risk in terms of total land area exposure, with confidence intervals broadly overlapping across locations (Table 3). However, Chittagong's dense, low-lying population makes it more vulnerable than the others, with over twice as many people on land at risk of permanent submergence as there are in Barisal and Khulna (Table 4, Figures 1–2), under a high emissions scenario. This is true despite the much slower rates of subsidence in Chittagong, compared to the western half of the country. Chittagong's population also faces flood risk during routine coastal tide surge, with an estimated 9.4 (8.0–15.7) lakh people exposed during the average maximum annual flood in 2100 (Figures 3–4). Further, Chittagong suffers a similar level of exposure even under reduced global emissions (<10% reduced median population exposure under RCP 2.6), in contrast to the other districts, such as Dhaka, which see strong benefits (36% reduced exposure under RCP 2.6). However, as described above, this discrepancy may also be explained by poor vertical resolution in the elevation model.

Our analysis also includes exposure estimates at the district level (Tables 4–5; Figures 5–8), though caution should be used in interpreting estimates at smaller spatial scales, due to wide and unpredictable errors in the digital elevation model [15]. Such data may be most useful in relative terms (i.e., identifying the most clearly at-risk locations, or potential change in exposure between water levels), rather than in their absolute values (exact land areas/populations affected). In this context, the district with the highest risk of frequent flooding by 2100 under RCP 8.5 is Chittagong, Chittagong, which sees more than 60% more people exposed than the second-highest district (Cox's Bazar, Chittagong). Across all districts of median exposure of one thousand people or more (RCP 8.5, MAM), reducing global emissions (RCP 2.6) reduces both permanent and routine storm surge population inundation by an average of 19%.

Table 3. Projected total land exposure in Bangladesh Divisions in 2100, below the high tide line (MHHW) or the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP 2.6) or continued rising emissions (RCP 8.5).

DIVISION	LAND (THOUSANDS KM²)				
	TOTAL	MHHW		MAM	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Barisal	9.6	0.2 (0.1–0.3)	0.3 (0.2–0.5)	0.4 (0.2–0.6)	0.5 (0.4–0.7)
Chittagong	30.8	0.3 (0.2–0.3)	0.3 (0.3–0.5)	0.6 (0.5–0.7)	0.7 (0.5–1)
Dhaka	29.8	0.1 (0.0–0.1)	0.1 (0.1–0.1)	0.1 (0.1–0.2)	0.2 (0.1–0.3)
Khulna	19.9	0.3 (0.2–0.4)	0.3 (0.3–0.6)	0.6 (0.3–0.8)	0.8 (0.5–1)
Rajshahi	33.7	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)
Sylhet	12.3	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.0)

Table 4. Projected total population exposure in Bangladesh Divisions in 2100, below the high tide line (MHHW) or the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP 2.6) or continued rising emissions (RCP 8.5).

DIVISION	POPULATION (LAKH PEOPLE)				
	TOTAL	MHHW		MAM	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Barisal	102.1	1.3 (0.7–1.9)	1.6 (1.1–3.3)	3.0 (1.5–4.0)	3.8 (2.6–5.4)
Chittagong	305.1	3.6 (2.4–4.4)	4.1 (3.1–6.7)	8.5 (6.4–10.6)	9.4 (8.0–15.7)
Dhaka	490.5	0.7 (0.6–1.0)	0.9 (0.7–1.4)	1.4 (1.0–2.2)	2.2 (1.4–3.2)
Khulna	184.1	1.6 (1.3–2.6)	2.0 (1.5–4.0)	3.9 (2.0–5.2)	5.1 (2.9–7.0)
Rajshahi	379.8	0.0 (0.0–0.0)	0.0 (0.0–0.1)	0.1 (0.1–0.1)	0.1 (0.1–0.2)
Sylhet	99.7	0.0 (0.0–0.0)	0.0 (0.0–0.0)	0.0 (0.0–0.1)	0.1 (0.0–0.1)

Conclusion

No matter which carbon emissions pathway the world follows, unless adequate protection is possible to put in place, Bangladesh is likely to experience major growth in damage caused by the rising tides and storms this century. In particular, the low-lying population centers in Chittagong appear to hold the greatest concentration of exposure risk, though every coastal division is threatened by high water levels. Furthermore, it must be emphasized that due to known errors in the elevation model, the values presented in this report may greatly underestimate future exposure, and actual damages could be significantly higher.

Table 4. Projected land exposure in Bangladesh Districts in 2100, below the high tide line (MHHW) and the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP 2.6) and continued rising emissions (RCP 8.5).

DISTRICT	LAND (KM²)				
	TOTAL	MHHW		MAM	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Bagerhat	3,023	26 (21–27)	37 (31–75)	34 (31–37)	79 (48–116)
Bandarbon	4,703	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Barisal	2,191	34 (21–46)	51 (43–133)	54 (51–130)	151 (129–201)
Bhola	1,786	44 (38–51)	70 (50–110)	81 (70–84)	129 (83–170)
Bogra	2,818	0 (0–0)	0 (0–1)	0 (0–0)	1 (1–1)
Borgona	1,357	24 (19–27)	39 (32–70)	36 (33–38)	74 (43–104)
Brahmanbaria	1,878	5 (5–5)	8 (5–16)	15 (15–15)	17 (15–42)
Chandpur	1,434	2 (1–3)	8 (3–10)	8 (8–9)	13 (9–15)
Chittagong	4,449	50 (47–62)	93 (60–140)	159 (134–184)	239 (172–351)
Choua Danga	1,155	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Comilla	3,117	2 (2–2)	3 (2–4)	4 (3–4)	4 (4–8)
Cox's Bazar	2,204	134 (119–140)	145 (135–239)	235 (225–239)	252 (236–383)
Dhaka	1,491	2 (1–2)	2 (2–4)	3 (2–4)	6 (4–13)
Dinajpur	3,469	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Faridpur	1,825	1 (1–1)	11 (11–15)	11 (11–11)	18 (15–22)
Feni	882	1 (1–2)	3 (1–3)	3 (3–3)	7 (3–7)
Gaibanda	2,058	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Gazipur	1,671	0 (0–0)	0 (0–1)	1 (1–1)	1 (1–2)
Gopalgonj	1,538	1 (1–3)	5 (4–21)	4 (4–5)	22 (21–90)
Hobiganj	2,560	1 (1–1)	1 (1–1)	1 (1–1)	2 (1–5)

