Land Degradation, Less Favored Lands and the Rural Poor:

A Spatial and Economic Analysis

A Report for the Economics of Land Degradation Initiative

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Executive Summary

This study has three objectives:

- To determine the spatial distribution of global rural populations on less favored agricultural land and in less favored agricultural areas from 2000 to 2010.
- To determine the spatial distribution of global rural populations on degrading and improving agricultural land from 2000 to 2010.
- To analyze how these spatial distributions affect poverty in developing countries.

Less favored agricultural land is susceptible to low productivity and degradation, because its agricultural potential is constrained biophysically by terrain, poor soil quality or limited rainfall. We include in this category irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). *Less favored agricultural areas* include all less favored agricultural land plus favorable agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Degrading agricultural land consists of agricultural land with a negative change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over this time period after subtracting respiration losses. *Improving agricultural land* consists of agricultural land with a non-negative change in NPP from 1981-2000.

Using a variety of global spatially referenced datasets, we analyze the spatial distribution of global rural populations on these four types of land in 2000 and 2010.

	Population in 2000 (millions)		Population in 2010 (millions)	
	Global	Developing country	Global	Developing country
Rural population	4,111.5	3,706.8	4,663.9	4,248.6
Rural population on less favored agricultural land	1,486.3	1,314.5	1,666.6	1,499.7
Rural population in less favored agricultural areas	1,556.4	1,382.7	1,748.6	1,579.8
Rural population on remote less favored agricultural land	298.4	288.2	332.4	322.5
Rural population on all degrading agricultural land	1,331.3	1,258.7	1,496.9	1,426.3
Rural population on remote degrading agricultural land	205.4	202.2	233.2	230.2
Rural population on all improving agricultural land	1,537.1	1,340.7	1,729.9	1,539.4
Rural population on remote improving agricultural land	164.3	155.3	178.2	169.2

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Our spatial analysis confirms that the concentration of rural populations on less favored agricultural lands, less favored agricultural areas and degrading agricultural lands is predominantly a developing country problem. The number of people in these locations has increased significantly from 2000 to 2010, both globally and in each major developing country region. In 2000, over 1.3 billion rural people in developing countries were located on less favored agricultural lands, and their numbers increased to 1.5 billion in 2010. In 2000, nearly 1.4 billion people lived in these areas in developing countries, increasing to nearly 1.6 billion in 2010. Thus, well over a third of the rural population is located in less favored agricultural lands and less favored agricultural areas. In 2000, nearly 1.3 billion were located on all degrading agricultural land, which included 202 million without market access (around 6% of the rural population). By 2010, over 1.4 billion people were located on degrading agricultural land, which included 230 million people in remote areas. They account for 34% and 5% of the rural population, respectively.

Of particular concern is the continuing expansion in the number of rural people in developing countries on less favored agricultural land without market access, from nearly 300 million in 2000 to over 330 million in 2010. This critical population group appears to be increasing by over 1% annually across the developing world, and at annual rates approaching 2% in Latin America & Caribbean and South Asia and over 3% in Sub-Saharan Africa. But there should also be concern over the growth in the rural population of developing countries on remote degraded agricultural land. This segment of the rural population appears to be expanding by over 1% annually across the developing world, and at annual rates of 2% in Latin America & Caribbean and South Asia and 4% in Sub-Saharan Africa.

However, an encouraging trend is the growth in the population of developing countries on all improving agricultural land, even in some remote areas. In 2000, there were 1.3 billion people on improving agricultural land, which included 155 million people without market access. By 2010, there were over 1.5 billion people on improving agricultural land in developing countries, and the numbers in remote areas increased to 169 million people. These comprised 36% and 4% of the rural population, respectively.

Our poverty analysis examines whether the 2000 spatial distribution of rural populations in developing countries on degraded and improving agricultural land, less favored agricultural lands and less favored agricultural areas have a direct influence on changes in poverty over 2000-2012 or an indirect influence through attenuating the poverty-reducing impact of income growth. We test these hypotheses through examining how the spatial distribution of rural populations in 2000 influences poverty changes from 2000 to 2012 in 83 developing countries.

We find no evidence of a direct impact on poverty changes from the spatial distribution of rural populations on less favored agricultural land, less favored agricultural areas or degrading and improving agricultural land, but there is a significant indirect impact of these distributions on the poverty-reducing effects of income growth. The following table summarizes the poverty impacts of a hypothetical change in the spatial distributions we analyze, using a one-standard-deviation change in these distributions for our sample of developing countries.

