The Impacts of Climate Change on the Poor in Disadvantaged Regions

Edward B. Barbier* and Jacob P. Hochard†

Introduction

The literature on the impacts of climate change on poverty suggests that there are two key vulnerable groups in the rural areas of developing countries: people living in less-favored agricultural areas (LFAAs) and people living in rural low-elevation coastal zones (LECZs) (Skoufias, Rabassa, and Olivieri 2011; de Sherbinin 2014; IPCC 2014; Barbier 2015; Hallegatte et al. 2015). LFAAs include agricultural lands that are constrained by difficult terrain, poor soil quality, or limited rainfall (referred to as less-favored agricultural lands) and any favorable agricultural land with limited access to markets (i.e., five hours or more travel to a market city with a population of at least 50,000). LECZs refer to contiguous areas along coasts that have less than 10 meters elevation and are thus most vulnerable to sea level rise and other coastal hazards, such as storm surges, coastal erosion, and saltwater intrusion. The populations in these two types of locations are vulnerable not only to short-lived hazards with immediate and often extreme impacts, such as flooding, droughts, and storm surges, but also to long-term climatic changes with more gradual impacts, such as precipitation and temperature change, sea level rise, saltwater intrusion, and erosion (IPCC 2014; de Sherbinin 2014; Barbier 2015; Hallegatte et al. 2015, 2017). Moreover, many of the natural resource systems on which rural households in these marginal areas depend are impacted by climate change disruptions and hazards such as droughts, floods, varying temperatures and rainfall, and sea level rise (Hertel and Rosch 2010; Barbier 2015).

To date, there has been no comprehensive review of the implications of climate change for poverty in specific disadvantaged regions, such as LFAAs and rural LECZs, that are particularly vulnerable to poverty-environment traps (i.e., overreliance on marginal agricultural land and resource commons, which leads to stagnant, low incomes). This article conducts and presents the findings of such a review. We will show that although the populations in LFAAs and rural LECZs have a high incidence of poverty (the percentage of a given population living in poverty), this incidence—at least as proxied by infant mortality rates—may not necessarily be higher than those of the rural population generally. We will argue that the

*Department of Economics, Colorado State University, Fort Collins, CO 80523-1771; Tel: +1 (970) 491-6324; Fax: +1 (970) 491-2925; e-mail: edward.barbier@colostate.edu.
†Department of Economics, Brewster Building A-427 and Institute for Coastal Science and Policy (ICSP), Flanagan Building Suite 250, East Carolina University, Greenville, NC 27858; Tel: +1 252-328-6383; Fax: +1 252-328-6743; e-mail: Hochardj15@ecu.edu.

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main reason LFAA and rural LECZ populations are vulnerable to climate change impacts is that the marginal environmental conditions faced by poor populations in these regions make them particularly susceptible to poverty-environment traps (Barbier 2010, 2015; Hallegatte et al. 2015). For example, the World Bank (2008, p. 49) concludes that "the extreme poor in more marginal areas are especially vulnerable" and "one concern is the existence of geographical poverty traps." Similarly, Kraay and McKenzie (2014, p. 143) suggest that "the evidence most consistent with poverty traps comes from poor households in remote rural regions." The most common environmental characteristics that lead to such vulnerability to poverty-environment traps include the prevalence of marginal agricultural lands, forests, and woodland areas; LECZs; arid zones that are less suitable for agricultural production; and a lack of access to markets and infrastructure, which may constrain the ability of poor households to improve their farming systems and livelihoods or obtain off-farm employment (Hertel and Rosch 2010; de Sherbinin 2014; Barbier 2015; Hallegatte et al. 2015). This means that the existence of poverty-environment traps among rural populations in LFAAs and LECZs further increases their vulnerability to the environmental and economic impacts of climate change.

Using infant mortality rates as a proxy for poverty, we first estimate both the extent and incidence of high infant mortality in 2000 and 2010 in LFAAs and LECZs, respectively, across developing countries and then analyze the main trends between 2000 and 2010.[1] Then, drawing on available case studies, we examine the evidence concerning the economic and environmental impacts of climate change on the rural poor in LFAAs and LECZs. In particular, we explore how such impacts can reinforce the poverty-environment trap faced by some households or, for many others, tip them into the trap. We also examine how poverty-environment traps increase the vulnerability of these households to climate change impacts. Finally, we compare and contrast alternative policy strategies for reducing climate change impacts on poverty among LFAA and rural LECZ households.

Infant Mortality in Less-Favored Agricultural Areas

Several studies of the spatial location of populations in developing countries indicate that it is the rural poor whose livelihoods are most dependent on less-favored lands and/or less-favored areas (CGIAR 1999; Pender and Hazell 2000; World Bank 2003, 2008; Fan and Chan-Kang 2004; CAWMA 2008; Pender 2008; Barbier 2010). These two land classifications—less-favored lands and less-favored areas—are related (Pender and Hazell 2000). More specifically, less-favored agricultural lands refers to lands that are susceptible to low productivity and degradation because their agricultural potential is constrained *biophysically* by terrain, poor soil quality, or limited rainfall (see boxes A and B in figure 1). LFAAs include *all* less-favored agricultural lands plus any favorable agricultural land that is also remote—that is, land in rural areas with high agricultural potential but with limited access to infrastructure and markets (see box D in figure 1). LFAAs are indicated by the shaded grey boxes (A, B, and D) in figure 1.

[1]Full details of the geospatially referenced data and methods used in this analysis are available in the online supplementary materials.

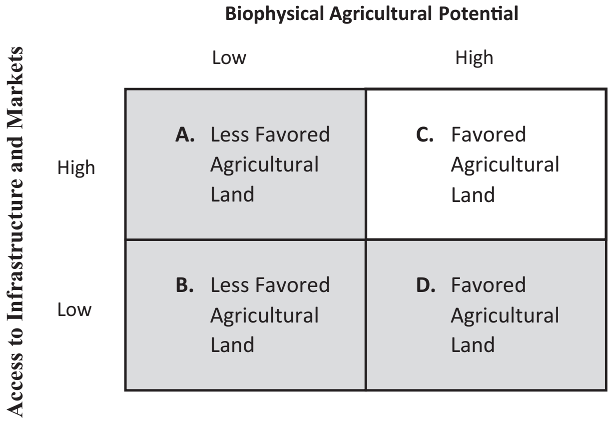


Figure 1 Classification of less-favored agricultural lands and areas
Source: Based on the definition and classification of less-favored areas in Pender and Hazell (2000).

In the remainder of this section, we first review past studies of the number of people living in the less-favored rural areas of developing countries. We then outline our methodology for estimating the extent and incidence of poverty (using infant mortality as a proxy) among rural populations in LFAAs for 2000 and 2010 and present our key findings. We conclude this section by discussing the resulting patterns in the rate of infant mortality in LFAAs.