Jaipurhat	966	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Jamalpur	2,014	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–1)
Jessore	2,516	7 (7–7)	26 (24–40)	10 (8–14)	76 (26–77)
Jhalakati	707	3 (2–4)	6 (5–14)	7 (6–7)	20 (8–24)
Jhenaidah	1,965	0 (0–0)	0 (0–1)	0 (0–0)	1 (0–1)
Khagrachari	2,747	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Khulna	3,295	45 (41–47)	84 (63–171)	68 (54–109)	181 (120–318)
Kishoreganj	2,411	2 (2–2)	2 (2–7)	4 (3–6)	7 (5–15)
Kurigram	2,109	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Kustia	1,623	1 (1–1)	1 (1–1)	1 (1–1)	4 (2–4)
Lakshmipur	1,186	1 (0–3)	3 (3–6)	4 (3–6)	6 (6–13)
Lalmonirhat	1,211	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Madaripur	1,006	0 (0–1)	3 (1–5)	3 (3–3)	9 (5–18)
Magura	1,036	1 (0–1)	1 (1–4)	1 (1–1)	5 (1–5)
Manikgonj	1,210	1 (1–1)	18 (18–22)	18 (18–18)	22 (22–27)
Meherpur	735	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Moulvibazar	2,677	0 (0–0)	0 (0–0)	0 (0–1)	1 (1–1)
Munshigonj	816	4 (2–4)	7 (4–10)	9 (8–10)	13 (10–17)
Naogaon	3,426	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Narail	949	5 (4–5)	16 (16–49)	7 (5–16)	50 (16–51)
Naray Angonj	732	2 (1–2)	2 (2–4)	3 (2–4)	4 (4–7)
Narshingdi	1,107	1 (1–2)	4 (2–5)	4 (4–4)	6 (4–7)
Nasirabad	4,268	0 (0–0)	1 (0–1)	1 (1–1)	1 (1–1)
Natore	1,900	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
Nawabganj	1,646	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Netrakona	2,845	1 (1–1)	1 (1–2)	2 (1–2)	2 (2–6)
Nilphamari	1,671	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Noakhali	2,735	40 (34–44)	51 (44–88)	94 (71–103)	119 (102–199)
Pabna	2,320	2 (2–2)	5 (5–8)	5 (5–5)	9 (8–11)
Panchagarh	1,391	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Parbattya Ch.	5,434	0 (0–0)	0 (0–0)	0 (0–0)	1 (0–1)
Patuakhali	2,406	35 (32–38)	80 (44–112)	57 (48–71)	116 (70–164)
Pirojpur	1,202	12 (8–12)	20 (12–37)	13 (13–16)	38 (32–69)
Pirojpur	518	9 (9–9)	13 (9–14)	9 (9–11)	14 (13–26)
Rajbari	1,061	1 (1–1)	3 (3–5)	3 (3–3)	5 (5–6)
Rajshahi	2,317	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Rongpur	2,323	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Shariatpur	1,122	4 (4–5)	36 (5–36)	36 (36–36)	46 (36–47)
Shatkhira	3,090	87 (70–92)	162 (114–277)	141 (129–184)	364 (225–439)

Sherpur	1,325	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Sirajgonj	2,278	2 (2–2)	3 (3–5)	3 (3–3)	5 (5–9)
Sun Amgonj	3,598	3 (3–4)	5 (4–8)	7 (5–8)	12 (8–20)
Sylhet	3,418	1 (0–1)	1 (1–1)	1 (1–1)	1 (1–2)
Tangail	3,397	0 (0–0)	1 (1–2)	1 (1–1)	2 (2–3)
Thakurgaon	1,819	0.0 (0.0–0.0)	0 (0–0)	0 (0–0)	0 (0–0)

Table 5. Projected population exposure in Bangladesh Districts in 2100, below the high tide line (MHHW) and the mean annual maximum flood level (MAM), given sharp carbon cuts (RCP 2.6) and continued rising emissions (RCP 8.5).

DISTRICT	POPULATION (THOUSANDS OF PEOPLE)				
	TOTAL	MHHW		MAM	
		RCP 2.6	RCP 8.5	RCP 2.6	RCP 8.5
Bagerhat	1,753	13 (11–29)	14 (12–46)	41 (13–50)	47 (24–70)
Bandarbon	223	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Barisal	2,904	41 (16–43)	43 (37–129)	134 (44–140)	140 (125–187)
Bhola	2,097	22 (10–31)	28 (20–46)	47 (33–71)	68 (35–90)
Bogra	3,780	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Borgona	1,067	21 (14–32)	25 (18–48)	30 (24–62)	52 (27–79)
Brahmanbaria	3,023	6 (5–14)	8 (5–14)	14 (13–19)	15 (13–33)
Chandpur	2,837	9 (2–10)	10 (8–14)	19 (11–22)	21 (12–26)
Chittagong	8,450	156 (81–203)	189 (112–287)	447 (301–573)	519 (416–863)
Choua Danga	1,252	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Comilla	5,798	4 (3–4)	4 (4–6)	6 (5–7)	7 (5–11)
Cox's Bazar	2,242	171 (146–186)	176 (166–303)	303 (283–376)	324 (301–496)
Dhaka	10,736	8 (7–9)	8 (8–21)	21 (13–24)	24 (21–60)
Dinajpur	3,318	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Faridpur	2,213	3 (3–3)	3 (3–5)	6 (3–32)	32 (5–32)
Feni	1,533	2 (1–3)	3 (1–3)	4 (3–7)	6 (3–8)
Gaibanda	2,684	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Gazipur	2,513	0 (0–1)	0 (0–1)	1 (1–1)	1 (1–2)
Gopalgonj	1,469	2 (1–2)	2 (2–10)	10 (2–11)	11 (10–44)
Hobiganj	2,200	0 (0–1)	0 (0–1)	1 (1–1)	1 (1–3)
Jaipurhat	1,071	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Jamalpur	2,635	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Jessore	3,103	15 (7–17)	17 (15–24)	19 (17–48)	48 (17–48)
Jhalakati	875	6 (4–8)	6 (5–15)	18 (7–23)	23 (9–28)
Jhenaidah	1,979	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Khagrachari	646	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)