	Initial level	Final level	% change in poverty rate per year
Share (%) of rural population on less favored agricultural land	38.15%	59.10%	0.92% to 0.99%
Share (%) of rural population in less favored agricultural areas	40.04%	60.83%	0.97% to 1.11%
Share (%) of rural population located on remote less favored agricultural land	8.50%	16.90%	0.35% to 0.47%
Share (%) of rural population on less favored agricultural land located on remote land	24.74%	43.55%	0.95% to 1.32%
Share (%) of rural population on all degrading agricultural land	27.11%	48.15%	0.98% to 1.04%
Share (%) of rural population on all remote degrading agricultural land	5.02%	9.45%	0.18% to 0.25%
Share (%) of rural population on all improving agricultural land	31.89%	52.94%	-0.57% to -0.76%
Share (%) of rural population on all remote improving agricultural land	13.45%	32.28%	-0.55% to -0.74%

The initial level is based on the mean and the final level on a one-standard-deviation change in the relevant variables listed in the far-left column for the sample of 83 developing countries.

Across a wide range of developing countries, as more rural people are located on less-favored and degrading agricultural land, as well as in less favored agricultural areas, the result is an increase in the overall poverty rate. However, if the share of the rural population on improving agricultural land rises, then poverty is reduced. The most critical population groups appear to be rural populations on less favored and degrading agricultural land without market access. If there is a substantial reduction in the share of the rural population on remote less favored and degrading agricultural land, then poverty rates could fall across a wide range of developing countries.

These results lend credence to recent concerns about the prevalence of geographical poverty traps in the rural areas of developing countries. Reducing rural poverty may require either a large-scale regional approach or assisting the exit of populations to alleviate the problem of the concentration of rural populations on less favored agricultural lands, degrading agricultural lands and less favored agricultural areas. In particular, our results suggest that the most critical and vulnerable rural population group are those located on less favored and degrading agricultural lands that are also remote from markets. It is these segments of the rural population that should be the main target of any strategy aimed at encouraging out-migration while investing in improving the livelihoods of those who remain in such areas.

1. Introduction

About a quarter of global land area is degraded, affecting around 1.5 billion people worldwide (Bai et al. 2008; von Braun et al. 2012). However, the economic consequences of land degradation are not the same for all people or countries. A number of studies of the spatial location of populations in marginal areas indicate that it is the rural poor of the least developed economies whose livelihoods are most dependent on degraded and less favored lands (Barbier 2010 and 2012; CGIAR 1999; Nachtergaele et al. 2010; World Bank 2003 and 2008). Such evidence has important implications for policies to promote sustainable land management, alleviate poverty and foster economic development.

For example, as the World Bank (2008, p. 49) concludes, "the extreme poor in more marginal areas are especially vulnerable", and "one concern is the existence of geographical poverty traps". Such traps may occur because production on less favored agricultural lands is subject to low yields and soil degradation, while lack of access to markets and infrastructure may constrain the ability of poor households to improve their farming systems and livelihoods or obtain off-farm employment. If the spatial concentration of rural populations on less favored agricultural lands and areas perpetuates geographical poverty traps, such "spatial inequality" may have significant implications for the reduction of overall poverty in developing countries (Barbier 2012; Bird et al. 2002 and 2010; Jalan and Ravallion 2002; Kanbur and Venables 2005).

One of the first studies to determine the distribution of the rural poor on less favored lands globally was CGIAR (1999), which concluded that nearly two-thirds of the rural population of developing countries—almost 1.8 billion people—live on less-favored lands, including marginal agricultural lands, forest and woodland areas, and arid zones. By applying national rural poverty percentages, CGIAR (1999) determined that 633 million poor people lived on less favored lands in developing countries, or around two-thirds of the total rural poor (see also CAWMA 2008).

A subsequent analysis by the World Bank (2003) sought to identify the percentage of total population in a selection of low and middle-income economies located on "fragile lands" in 2000. This classification comprised four categories of land: terrain greater than 8% median slope, soil unsuitable for rainfed agriculture, arid and dry semi-arid land without access to irrigation, and forests (deciduous, evergreen and mixed). The study estimated that nearly 1.3 billion people in 2000 – almost a fifth of the world's population – lived in such areas in developing regions, and concluded that since 1950, the estimated population in developing economies on "fragile lands" may have doubled (World Bank 2003).