Past Efforts to Estimate Populations Living in LFAAs

The CGIAR (1999; formerly the Consultative Group for International Agricultural Research) estimated that nearly two-thirds of the rural population of developing countries—almost 1.8 billion people—live on marginal agricultural lands, forest and woodland areas, and arid zones. By applying national rural poverty percentages, the CGIAR (1999) determined that 633 million poor people in developing countries lived on less-favored lands, or around two-thirds of the total rural poor (also see CAWMA 2008). A subsequent analysis (World Bank 2003) estimated that nearly 1.3 billion people in 2000—almost one-fifth of the world's population—lived on less-favored lands in developing regions and concluded that since 1950 the estimated population in developing countries living on marginal lands may have doubled. The World Bank (2008) later estimated that in 2000 approximately 430 million people in developing countries lived in rural areas requiring five or more hours of travel to reach a market town of 5,000 or more, and nearly half (49 percent) of these populations were located in arid and semiarid regions characterized by frequent moisture stress that limits agricultural production.

A key limitation of these studies is that their population estimates are for one year only, and the most recent are for 2000. In addition, none of these studies estimate the extent and incidence of poverty in such disadvantaged regions, although the CGIAR (1999) study provides approximations. Finally, the studies also vary in terms of the type of populations measured. For example, World Bank (2003) estimates the total population living on less-favored lands (boxes A and B in figure 1), whereas World Bank (2008) measures the population with poor market access (boxes B and D in figure 1).

Methodology for Estimating Infant Mortality in LFAAs

We improve on these past studies by constructing a new global dataset based on a variety of global spatially referenced datasets[2] to estimate the rural population living in LFAAs (boxes A, B, and D in figure 1) and the differing rates of infant mortality among these populations in both 2000 and 2010. Following the classification of figure 1, LFAAs comprise all less-favored agricultural land plus any favored agricultural land located in remote regions with poor market access (i.e., boxes A, B, and D in figure 1). Less-favored agricultural land consists of irrigated land on terrain with greater than 8 percent median slope, rain-fed land with a length of growing period (LGP) of more than 120 days but either on terrain with greater than 8 percent median slope or with poor soil quality, semiarid land (land with an LGP of 60 to 119 days), and arid land (land with an LGP less than 60 to 119 days). Market accessibility was used to identify remote favored agricultural land following Nelson (2008), which identifies adequate market access as less than five hours of travel to a market city with a population of 50,000 or more.

We identify the rates of infant mortality among populations in LFAAs for 2000 and 2010 using geospatially referenced infant mortality data. Infant mortality rates (IMRs) measure the number of deaths of infants younger than age 1 year per 1,000 live births in a given year. In the absence of globally gridded datasets for income- or consumption-based measures of poverty, IMRs serve as a useful proxy for overall poverty levels because they are highly correlated with important poverty-related metrics such as income, education levels, and health status (de Sherbinin 2008; Sartorius and Sartorius 2014; Barbier 2015; Fritzell et al. 2015). We consider areas with an IMR of at least 32 deaths per 1,000 live births to have high infant mortality and areas with more than 65 deaths to have extremely high infant mortality.[3]

Findings Concerning Infant Mortality in LFAAs

We found that in 2010 there were approximately 1.6 billion people living in LFAAs in developing countries, or around 37 percent of the total rural population (see table 1). Of this LFAA population, 586 million are in areas with at least 32 infant deaths per 1,000 live births, which suggests an incidence of high IMR of about 37 percent. Most of the LFAA populations with high infant mortality live in low-income (216 million) and lower middle-income countries (315 million). In low-income countries, the incidence of high IMR in LFAAs exceeds 90 percent, whereas it is around 53 percent in lower middle-income countries and only 7 percent in upper middle-income countries. This suggests that the extent and incidence of high infant mortality in LFAAs are correlated with the overall level of economic development.

Sub-Saharan Africa (240 million) and South Asia (242 million) account for most of the world's LFAA population with high infant mortality (see table 1). Virtually all (98 percent) of the LFAA population in sub-Saharan Africa and around 72 percent of the LFAA population in

[2]These include datasets from the Center for International Earth Science Information Network (CIESIN), NASA's Socioeconomic Data and Applications Center (SEDAC), the European Commission's Global Environment Monitoring Unit, the Pilot Analysis of Global Ecosystem (PAGE), and the United Nations Food and Agriculture Organization's Global Agro-Ecological Zones (GAEZ) Data Portal. See the online supplementary materials for detailed data and methods.

[3]These threshold designations are similar to those in other studies that have used the CIESN 2000 infant mortality gridded dataset (de Sherbinin 2008; Barbier 2015), which is the dataset we have used here.

Table 1 High infant mortality (HIM) among less-favored agricultural area (LFAA) populations, 2010

	LFAA population (millions)	Share (%) of rural population in LFAA	LFAA populations with HIM (millions)			HIM incidence (%) in LFAA			2000–2010 change (%) in LFAA			
			32–65	>65	Total	32–65	>65	Total	Population	32–65	>65	Total
Developing country	**1,579.8**	**37.2%**	**455.6**	**130.6**	**586.2**	**28.8%**	**8.3%**	**37.1%**	**14.3%**	**−0.8%**	**−66.6%**	**−31.1%**
By income												
Low income	239.0	33.3%	138.8	77.3	216.1	58.1%	32.4%	90.4%	34.1%	230.1%	−43.2%	21.2%
Lower middle income	594.4	32.6%	267.0	47.7	314.7	44.9%	8.0%	52.9%	21.0%	28.0%	−74.4%	−20.3%
Upper middle income	746.4	43.8%	49.9	5.6	55.4	6.7%	0.7%	7.4%	4.7%	−76.1%	−91.9%	−80.0%
By region												
East Asia and Pacific	739.7	49.3%	74.2	3.5	77.7	10.0%	0.5%	10.5%	9.9%	−64.1%	−94.9%	−71.9%
Europe and Central Asia	98.5	54.5%	8.7	0.9	9.6	8.8%	0.9%	9.7%	1.4%	−80.7%	0.0%	−80.4%
Latin America and Caribbean	111.7	33.2%	6.9	1.2	8.2	6.2%	1.1%	7.3%	15.2%	−73.1%	−86.5%	−76.6%
Middle East and North Africa	50.9	21.4%	8.4	0.8	9.2	16.4%	1.7%	18.1%	12.4%	−63.7%	−81.8%	−66.7%
South Asia	335.3	26.1%	232.7	9.5	242.1	69.4%	2.8%	72.2%	15.2%	75.1%	−93.7%	−14.4%
Sub-Saharan Africa	243.8	34.3%	124.8	114.7	239.5	51.2%	47.1%	98.2%	35.8%	405.5%	−25.8%	33.6%
Developed country	**168.7**	**40.6%**	**0.01**	**0.02**	**0.02**	**0.0%**	**0.0%**	**0.0%**	**−2.8%**	**−98.5%**	**10.3%**	**−93.9%**
World	**1,748.6**	**37.5%**	**455.6**	**130.6**	**586.2**	**26.1%**	**7.5%**	**33.5%**	**12.4%**	**−0.9%**	**−66.6%**	**−31.1%**

Notes: See the online supplementary materials for details on the methods used to calculate population distributions. Low-income economies are those in which 2013 per capita income was $1,045 or less, lower middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, and upper middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745 as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

Source: Authors' calculations based on online supplementary materials and data.