Khulna	2,983	34 (27–83)	48 (33–115)	95 (41–132)	120 (84–243)
Kishoreganj	3,265	1 (1–4)	1 (1–4)	5 (2–5)	5 (3–9)
Kurigram	2,264	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Kustia	2,177	0 (0–0)	0 (0–0)	2 (0–2)	2 (0–2)
Lakshmipur	1,868	2 (1–2)	2 (2–6)	6 (3–6)	6 (6–17)
Lalmonirhat	1,388	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Madaripur	1,427	0 (0–2)	2 (0–3)	3 (2–44)	43 (3–47)
Magura	1,036	1 (1–1)	1 (1–2)	1 (1–3)	3 (1–3)
Manikgonj	1,597	33 (33–33)	33 (33–34)	34 (34–34)	34 (34–38)
Meherpur	747	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Moulvibazar	2,032	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–1)
Munshigonj	1,607	9 (3–12)	12 (7–16)	16 (12–18)	18 (16–23)
Naogaon	2,996	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Narail	874	8 (8–9)	8 (8–26)	17 (8–27)	27 (9–27)
Naray Angonj	2,730	7 (5–7)	7 (7–18)	18 (8–19)	18 (18–29)
Narshingdi	2,391	3 (0–4)	3 (2–4)	5 (3–6)	5 (3–6)
Nasirabad	5,614	0 (0–0)	0 (0–0)	1 (0–1)	1 (0–1)
Natore	1,907	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Nawabganj	1,807	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Netrakona	2,503	0 (0–1)	1 (0–1)	1 (1–1)	1 (1–2)
Nilphamari	1,981	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Noakhali	3,243	11 (5–14)	13 (10–34)	45 (26–46)	46 (43–111)
Pabna	2,733	1 (1–1)	1 (1–6)	6 (1–6)	6 (6–7)
Panchagarh	1,086	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Parbattya Ch.	648	1 (0–1)	1 (0–1)	1 (1–2)	1 (1–2)
Patuakhali	1,833	23 (16–37)	32 (20–53)	33 (24–62)	54 (30–79)
Pirojpur	1,435	13 (12–35)	23 (13–39)	39 (16–40)	40 (33–73)
Pirojpur	141	2 (2–6)	5 (2–6)	6 (2–6)	6 (6–17)
Rajbari	1,183	0 (0–0)	0 (0–1)	1 (0–1)	1 (1–1)
Rajshahi	2,861	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Rongpur	3,199	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Shariatpur	1,414	2 (1–18)	18 (1–18)	18 (18–23)	22 (18–23)
Shatkhira	2,369	86 (72–119)	106 (76–185)	212 (114–255)	255 (147–293)
Sherpur	1,610	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)
Sirajgonj	3,383	3 (3–3)	3 (3–5)	5 (5–5)	5 (5–9)
Sun Amgonj	2,519	1 (1–2)	1 (1–2)	2 (2–3)	3 (2–5)
Sylhet	3,219	1 (0–1)	1 (0–1)	1 (1–1)	1 (1–2)
Tangail	4,143	1 (0–1)	1 (0–1)	1 (1–2)	2 (1–2)
Thakurgaon	1,520	0 (0–0)	0 (0–0)	0 (0–0)	0 (0–0)

Appendix

Additional Detail on Methods

In order to work with elevation and population datasets available in Bangladesh, this report reprocesses certain datasets to function better in the context of coastal flood risk assessment. More specifically, we convert a global elevation data source (SRTM) to vertically reference tidal datums, and refine a global population density raster (LandScan) to fit to the shape of the Bengali coastline.

As distributed by NASA, the 1-arcsecond SRTM 3.0 elevation model [18] is referenced to the EGM96 geoid (SRTMEGM96), which we first convert to reference the WGS84 ellipsoid.. The analysis employs a series of steps to develop a conversion grid between WGS84 and two local tidal datums, mean higher-high water (MHHW) and mean annual maximum water level (MAM). The same steps are performed with both datums, so we denote the tidal datum with the variable TD.

- Begin with the global 2-arcminute mean sea surface MSS_CNES_CLS_11 (Aviso 2014) based on 16 years of satellite altimetry observations (1993–2009), referenced to the Topex-Poseidon ellipsoid, and here called MSLTP;

- Employ a global TD grid, TDMSL, referenced to the MSL tidal datum, provided by Mark Merrifield of the University of Hawaii, and developed using the model TPXO8 at 2-arcminute resolution (Egbert et. al, 2002);

- Upsample these grids to 1-arcsecond SRTM resolution using nearest-neighbor interpolation;

- Convert MSLTP to reference the WGS84 ellipsoid, and compute the final conversion grid, TDWGS84 = MSLWGS84 + TDMSL;

- Subtract TDWGS84 from SRTMWGS84 to produce elevation maps referenced to the local tidal datum, SRTMTD; and

- Compute a series of flood maps by thresholding SRTMTD to local sea level rise projections [8], interpolated using nearest neighbor.

For population density data, this analysis employs the LandScan edition for 2010, produced by Bright et al. (2011), which provides total estimated populations living

in 1 km square cells across Bangladesh. The SRTM Water Body Dataset (SWBD) is utilized to define land cells at SRTM resolution. For each cell in LandScan, the analysis counts the number of SWBD-defined land pixels within it, and divides the cell population by the count to find per-pixel population density. A new raster, LSDensity, is thus defined, georeferenced identically to SRTM, and in which each pixel is set to zero if SWBD defines it as non-land, or otherwise is set to its population density.

Figures

Figure 1. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely number of people currently living under the projected high tide line in 2100 in Bangladesh divisions, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).


Population Exposure in 2100
(RCP 2.6, 5% MAM)

Population Exposure in 2100
(RCP 8.5, 5% MAM)

Population Exposure in 2100
(RCP 2.6, 95% MAM)

Population Exposure in 2100
(RCP 8.5, 95% MAM)