A further study by the World Bank (2008) employed the definition proposed by Pender and Hazell (2000) for less favored areas to determine the spatial distribution of rural populations in 2000. However, the analysis was able to determine only the distribution of rural population on lands limited by rainfall (arid and semi-arid lands) and in remote areas. The latter are defined as locations with poor market access, requiring five or more hours to reach a market town of 5,000 or more. Around 430 million people in developing countries in 2000 lived in such distant rural areas, and nearly half (49%) of these populations were located in semi and semi-arid regions characterized by frequent moisture stress that limits agricultural production (World Bank 2008).

Since the 1980s, remotely sensed global normalized difference vegetation index (NDVI) data trends have been used as a proxy for land degradation (Bai et al. 2008 and 2010; de Jong et al. 2011). This has been facilitated by the availability of a long time series of consistent global NDVI data and detailed studies of its relationship with leaf area index (LAI) and net primary productivity (NPP). For example, Bai et al. (2008) depict global change in NDVI, scaled in terms of NPP, over the period 1981–2003, and have determined that over 1.5 billion people, or nearly a quarter of the world's population is affected by land degradation. Nachtergaele et al. (2010) employ NDVI to determine the spatial location of the rural poor with respect to degraded land. Globally, around 42% of the poor are located on degraded land, compared with 32% of the moderately poor and 15% of the non-poor (Nachtergaele et al. 2010). Other studies also use NDVI to indicate correlations between land degradation and GDP in various global regions (Nkonya et al. 2011; von Braun et al. 2012). The results show that, in all regions, GDP changes are positively correlated with NDVI changes, and this trend is especially noticeable in North America, Russia, India, central Africa (north of the equator), and China.

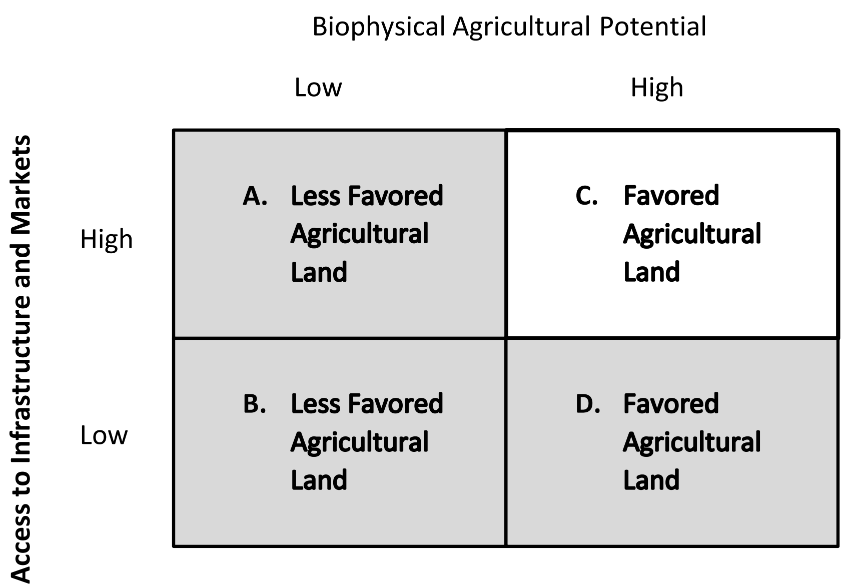
However, these past studies on the spatial location of rural populations with respect to degraded and unfavorable land have two shortcomings. First, the studies differ significantly in their use of key spatial land and population indicators (Nkonya et al. 2011). Second, the spatially referenced data generated are inadequate for cross-country economic analysis of the impact of land degradation on global poverty (von Braun et al. 2012).

The following study addresses these two shortcomings. First, through geographic information system (GIS) analysis, spatially referenced data are employed to map globally indicators of degrading versus improving agricultural land, less favored agricultural land and less favored agricultural areas. Second, GIS is also used to overlay the latter indicators with spatially referenced data on rural population. This analysis is conducted globally, across the developing world, by region and by country, and for two time periods, 2000 and 2010. Third, these spatial data sets are used in a cross-country econometric analysis to determine how changes in poverty are affected by the spatial distribution of rural populations in developing countries on degrading and improving agricultural land, less favored agricultural lands and less favored agricultural areas. Finally, the results of the spatial and econometric analysis inform how better policies can be implemented to improve sustainable land management and poverty alleviation.