South Asia have high IMRs. Moreover, approximately 115 million of the sub-Saharan African LFAA population has extremely high infant mortality (IMR greater than 65 deaths), which is about 90 percent of the global total of 131 million.

As shown in table 1, although LFAA populations have risen overall across developing countries, the total number of LFAAs with high IMRs declined by 31 percent from 2000 to 2010. Even larger declines occurred among upper middle-income countries (80 percent) and in the East Asia and Pacific (72 percent), Europe and Central Asia (80 percent), and Latin America and Caribbean (77 percent) regions. However, in low-income countries, the LFAA population with high IMR rose by 21 percent between 2000 and 2010, and in sub-Saharan Africa this population group increased by 34 percent.

Trends in Incidence of High IMR in LFAAs

Although there appears to have been a shift from high to low IMR among LFAA populations across all developing countries between 2000 and 2010 (see appendix figure 1), we find that this has not been the case for low-income countries and sub-Saharan Africa. Thus it appears that in low-income countries and sub-Saharan Africa, LFAAs remain notable "poverty sinks" in terms of high infant mortality.

Twenty countries account for more than 80 percent of the LFAA population with high IMRs in all developing countries (see appendix table 1).[4] India alone accounts for one-third of the global LFAAs with high infant mortality. Across all twenty countries, the incidence of high infant mortality in LFAAs is around 43 percent. With the exception of China and Indonesia, the IMR among the LFAA populations of the twenty countries is extremely high. Although LFAA populations with high IMRs in these countries fell by 26 percent between 2000 and 2010, declines occurred only in India, China, Bangladesh, Indonesia, and South Africa. In the remaining fifteen countries, LFAA populations with high IMRs rose considerably between 2000 and 2010.

Finally, we calculated the high infant mortality incidence for rural populations in the twenty countries with the largest LFAA populations with high IMRs. We found that for all countries, the high infant mortality incidence among the LFAA populations is similar to the incidence rate across rural populations. Thus, although the populations in LFAAs display high IMR incidence, this incidence does not appear be significantly greater than for the overall rural population. This suggests that it may be the marginal environmental conditions of the LFAAs that make poor populations in these regions susceptible to poverty-environment traps, which further increases their vulnerability to climate change impacts.[5]

Infant Mortality in Rural Low-Elevation Coastal Zones

The coastal areas of the world are the frontlines of climate change, and the most vulnerable populations are the poor living in the LECZs of developing countries. As noted earlier, LECZs

[4]The countries are Afghanistan, Bangladesh, Cambodia, China, Côte d'Ivoire, Democratic Republic of Congo, Ethiopia, Ghana, India, Indonesia, Kenya, Mozambique, Myanmar, Nepal, Nigeria, Pakistan, Rwanda, South Africa, Tanzania, and Uganda.

[5]We explore this issue in detail later.

are the contiguous area along the coast with less than 10 meters elevation. The rural poor in LECZs are most at risk from coastal hazards, including storm surge, saltwater intrusion, and coastal erosion, and these hazards will only increase in frequency and severity with the onset of climate change (IPCC 2014; Barbier 2015; Hallegatte et al. 2015). Moreover, the rural LECZ population in developing countries continues to increase, from 212 million in 1990 to 267 million in 2010 (CIESIN 2013).

Barbier (2015) used geospatially referenced malnutrition and infant mortality data as a proxy for poverty and found that, in 2000, just 15 developing countries contained more than 90 percent of the world's LECZ rural poor. Low-income countries had the highest incidence of high malnutrition and infant mortality. This incidence declined for lower middle-income countries and was substantially lower for upper middle-income economies. We extend Barbier (2015) to estimate and compare the extent and incidence of infant mortality among rural LECZ populations in 2000 and 2010.

As in our analysis for LFAAs, areas with an IMR of at least 32 deaths per 1,000 live births are considered to have high infant mortality and areas with more than 65 deaths are considered to have extremely high infant mortality.[6] First, we present our new estimates for 2010 and then we compare the trends in IMRs in the rural LECZs between 2000 and 2010.

Estimates of High Infant Mortality in the Rural LECZs

In 2010 there were approximately 267 million people living in the rural LECZs of developing countries, or about 46 percent of the total LECZ population (see table 2). We found that 85 million of the rural LECZ population in developing countries have high IMRs, suggesting an incidence of 32 percent. Nearly all of the rural LECZ populations with high IMRs live in low-income (47 million) and lower middle-income countries (37 million). In low-income countries, the high IMR incidence in rural LECZs is 71 percent, whereas it is 28 percent in lower middle-income economies and less than 1 percent in upper middle-income countries. This suggests that as with LFAAs, the extent and incidence of high infant mortality among rural LECZ populations appear to be highly correlated with the overall level of economic development.

Almost all of the rural LECZ populations with high infant mortality are located in South Asia (58 million), East Asia and the Pacific (15 million), and sub-Saharan Africa (10 million), with sub-Saharan Africa accounting for most of those with extremely high infant mortality (see table 2).

Trends in Incidence of High IMRs in Rural LECZs

As shown in table 2, across all developing countries, high infant mortality among rural LECZ populations has fallen by one-third from 2000 to 2010. Even larger declines occurred in upper middle-income countries (96 percent), East Asia and the Pacific (55 percent), Europe and Central Asia (100 percent), Latin America and the Caribbean (79 percent), and the Middle East and North Africa (89 percent). However, rural LECZ populations with high IMRs fell by only 19 percent in low-income economies between 2000 and 2010 and actually rose by 28 percent in sub-Saharan Africa.

[6]Again, detailed data and methods are presented in the online supplementary materials.

Table 2 High infant mortality (HIM) among rural low-elevation coastal zone (LECZ) populations, 2010

	Rural LECZ populations (millions)	Share (%) of total LECZ population	Rural LECZ populations with HIM (millions)			HIM incidence (%) in rural LECZ			2000–2010 change (%) in rural LECZ			
			32–65	>65	Total	32–65	>65	Total	Population	32–65	>65	Total
Developing country	**266.8**	**46.2%**	**77.5**	**7.0**	**84.5**	**29.1%**	**2.6%**	**31.7%**	**13.1%**	**−18.1%**	**−77.8%**	**−33.0%**
By income												
Low income	66.2	70.8%	43.3	3.5	46.8	65.3%	5.3%	70.6%	14.3%	1.2%	−76.9%	−19.3%
Lower middle income	132.0	52.3%	33.9	3.4	37.3	25.7%	2.6%	28.3%	17.4%	−23.4%	−76.0%	−36.2%
Upper middle income	68.5	29.6%	0.4	0.1	0.4	0.5%	0.1%	0.7%	4.7%	−95.3%	−96.1%	−95.5%
By region												
East Asia and Pacific	132.9	42.4%	14.9	0.1	15.0	11.2%	0.1%	11.3%	7.9%	−30.7%	−99.4%	−54.6%
Europe and Central Asia	1.5	30.9%	0.0	0.0	0.0	0.0%	0.0%	0.0%	−0.8%	−100.0%	0.0%	−100.0%
Latin America and Caribbean	8.3	25.1%	0.4	0.1	0.5	4.9%	1.5%	6.3%	11.0%	−79.0%	−78.4%	−78.8%
Middle East and North Africa	20.5	51.6%	0.3	0.1	0.4	1.6%	0.6%	2.2%	22.2%	−87.5%	−92.3%	−89.3%
South Asia	93.0	59.9%	57.7	0.5	58.2	62.1%	0.5%	62.6%	17.9%	−14.5%	−95.6%	−25.3%
Sub-Saharan Africa	10.6	33.8%	4.1	6.2	10.3	38.7%	58.5%	97.3%	29.9%	573.9%	−16.7%	28.0%
Developed country	**16.4**	**13.5%**	**0.00**	**0.01**	**0.01**	**0.0%**	**0.0%**	**0.1%**	**4.4%**	**80.5%**	**−14.5%**	**−52.8%**
World	**283.2**	**40.5%**	**77.5**	**7.0**	**84.5**	**27.4%**	**2.5%**	**29.8%**	**12.5%**	**−18.1%**	**−77.8%**	**−33.0%**