Lakh People
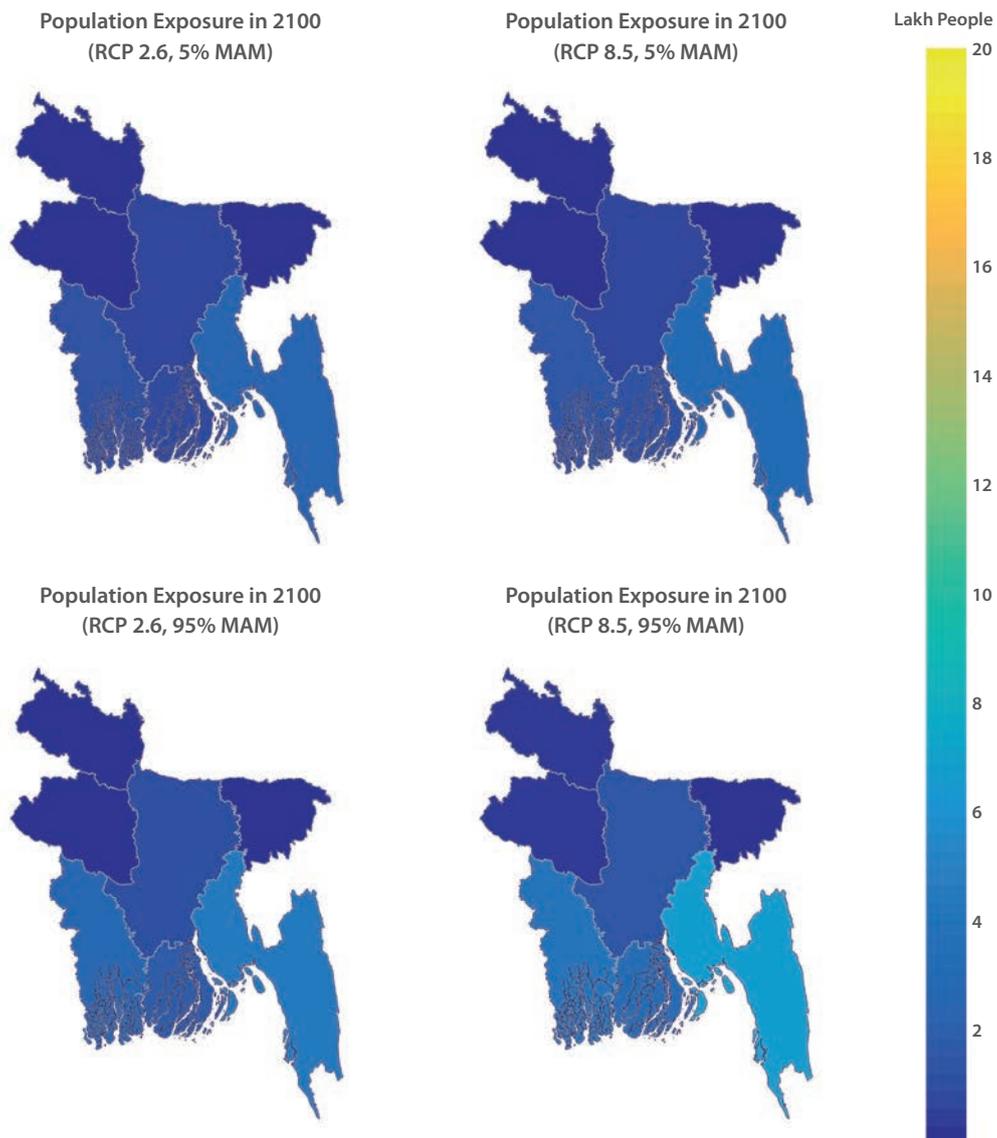
Figure 2. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely number of people currently living under the projected mean annual maximum water level in 2100 in Bangladesh divisions, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).


Population Exposure in 2100
(RCP 2.6, 5% MAM)

Population Exposure in 2100
(RCP 8.5, 5% MAM)

Population Exposure in 2100
(RCP 2.6, 95% MAM)

Population Exposure in 2100
(RCP 8.5, 95% MAM)

Lakh People
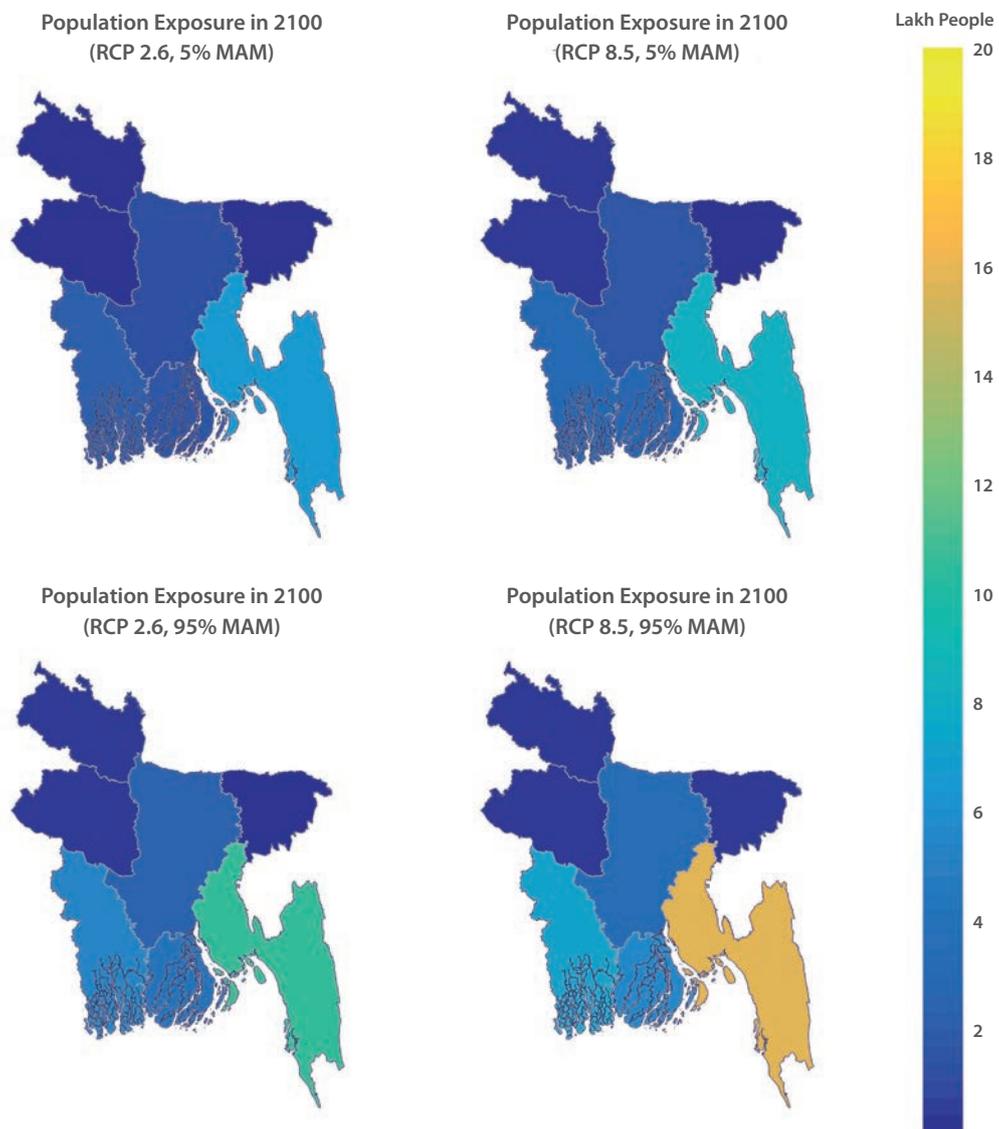
Figure 3. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely number of people currently living under the projected high tide line in 2100 in Bangladesh districts, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).