2. Rural Populations on Less Favored Agricultural Land and Areas

We first consider two types of spatial distributions of rural populations, the concentration of rural populations on *less favored agricultural land*, and their concentration in *less favored agricultural areas*. As shown in Figure 1, these two land classifications are related (Pender and Hazell 2000). Less favored agricultural land is susceptible to low productivity and degradation, because its agricultural potential is constrained biophysically by terrain, poor soil quality or limited rainfall (box A and B in Figure 1). Less favored agricultural areas include less favored agricultural land plus favorable agricultural land that is remote; i.e., it has high agricultural potential but is located in an area with limited access to infrastructure and markets (box D). Thus, in Figure 1, less favored agricultural areas are the shaded grey boxes A, B, and D. Of these areas, the most critical may be less favored agricultural land that is also remote due to poor access to infrastructure and markets (box B).

Figure 1. Classification of Less Favored Agricultural Lands and Areas



Less favored agricultural land (A and B) has low agricultural potential as it is constrained biophysically by terrain, poor soil quality or limited rainfall. *Less favored agricultural areas* (**shaded gray**) also include favored agricultural land that is remote due to poor access to infrastructure and markets (D).

See technical notes in Appendix for further details.

Source: Based on the definition and classification of less favored areas in Pender and Hazell (2000).

Using a variety of global spatially referenced datasets, we analyze the spatial distribution of global rural population in 2000 and 2010, following the classification of less favored agricultural land and areas of Figure 1 (See the technical notes in Appendix for further details). Less favored agricultural land consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). These various land areas were determined by employing in Arc

GIS 10.1 the datasets from the FAO Global Agro-Ecological Zones (GAEZ) Data Portal version 3 (Available online: http://gaez.fao.org/) combined with national boundaries from the Gridded Population of the World, Version 3 (GPWv3) of the Center for International Earth Science Information Network (CIESIN) and Centro Internacional de Agricultura Tropical (CIAT). Agricultural land extent was obtained from the Pilot Analysis of Global Ecosystems (PAGE) (http://www.ifpri.org/dataset/pilot-analysis-global-ecosystems-page), and rural populations determined from the rural-urban extent dataset that was published as part of CIESIN Global Rural Urban Mapping Project (GRUMPv1). Market accessibility was used to identify remote areas using Nelson (2008) as released by the Global Environment Monitoring Unit of the Joint Research Centre of the European Commission. Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

The results of this analysis for 2000 are depicted in Table 1. Just under 1.5 billion people in the world lived on less favored agricultural lands, and nearly all (1.3 billion) were found in low and middle-income economies. Almost 36% of the 2000 rural population in developing countries was located on such marginal agricultural land, although this share ranged from 23% in Middle East & North Africa to 56% in Europe & Central Asia. In 2000, around 1.6 billion people worldwide lived in less favored agricultural areas, with nearly 1.4 billion in low and middle-income economies. Over 37% of the rural population in developing countries was in less favored agricultural areas, with the share again varying from 23% in Middle East & North Africa to nearly 56% in Europe & Central Asia. Given the similarity in population distributions in Table 1, it is clear that nearly all the rural populations in less favored agricultural areas comprise people living on marginal agricultural land.

Figure 2 displays the global distribution of the rural population in developing countries in 2000 on less favored agricultural lands. The figure shows the density of this distribution in terms of population per km^2. Figure 3 shows a similar global distribution for 2000 of the rural population in low and middle-income economies in less favored agricultural areas.

Table 1. Rural population on less favored agricultural lands and areas, 2000

	Population in 2000 (millions)				
	Rural population (1)	Rural population on less favored agricultural land (LFAL) (2)	% share (2)/(1)	Rural population in less favored agricultural areas (LFAA) (3)	% share (3)/(1)
Developing country	**3,706.8**	**1,314.5**	**35.5%**	**1,382.7**	**37.3%**
East Asia & Pacific	1,398.4	645.0	46.1%	672.9	48.1%
Europe & C. Asia	173.8	96.4	55.5%	97.1	55.9%
Latin America & Caribbean	294.1	94.9	32.3%	97.0	33.0%
Middle East & N. Africa	195.6	44.9	23.0%	45.2	23.1%
South Asia	1,090.4	269.0	24.7%	291.0	26.7%
Sub-Saharan Africa	554.6	164.3	29.6%	179.5	32.4%
Developed country	**404.7**	**171.8**	**42.4%**	**173.8**	**42.9%**
World	**4,111.5**	**1,486.3**	**36.1%**	**1,556.4**	**37.9%**

Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 184 countries; one country was indeterminate due to changing political boundaries, and 20 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 2. Distribution of rural population of developing countries on less favored agricultural land, 2000

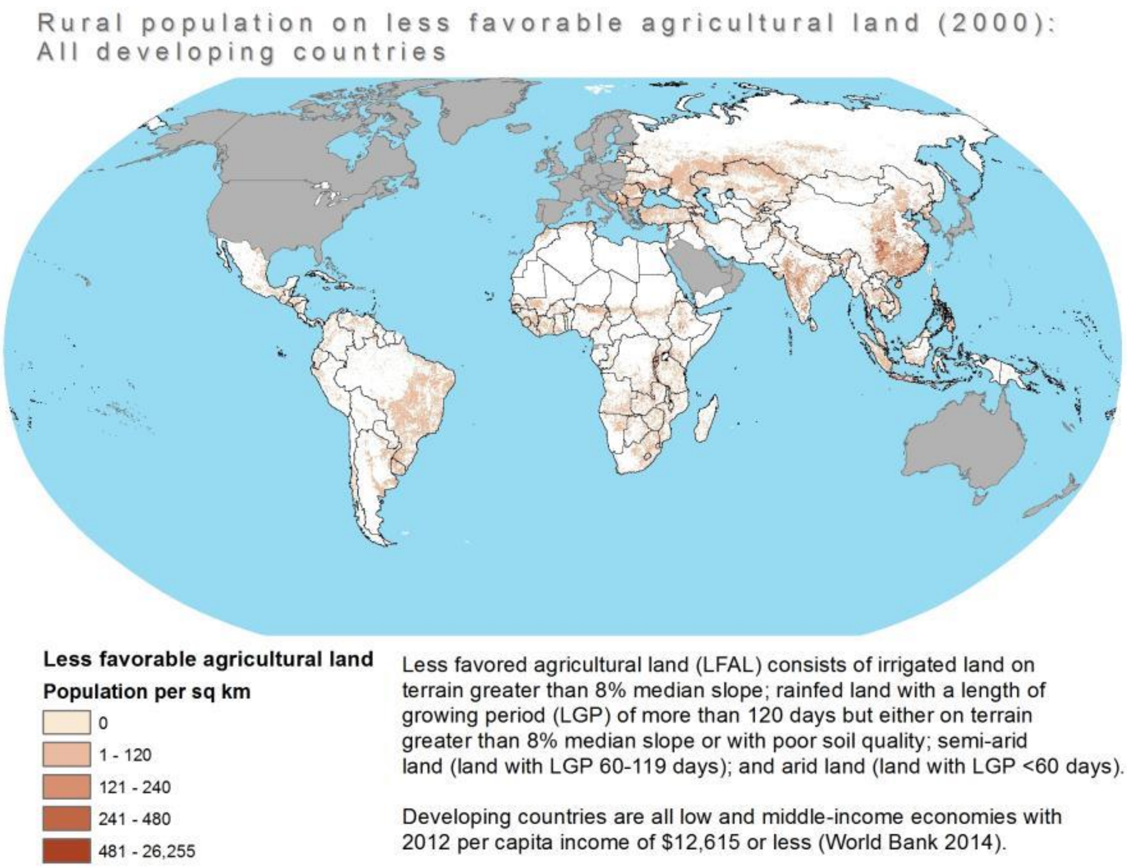


Figure 3. Distribution of rural population of developing countries in less favored agricultural areas, 2000