Notes: See the online supplementary materials for details on the spatial methods used to calculate these population distributions. Low-income economies are those in which 2013 per capita income was $1,045 or less, lower middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, and upper middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745 as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.

Source: Authors' calculations based on online supplementary materials and data.

Consistent with the results for LFAAs, we found that the changing pattern of IMR incidence in rural LECZs from 2000 to 2010 shows a lessening of high incidence across all developing countries, but not for low-income countries and sub-Saharan Africa (see appendix figure 2). Across all developing countries between 2000 and 2010, IMR incidence in rural LECZs of greater than 100 deaths per 1,000 live births and 65 to 100 deaths per 1,000 live births declined to very low levels, while the IMR incidence of 0 to 15 deaths increased, from 15 percent in 2000 to 36 percent in 2010.

Nearly all (97 percent) of the rural LECZ populations with high infant mortality are located in twenty developing countries,[7] with Bangladesh (30 million), India (26 million), and Myanmar (8 million) accounting for three-quarters of the rural LECZ populations globally with high infant mortality (see appendix table 2). Across all twenty countries, the incidence of high IMRs in rural LECZs is approximately 47 percent.

As we will explore in the next two sections, the environmental conditions faced by households in both LFAA and rural LECZ regions make them susceptible to poverty-environment traps, which in turn increases their vulnerability to climate change.

Climate Change Impacts and Poverty-Environment Traps in LFAAs

Many poor households in LFAAs undertake a range of activities to help them cope financially and to reduce the risks associated with their high economic dependence on a single activity (Narain, Gupta, and van't Veld 2008; Barbier 2010; Debela et al. 2012; Ahmed, Hill, and Naeem 2014; López-Feldman 2014; Pingali, Schneider, and Zurek 2014; Wunder et al 2014; Robinson 2016). Land is one of the few productive assets owned by the rural poor, and almost all households engage in some form of agriculture. However, difficult terrain, poor soil quality, limited rainfall, and other biophysical constraints restrict land productivity and induce degradation. Moreover, limited access to markets restricts agricultural earnings. This means that households must often seek additional income from off-farm work or occupations outside of agriculture (Shively and Fisher 2004; Carter and Barrett 2006; Jansen et al. 2006; Banerjeee and Duflo 2007; Carter et al. 2007; Pascual and Barbier 2007; Ahmed, Hill, and Naeem 2014; Barrett, Garg, and McBride 2016). When households engage in outside employment, they tend to migrate only temporarily and for short distances, with permanent migration over long distances being rare (Banerjee and Duflo 2007). Given the rural poor's lack of ownership of assets and their tendency to stay where they are located, it is not surprising that the "assetless" poor depend on the surrounding natural environments for their livelihoods (Robinson 2016).

The Poverty-Environment Trap

These characteristics of poor households located in LFAAs means that they are particularly vulnerable to falling into a poverty-environment trap (Barbier 2010). If the assetless poor are

[7]The countries are Bangladesh, Benin, Cambodia, Ghana, Guinea-Bissau, India, Indonesia, Madagascar, Mauritania, Mozambique, Myanmar, Nigeria, Pakistan, the Philippines, Senegal, Sierra Leone, Somalia, Tanzania, Vietnam, and the Republic of Yemen.

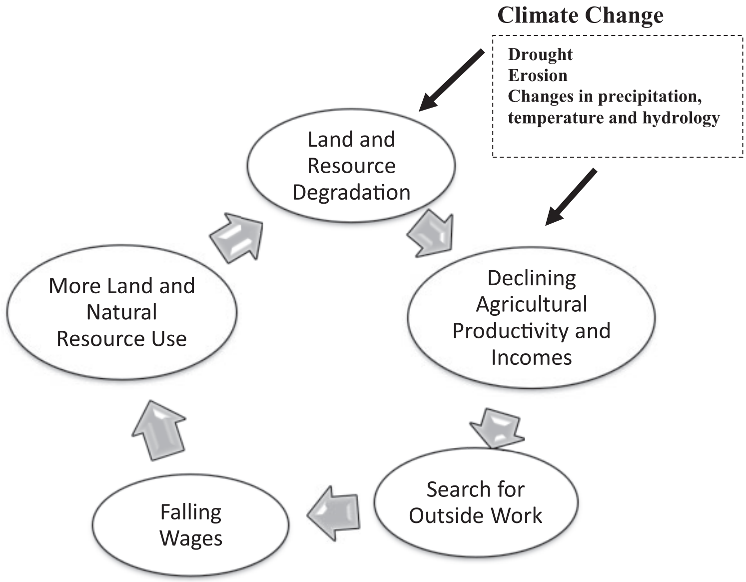


Figure 2 The poverty-environment trap and climate change in less-favored agricultural areas
Source: The authors.

also located in remote areas, then the geographical isolation of these rural communities and local markets can reinforce the conditions that result in a poverty-environment trap. Geographical isolation substantially raises the costs of agricultural commerce and crop production in remote markets and discourages smallholder market participation and investment in improved farming systems and land management (Coxhead, Shively, and Shuai 2002; González-Vega et al. 2004; Holden, Shiferaw, and Pender 2004; Shively and Fisher 2004; Jansen et al. 2006; Barrett 2008; Narain, Gupta, and van't Veld 2008; Ansoms and McKay 2010). Thus the vicious cycle of the poverty-environment trap is reinforced when the poor are located far from major urban centers and markets (Jalan and Ravallion 2002; Barrett 2008; Kraay and McKenzie 2014; Barrett, Garg, and McBride 2016).