Population Exposure in 2100
(RCP 2.6, 5% MAM)

Population Exposure in 2100
(RCP 8.5, 5% MAM)

Population Exposure in 2100
(RCP 2.6, 95% MAM)

Population Exposure in 2100
(RCP 8.5, 95% MAM)

Lakh People
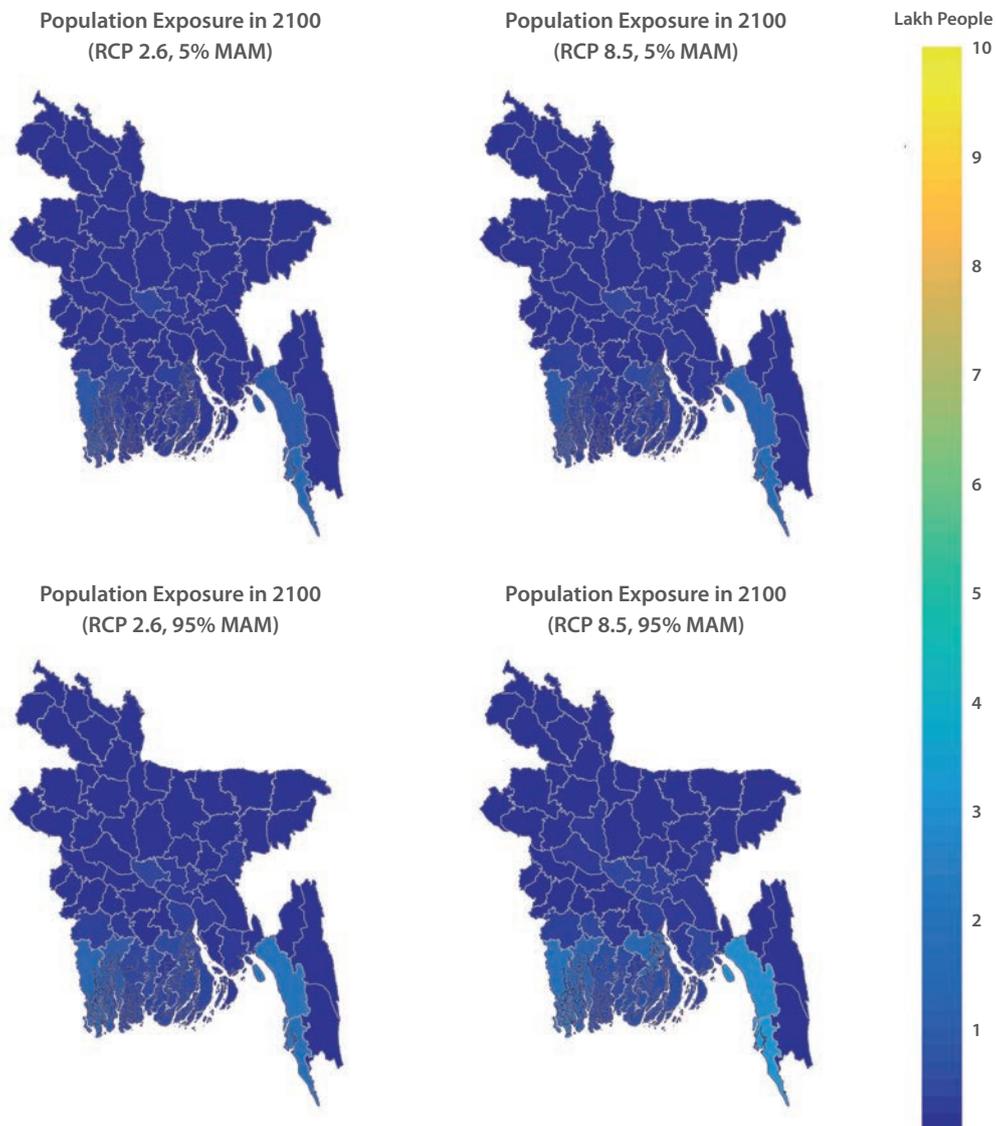
Figure 4. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely number of people currently living under the projected mean annual maximum water level in 2100 in Bangladesh districts, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).


Population Exposure in 2100 (RCP 2.6, 5% MAM)

Population Exposure in 2100 (RCP 8.5, 5% MAM)

Population Exposure in 2100 (RCP 2.6, 95% MAM)

Population Exposure in 2100 (RCP 8.5, 95% MAM)