The core of the poverty-environment trap in LFAAs is that much of the agricultural land has low productive potential or is located far from markets, and thus discourages investment in land improvement, and that agriculture is prone to soil degradation and low productivity. If agricultural productivity and incomes for these poor households decline, more household labor will be allocated to finding outside work to boost or supplement incomes. However, with large numbers of households seeking outside employment in these geographically isolated areas, the supply of labor for paid work could exceed demand, resulting in a decline in the market wage for hired labor. If the wage rate falls below the reservation wage (i.e., the wage rate required to seek outside work) of some households, they will have little choice but to forego outside employment and instead allocate all household labor to production activities that depend on agriculture and the surrounding natural resources. In LFAAs, many poor households will face problems of environmental degradation from farming marginal lands and exploiting natural resources found in the commons or open access locations. The result is the self-perpetuating vicious cycle depicted in figure 2. This cycle can be even worse for the household if there are widespread land and environmental degradation problems in the region that affect many households. In this case, the large numbers of households seeking outside employment will quickly force the market wage down to subsistence levels.

There are numerous examples of this type of poverty-environment trap in the literature. For example, Pascual and Barbier (2007) found that in the Yucatán, Mexico, poor households on LFAAs tend to oversupply labor to shifting cultivation, which causes more deforestation and thus forces these households to search for outside work, which can be the first step in the process leading to the poverty-environment trap (see figure 2). Similarly, Coomes, Takasaki, and Rhemtulla (2011) identify a land-use poverty trap for shifting cultivators in the Amazon, whereby insufficient initial land holdings induce land use patterns that trap households in low agricultural productivity as well as furthering forest conversion. Caviglia-Harris (2004) also documents the relationship between low-productivity agroforestry systems, forest clearing, and poverty in Amazonia. In Rwanda, resource-poor households in LFAAs are very dependent on subsistence production, and when they can find outside employment, they receive the lowest median pay per hour (Ansoms and McKay 2010). Similar poverty trap relationships have been found between declining productivity, outside employment, and poverty for resource-poor households in LFAAs in El Salvador, Ethiopia, Honduras, India, Malawi, and the Philippines (Coxhead, Shively, and Shuai 2002; González-Vega et al. 2004; Holden, Shiferaw, and Pender 2004; Shively and Fisher 2004; Jansen et al. 2006; Narain, Gupta, and van't Veld 2008).

Climate Change Impacts and the Poverty-Environment Trap in LFAAs

Climate change impacts, such as drought and erosion, and changes in precipitation, temperature, and hydrology, may directly affect poor LFAA households through their negative impact on agricultural productivity and income, or indirectly through their effect on land and natural resource use (see figure 2). In many developing regions, poor households in LFAAs rely on natural resources not for protection against climate-related events, but rather as insurance and coping strategies for avoiding the income and subsistence losses associated with such shocks (McSweeney 2005; Carter et al. 2007; Narain, Gupta, and van't Veld 2008; Debela et al. 2012; López-Feldman 2014; Wunder et al 2014; Angelsen and Dokken 2015; Hallegatte et al. 2015). In an analysis of environmental reliance, poverty, and climate vulnerability among more than 7,300 households in forest-adjacent communities in twenty-four developing countries, Angelsen and Dokken (2015) found that the poor tend to live in the less favorable areas, generate 29 percent of their income from environmental resources, and are more exposed to extreme and variable climate conditions. In sub-Saharan Africa, poor rural households located in less-favored arid areas are already directly experiencing declining incomes from extreme climate conditions and high forest loss and face further loss of future forest benefits due to climate change (Angelsen and Dokken 2015).

These climate change impacts can exacerbate the environmental conditions leading to a poverty-environment trap. For example, in rural Uganda, poorer households attempt to diversify their income sources from the use of forests and outside employment; however, large negative shocks, such as droughts and other climate-related disasters, force them to rely even more on forest resources, which leads to more land and natural resource degradation, especially among those households with below-average and poor-quality land holdings (Debela et al. 2012). In rural Mexico, the poor rely more than wealthier households on natural resource extraction as an income-generating activity, and especially depend on such extractions for subsistence needs (López-Feldman 2014). In addition, poor households in isolated villages have less productive alternatives to resource-extraction activities. In Vietnam, poorer rural households are much more exposed to multiple environment risks, including climate change, and such risks induce not only lower consumption levels but also lower consumption growth over time (Narloch and Bangalore 2016). Finally, López-Feldman (2014) shows that the probability of participation in resource extraction increases considerably when poor households experience climate-related impacts and other shocks to their agricultural systems.

Climate Change Impacts and Poverty-Environment Traps in Rural LECZs

Because of their lack of assets, their dependence on marine and coastal resources, and their need for diversified sources of income, the rural poor in LECZs are also prone to a poverty-environment trap (Barbier 2015).

The Poverty-Environment Trap

The dynamics of the poverty-environment trap's vicious cycle are as follows. Increased use of coastal and marine resources, including available agricultural land, causes extensive degradation. For coastal households, exploitation of marine and coastal resources—that is, collection of products from local forests, such as mangroves, and small-scale fishing—seems to predominate (Béné 2009; Barbier 2012; Dasgupta et al. 2016; Robinson 2016). This results in falling productivity and falling incomes for the households dependent on these resources, which leads to more people searching for available outside work to boost or supplement incomes (Tobey and Torell 2006; Barbier 2008; Béné 2009; Paul and Routray 2011; Stoop, Houssa, and Verpoorten 2016). If there are large numbers of households seeking outside employment in coastal areas, the supply of labor for paid work could exceed demand, resulting in a decline in the market wage for hired labor. For some households, the wage rate will fall to the level of the reservation wage or even lower, which means these households will forego outside employment opportunities and instead allocate all of their labor back to production activities that depend on coastal and marine resources. If this process degenerates into a vicious cycle, then these households will fall into a poverty-environment trap (see figure 3).

Climate Change Impacts and the Poverty-Environment Trap in Rural LECZs

These dynamics mean that the rural coastal households that are susceptible to this poverty-environment trap are also highly vulnerable to the increased coastal hazards caused by climate change. Natural disasters, sea level rise, saltwater intrusion, coastal erosion, and other hazards threaten these households' livelihoods either directly or indirectly through their impacts on the key coastal and near-shore ecosystems on which their livelihoods depend (Barbier 2015; Dasgupta et al. 2016; Dasgupta, Sobhan, and Wheeler 2016; Hallegatte et al. 2017). Two types of climate change impacts particularly affect the poor: short-lived natural disasters with

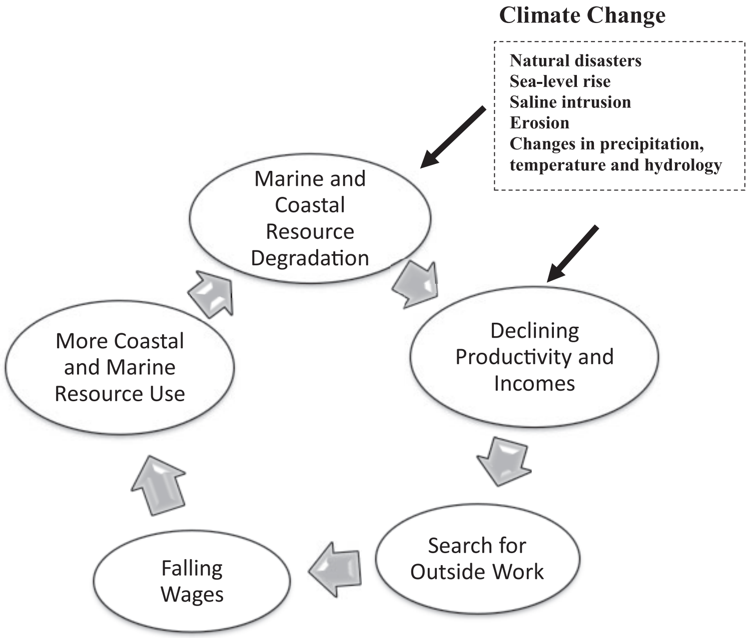


Figure 3 The poverty-environment trap and climate change in low-elevation coastal zones
Source: The authors.

immediate and often extreme impacts, such as flooding and storm surge, and long-term climatic changes with more gradual impacts, such as sea level rise, saltwater intrusion, and erosion. These hazards either degrade the coastal and marine systems and resources on which households depend or cause income and productivity losses (see figure 3). This suggests that climate change impacts can reinforce the poverty-environment trap faced by poor coastal households and tip many others into the trap.

Natural disaster shocks

The rural poor in coastal areas are especially vulnerable to natural disaster shocks, such as hurricanes, tsunamis, floods, and other extreme coastal events (Badola and Hussein 2005; McSweeney 2005; Carter et al. 2007; Barbier 2008, 2015; Das and Vincent 2009; Laso Bayas et al. 2011; Hallegatte et al. 2017). Moreover, the lack of protection infrastructure in rural areas, such as storm shelters, seawalls, and embankments, means that poor rural households often rely on "natural barriers" such as mangroves for protection (Badola and Hussain 2005; Barbier 2008; Das and Vincent 2009; Dasgupta, Sobhan, and Wheeler 2016). The loss of these habitats leaves these households more exposed to natural disasters. In many developing regions, poor households also use coastal resources as insurance and coping strategies for avoiding the income and subsistence losses associated with such disasters (McSweeney 2005; Carter et al. 2007; Robinson 2016).

Long-term impacts

Economic livelihoods in many rural LECZs are also threatened by the long-term impacts of climate change on salinization. For example, many areas of coastal Bangladesh are suffering from the effects of saltwater intrusion on agriculture (Rabbani, Rahman, and Minuddin 2013; Dasgupta et al. 2014; Shameem, Momtaz, and Rauscher 2014), which is caused by sea level rise and expansion of coastal agriculture. Changes in ocean temperature, acidity, freshwater inputs, circulation, and stratification—which are linked to climate change—are already altering the productivity and potential yields of many fisheries important to the livelihoods of coastal households (Brander 2010; Sumaila et al. 2011). Coral reef and near-shore fisheries are particularly important to the economic livelihoods of the rural coastal poor in many developing countries, yet these fisheries are threatened by both overexploitation and climate change impacts, such as temperature changes, ocean acidification, and coral bleaching (Sumaila et al. 2011; Cinner et al. 2012; Doney et al. 2012; Dasgupta et al. 2016).

In addition, climate change impacts on precipitation, temperature, and hydrology are affecting coastal and near-shore ecosystems, such as wetlands, mangroves, coral and oyster reefs, and seagrass beds (Doney et al. 2012; IPCC 2014; Spalding et al. 2014; Dasgupta, Sobhan, and Wheeler 2016). The benefits of these habitats are important for supporting fisheries; protecting agriculture through buffering coastlines from erosion and saltwater intrusion; providing raw materials, food, and forage; and filtering sediment and pollutants (Barbier 2012; Doney et al. 2012; Spalding et al. 2014). These benefits, as well as the cultural value of these marine ecosystems, can be significant to poor coastal households.

Thus sea level rise, saltwater intrusion, and erosion are all exacerbating the environmental conditions leading to a poverty-environment trap for many households in rural LECZs.

Summary and Conclusions

Poor populations in developing countries that are located in LFAAs and rural LECZs are at risk from poverty-environment traps that further increase their vulnerability to climate change impacts. We estimate that approximately 586 million people with high infant mortality live in LFAAs and 85 million with high infant mortality live in rural LECZs, although both of these populations declined between 2000 and 2010. Nearly all of these people are in low-income or lower middle-income countries, with twenty countries accounting for most of the LFAA or rural LECZ populations with high infant mortality.

Given the high incidence of rural LECZ and LFAA poverty among low-income countries, over the long-term, fostering economic growth may be one of the most effective ways to reduce the vulnerability of these populations to the impacts of climate change (Hallegatte et al. 2015). However, growth alone may not be sufficient to address this issue. The estimates and evidence we have presented here suggest that the persistent threat of a poverty-environment trap that faces many LECZ and LFAA rural households will leave them vulnerable to the short- and long-term risks posed by climate change. Thus it is likely that additional policy measures are needed to address the persistence of rural poverty in these disadvantaged areas.

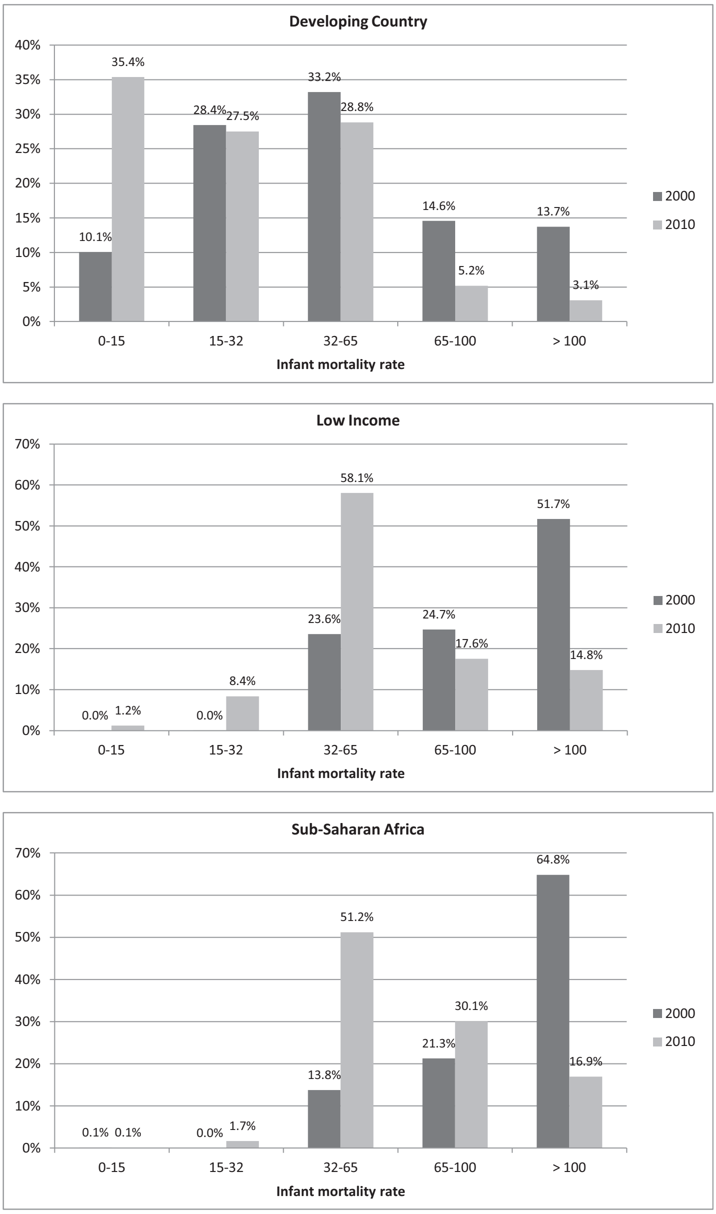
There is some evidence that addressing the persistence of rural poverty in LECZs requires more *location-specific* targeting of policies, especially in areas where poverty, environmental risks, and climate change impacts may be self-reinforcing (Cinner et al. 2012; Barbier 2015; Hallegatte et al. 2015, 2017). For example, actions that can be targeted to specific coastal communities and LECZ regions include improved information about weather events and early warning systems, evacuations from highly vulnerable areas, development of social safety nets, and diversification within coastal livelihoods, such as agriculture and fishing. Additional actions include strengthening community groups responsible for managing coastal resources and ecosystems, improvements in coastal infrastructure, and policies and investments to encourage the most vulnerable to migrate to noncoastal areas. Over the long-term, actions targeted to specific coastal communities and LECZs include livelihood diversification out of fishing, agriculture, and other coastal resource-based activities; investments in health and education; and broader investments in local governance and institutions.