Lakh People
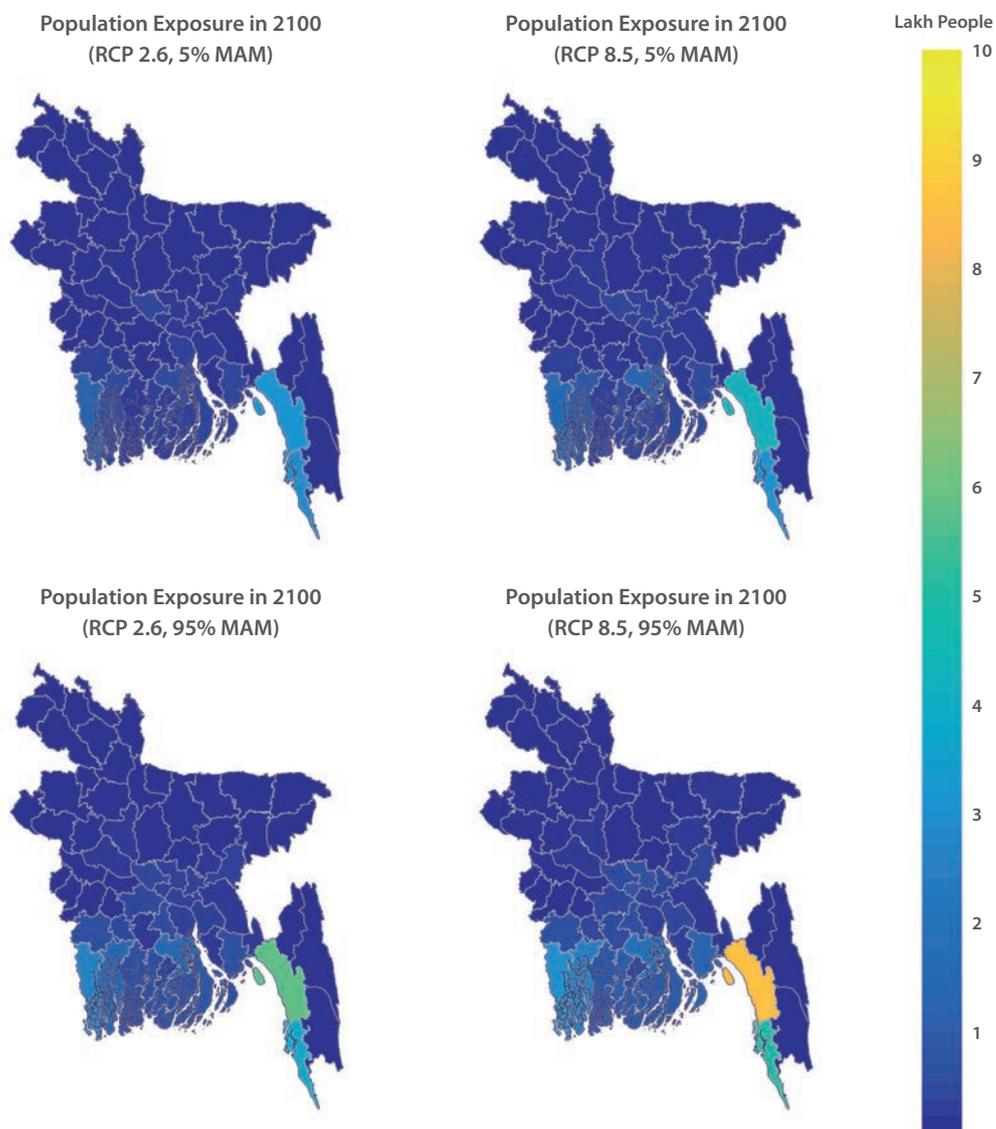
Figure 5. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely amount of land area under the projected high tide line in 2100 in Bangladesh divisions, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).

Population Exposure in 2100
(RCP 2.6, 5% MHHW)

Population Exposure in 2100
(RCP 8.5, 5% MHHW)

Population Exposure in 2100
(RCP 2.6, 95% MHHW)

Population Exposure in 2100
(RCP 8.5, 95% MHHW)
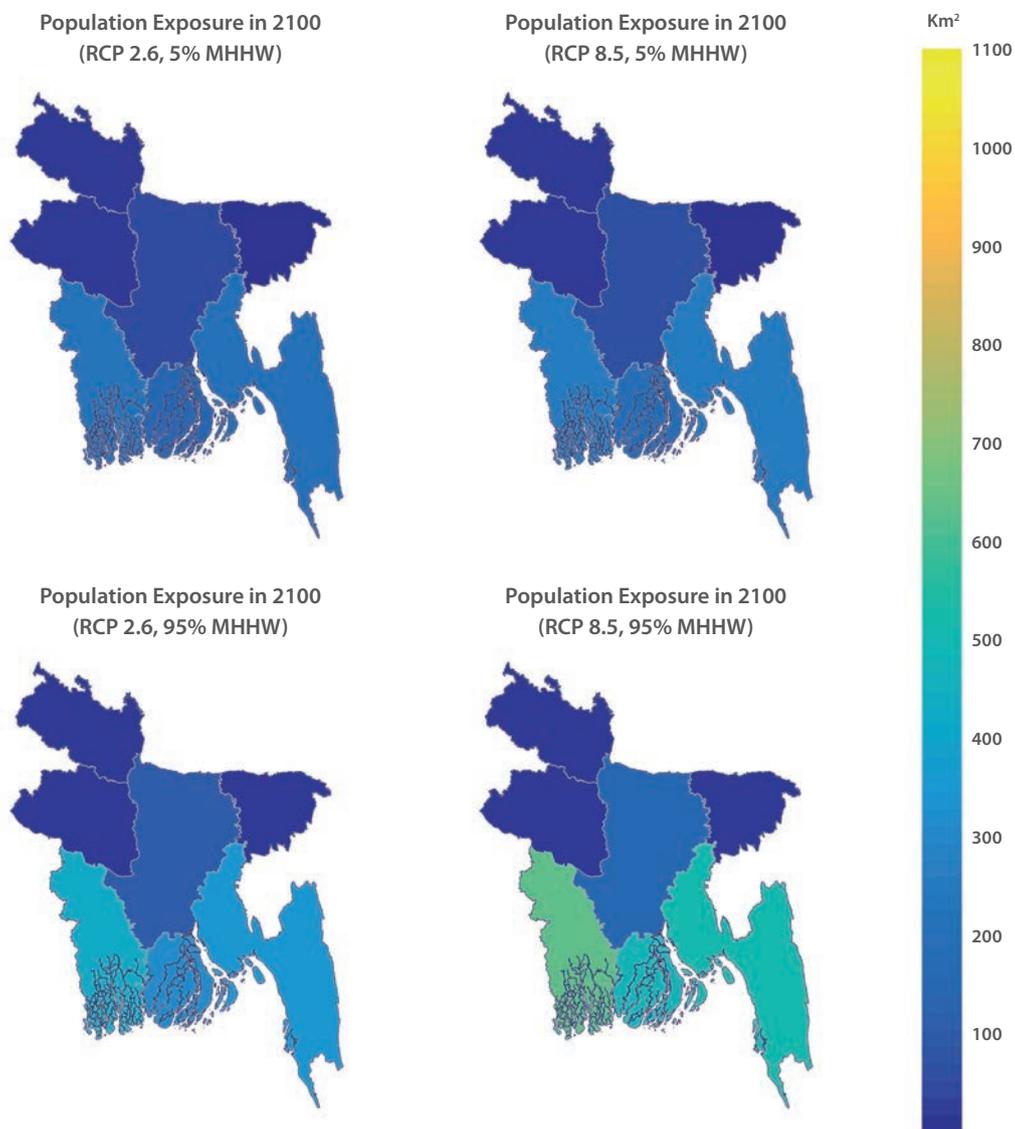
Figure 6. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely amount of land area under the projected mean annual maximum water level in 2100 in Bangladesh divisions, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).

Population Exposure in 2100
(RCP 2.6, 5% MAM)

Population Exposure in 2100
(RCP 8.5, 5% MAM)

Population Exposure in 2100
(RCP 2.6, 95% MAM)

Population Exposure in 2100
(RCP 8.5, 95% MAM)

Km²
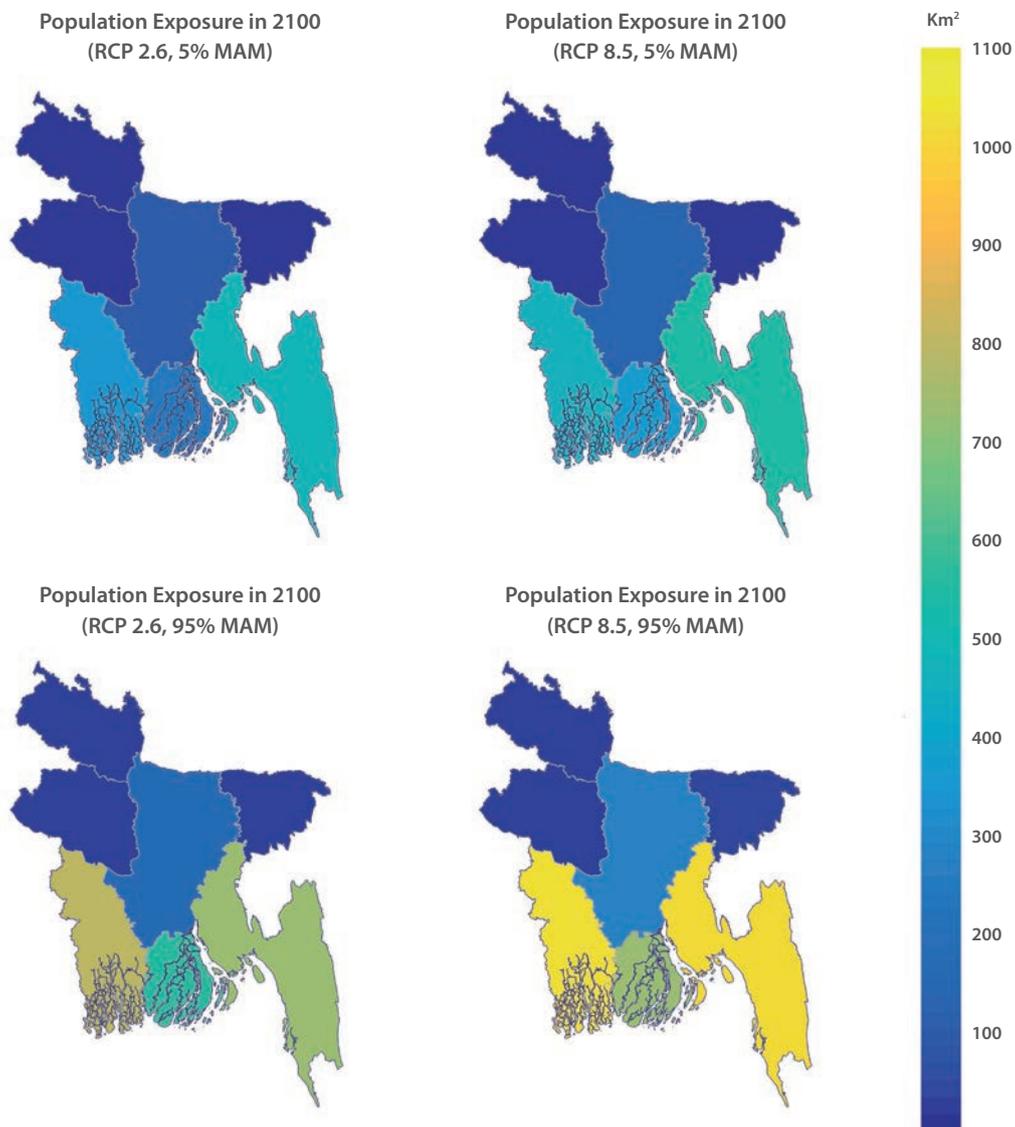
Figure 7. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely amount of land area under the projected high tide line in 2100 in Bangladesh districts, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).

Population Exposure in 2100
(RCP 2.6, 5% MHHW)

Population Exposure in 2100
(RCP 8.5, 5% MHHW)

Population Exposure in 2100
(RCP 2.6, 95% MHHW)

Population Exposure in 2100
(RCP 8.5, 95% MHHW)