Reducing the climate vulnerability of poor populations in LFAAs will likely require a similar set of targeted investments and policies (Barbier 2010; Hallegatte et al. 2015), including improving the productivity of agriculture and resource-productive activities, especially with higher-yielding and more climate-resistant practices, crop varieties, and livestock breeds. Additional actions include overcoming the constraints on broader market participation, especially through fostering well-functioning and affordable local markers for credit, insurance, and land; generating off-farm employment opportunities; and improving public services and infrastructure in remote locations, including roads, communications, marketing, education and health services, and research and extension. These actions should be accompanied by policies that encourage local governance and participation in efforts to enhance environmental protection and management of common resources.

Any policy strategy aimed at improving the livelihoods of the rural poor located in remote and fragile environments must be assessed against the alternative strategy of encouraging greater outmigration from these areas. As noted by Lall, Selod, and Shalizi (2006, p. 48), rural development is essentially an indirect way of deterring migration to cities; yet, because of the costliness of rural investments, "policies in developing countries are increasingly more concerned with influencing the direction of rural to urban migration flows—e.g. to particular areas—with the implicit understanding that migration will occur anyway and thus should be accommodated at as low a cost as possible." Thus Hallegatte et al. (2015, p. 160) maintain that "migration can be an important way of adapting to extreme weather events and climate change impacts, and thus of reducing impacts that lower welfare. . . . Particularly in areas where in situ adaptation is difficult or extremely costly (such as in low-density coastal areas or remote areas with low productivity), migration can be critical." But the authors also caution that "the poorest households have a lower capacity to migrate and may therefore be unable to use this option. . .. In addition, the ability to migrate depends on household assets (including land tenure), the ability to sell assets, information and social capital, financial resources, and human capital" (Hallegatte et al. 2015, pp. 160–61).

This suggests that a viable strategy for disadvantaged regions and poor rural populations vulnerable to climate change is likely to be a combination of policies that encourages outmigration for some households while investing in improving the livelihoods of those who remain in such areas. Both types of policies, along with the promotion of overall economic growth, will likely be required to help overcome poverty in LFAAs and rural LECZs, especially given the vulnerability of these populations and their economic livelihoods to poverty-environment traps and the impacts of climate change.

Appendix

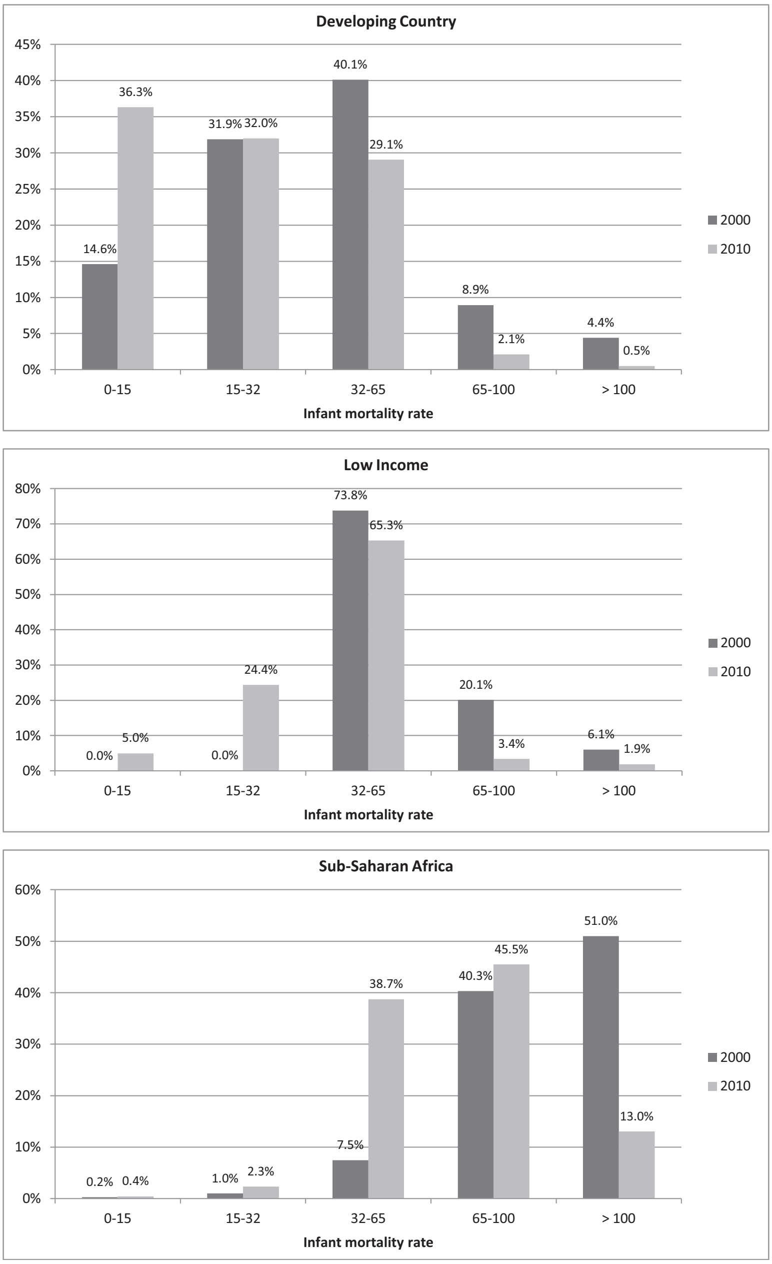


Appendix Figure 1 Incidence of infant mortality rates in less-favored agricultural areas (LFAAs), 2000 and 2010
Notes: Infant mortality rate (IMR) is the number of deaths within the first year of life per 1,000 births. An IMR of less than 15 deaths per 1,000 live births is considered to be low, in the range of 15 to 32 deaths is moderate, 32 to 65 is high, and greater than 65 is extremely high. IMR incidence expressed as the share (%) of total population in LFAAs. See the online supplementary materials for details on the spatial methods used to calculate these population distributions. Low-income economies are those in which 2013 per capita income was $1,045 or less, lower middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, and upper middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745 as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.
Source: Authors' calculations based on supplementary online materials and data.