Km²
500
450
400
350
300
250
200
150
100
50
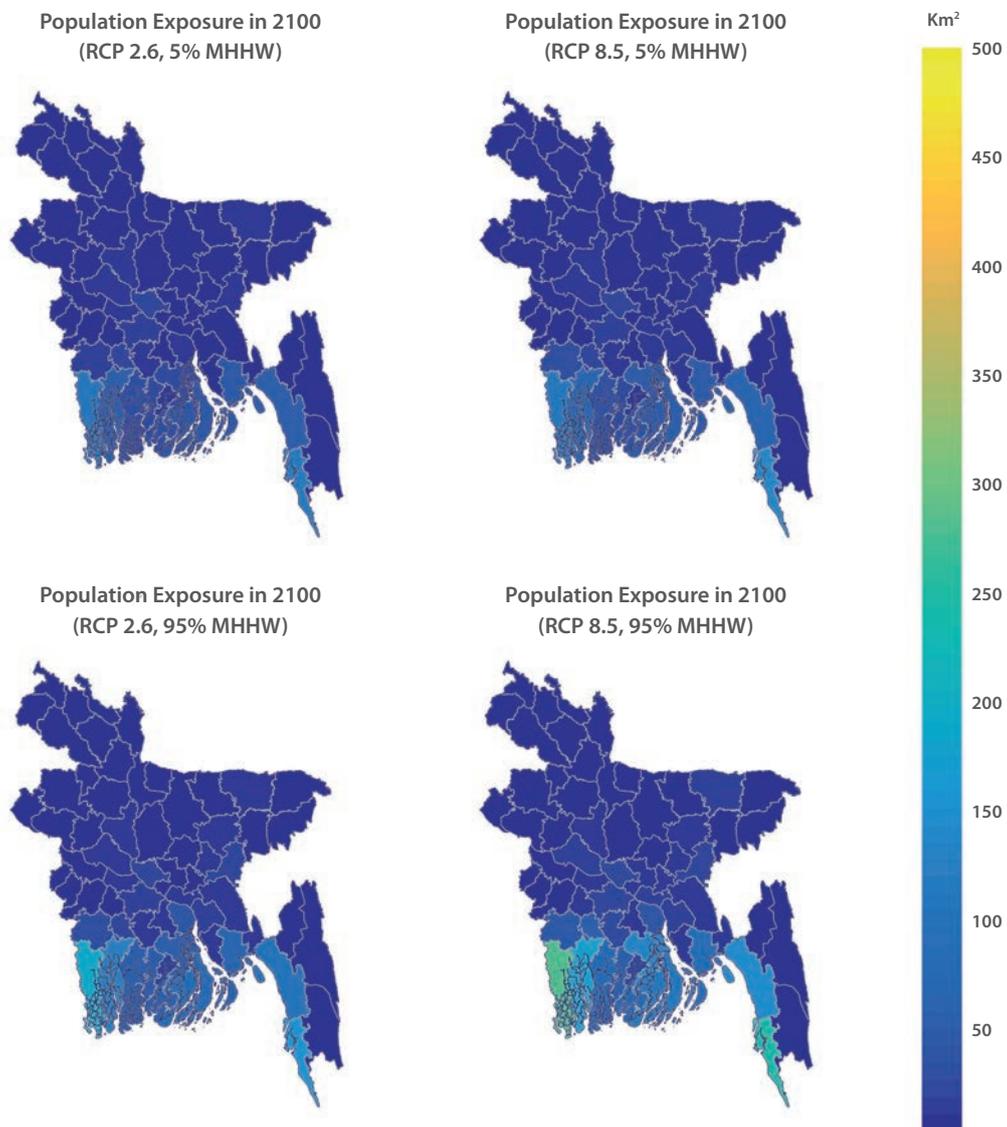
Figure 8. Lowest (5th percentile, top) and highest (95th percentile, bottom) likely amount of land area under the projected mean annual maximum water level in 2100 in Bangladesh districts, under emissions scenarios RCP 2.6 (large, immediate cuts to global emissions) and RCP 8.5 (global emissions continue to rise unabated).

Population Exposure in 2100 (RCP 2.6, 5% MAM)

Population Exposure in 2100 (RCP 8.5, 5% MAM)

Population Exposure in 2100 (RCP 2.6, 95% MAM)

Population Exposure in 2100 (RCP 8.5, 95% MAM)

Km²

500
450
400
350
300
250
200
150
100
50
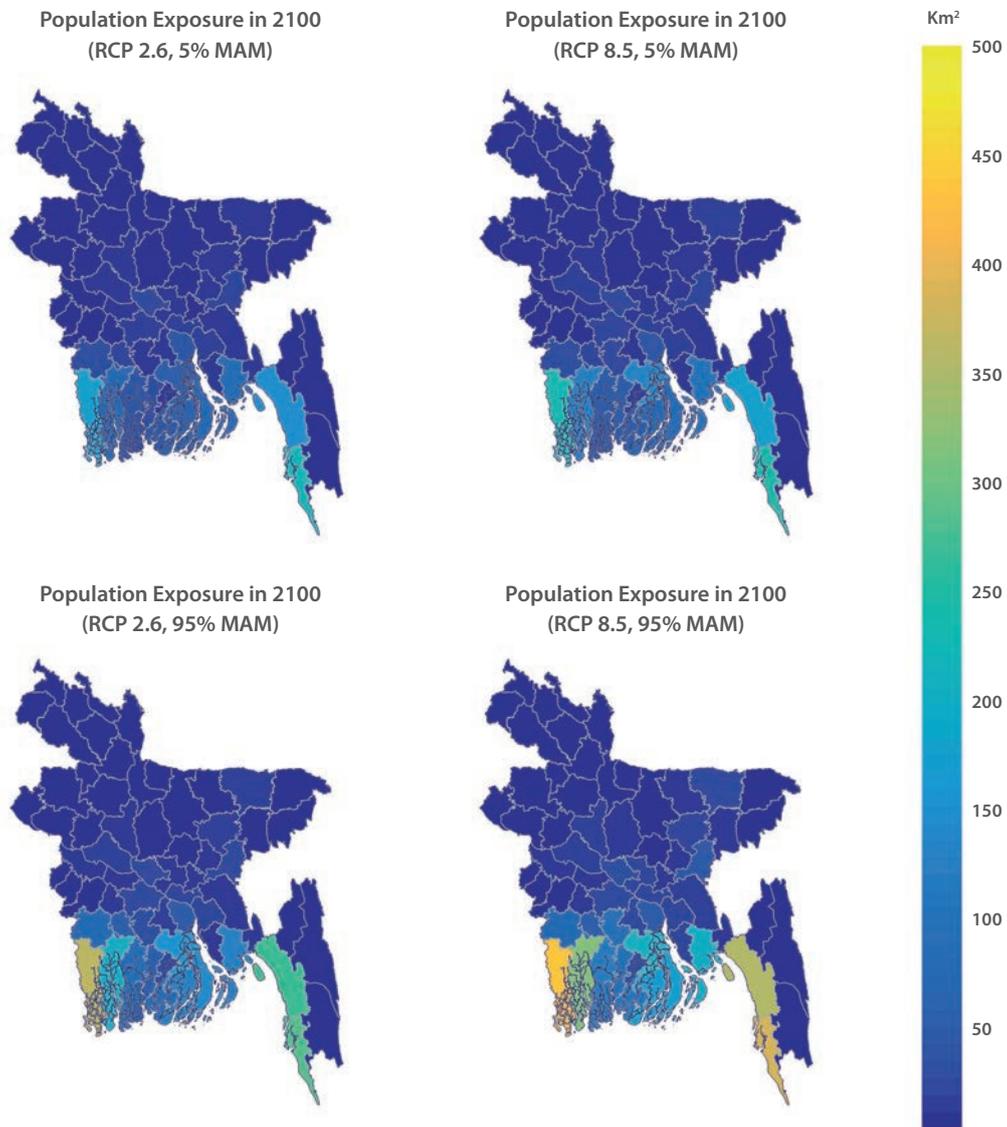
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