Appendix Table 1 Countries with high infant mortality (HIM) in less-favored agricultural areas (LFAAs), 2010

	LFAA populations with HIM (× 1000)	LFAA population (× 1000)	LFAA HIM incidence	Rural population HIM incidence	LFAA population	LFAA HIM
					2000–2010 Change	
India	193,473.2	270,712.2	71.5%	82.4%	13.4%	−18.8%
China	35,079.2	503,608.4	7.0%	5.4%	2.7%	−79.8%
Ethiopia	32,540.5	32,593.4	99.8%	99.8%	44.8%	44.6%
Nigeria	31,767.7	31,767.7	100.0%	100.0%	36.9%	36.9%
Tanzania	20,306.8	20,306.8	100.0%	100.0%	37.6%	37.6%
Pakistan	20,145.1	20,145.1	100.0%	100.0%	25.8%	25.8%
Myanmar	15,219.3	15,228.0	99.9%	99.9%	28.5%	28.4%
Democratic Republic of Congo	14.453.8	14,453.8	100.0%	100.0%	40.7%	40.7%
Kenya	12,596.4	12,596.4	100.0%	100.0%	20.2%	20.2%
Uganda	12.436.3	12,436.3	100.0%	100.0%	54.5%	54.5%
Nepal	10,909.0	10,909.3	100.0%	100.0%	22.8%	22.8%
Bangladesh	10,025.3	16,734.9	59.9%	62.5%	17.1%	−29.8%
Cambodia	9,879.8	9,940.3	99.4%	99.2%	50.3%	49.7%
Ghana	9,358.6	9,358.6	100.0%	100.0%	36.9%	36.9%
Côte d'Ivoire	8.702.4	8,702.4	100.0%	100.0%	31.7%	31.7%
Mozambique	8,572.5	8,656.3	99.0%	99.0%	23.0%	21.8%
Indonesia	8.095.5	95,392.8	8.5%	10.0%	35.1%	−81.6%
Rwanda	7,428.3	7,428.3	100.0%	100.0%	42.5%	42.5%
Afghanistan	7,029.8	7,029.9	100.0%	100.0%	44.3%	44.3%
South Africa	6,397.7	8,112.7	78.9%	77.9%	−1.0%	−19.4%
Total 20	**474,417.3**	**1,116,113.5**	**42.5%**	**54.6%**	**13.3%**	**−26.0%**
All developing countries with LFAA populations	**586,215.1**	**1,579,818.9**	**37.1%**	**47.3%**	**14.3%**	**−31.1%**

Notes: Populations with HIM live in areas with at least 32 deaths within the first year of life per 1,000 births. The above 20 countries account for 80.9% of LFAA populations with HIM in all developing countries. See the online supplementary materials for details on the spatial methods used to calculate these population distributions.
Source: Authors' calculations based on online supplementary materials and data.



Appendix Figure 2 Incidence of infant mortality rates in rural low-elevation coastal zones (LECZs), 2000 and 2010

Notes: Infant mortality rate (IMR) is the number of deaths within the first year of life per 1,000 births. An IMR of less than 15 deaths per 1,000 live births is considered to be low, in the range of 15 to 32 deaths is moderate, 32 to 65 is high, and greater than 65 is extremely high. IMR incidence expressed as the share (%) of rural population in the LECZ. See the online supplementary materials for details on the spatial methods used to calculate these population distributions. Low-income economies are those in which 2013 per capita income was $1,045 or less, lower middle-income economies are those in which 2013 per capita income was between $1,046 and $4,125, and upper middle-income economies are those in which 2013 per capita income was between $4,126 and $12,745 as defined by the World Development Indicators, available at http://databank.worldbank.org/data/views/variableselection/selectvariables.aspx?source=world-development-indicators.
Source: Authors' calculations based on online supplementary materials and data.

Appendix Table 2 Countries with High Infant Mortality (HIM) in Rural Low-Elevation Coastal Zone (LECZ), 2010

	Rural LECZ populations with HIM (× 1000)	Rural LECZ population (× 1000)	Rural LECZ HIM incidence	Rural population HIM incidence	Rural LECZ population	Rural LECZ HIM
					2000–2010 Change	
Bangladesh	30,276.2	47,626.3	63.6%	62.5%	15.7%	−26.4%
India	25,830.4	42,277.2	61.1%	82.4%	20.5%	−26.3%
Myanmar	7,827.5	7,830.5	100.0%	99.9%	0.2%	0.2%
Cambodia	3,590.7	3,721.2	96.5%	99.2%	12.0%	8.5%
Nigeria	2,592.8	2,952.8	100.0%	100.0%	35.8%	35.8%
Pakistan	2,094.0	2,094.0	100.0%	100.0%	22.9%	22.9%
Indonesia	1.995.2	19,278.5	10.3%	10.0%	13.4%	−80.2%
Mozambique	1,358.5	1,385.0	98.1%	99.0%	33.0%	30.5%
Senegal	984.3	984.3	100.0%	100.0%	22.6%	22.6%
Philippines	752.1	7,015.6	10.7%	10.8%	25.0%	−70.8%
Mauritania	682.3	682.4	100.0%	100.0%	33.6%	33.6%
Vietnam	626.7	36,257.3	1.7%	5.2%	11.3%	−72.4%
Madagascar	469.5	667.3	70.4%	82.5%	30.7%	−8.0%
Benin	437.0	437.0	100.0%	100.0%	24.2%	24.2%
Tanzania	405.7	405.7	100.0%	100.0%	31.9%	31.9%
Guinea-Bissau	376.9	376.9	100.0%	100.0%	11.6%	11.6%
Sierra Leone	365.1	365.1	100.0%	100.0%	32.1%	32.1%
Ghana	342.0	342.0	100.0%	100.0%	22.5%	22.5%
Somalia	339.8	339.8	100.0%	100.0%	35.7%	35.7%
Republic of Yemen	273.6	273.7	100.0%	99.9%	36,6%	36.6%
Total 20	**81,980.3**	**175,312.7**	**46.8%**	**74.2%**	**15.9%**	**−26.1%**
All developing countries with rural LECZ populations	**84,528.1**	**266,811.0**	**31.7%**	**43.7%**	**13.1%**	**−33.0%**

Notes: The above 20 countries account for 97.0% of rural LECZ populations with high infant mortality rates in all developing countries. See the online supplementary materials for details on the spatial methods used to calculate these population distributions.
Source: Authors' calculations based on online supplementary materials and data.

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