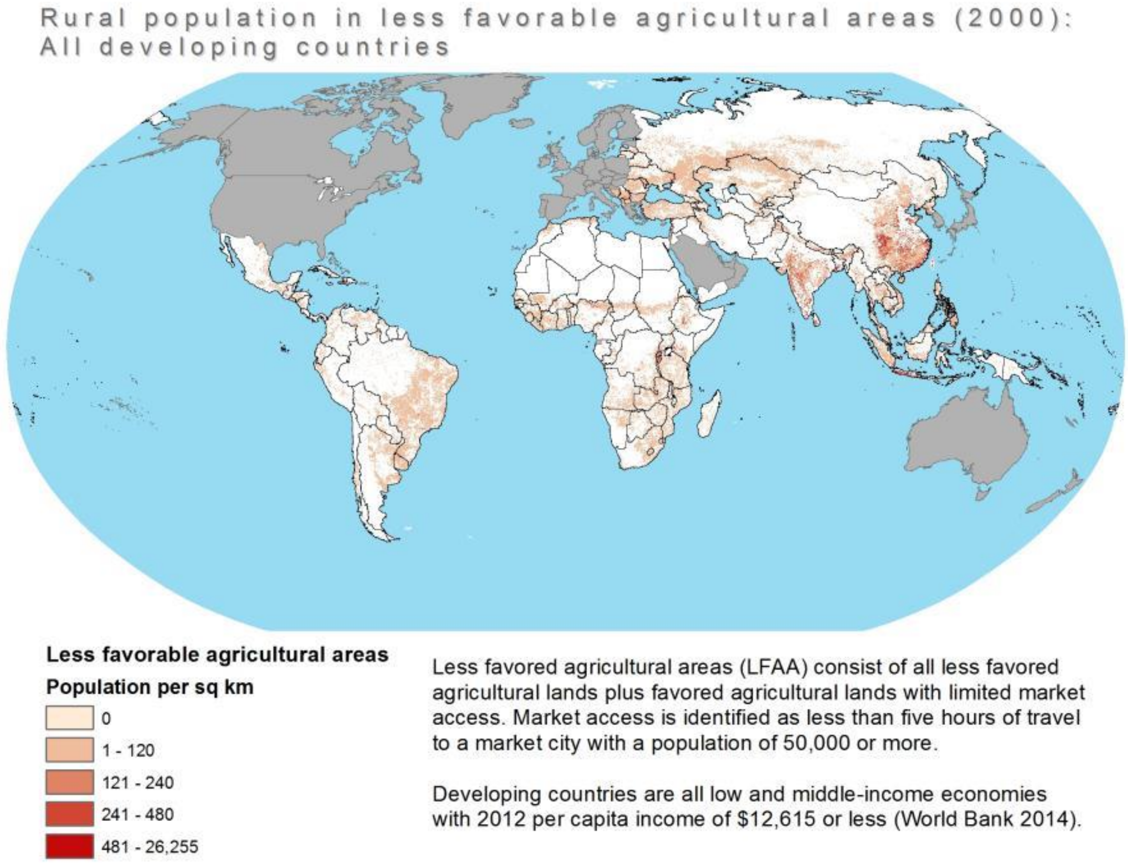


Table 2 indicates the distribution of people on remote less favored agricultural land, which is the critical population denoted by box B in Figure 1. In 2000, nearly 300 million people globally were located on remote less favored agricultural land, or over 7% of the rural population. Nearly all (288 million) were in low and middle-income economies, which accounted for almost 8% of the rural population. This share varies from around 4% in the Middle East & North Africa and South Asia to almost 12% in East Asia & Pacific. One fifth of the global rural population on less favored agricultural lands does not have market access, and for developing countries, this share rises to nearly 22%. It ranges from just over 12% in East Asia & Pacific to 30% in Sub-Saharan Africa.

The results of the distribution of people in 2010 on marginal agricultural lands and remote areas are indicated in Table 3. By 2010, there were nearly 1.7 billion people on less favored agricultural land and just over 1.7 billion in less favored agricultural areas, which comprised 36% and 38% of the rural population respectively. Again, nearly all these populations were in developing countries; 1.5 billion on marginal agricultural land and nearly 1.6 billion in less favored agricultural areas, or 35% and 37% of the rural population respectively. The rural population share for the six major developing country regions were largely the same as in 2000 (see Table 1).

Figures 4 and 5 display the global distribution per km^2 of the rural population in developing countries in 2010 on less favored agricultural lands and areas. Again, the distributions are relatively similar.

By 2010, the number of people worldwide on remote less favored agricultural land had increased to over 330 million, of which at least 320 million were in developing countries (see Table 4). Around 7% of the rural population globally and almost 8% in developing countries were on remote marginal agricultural land. This proportion changes from 3% in Middle East & North Africa to nearly 12% in East Asia & Pacific. About one fifth of the global rural population on less favored agricultural land does not have market access, and almost 22% in developing countries. Europe & Central Asia has the smallest share (13%) and Sub-Saharan Africa the largest (29%).

Table 2. Rural population on remote less favored agricultural lands, 2000

	Population in 2000 (millions)		
	Rural population on remote less favored agricultural land (LFAL)	% share of rural population	% share of rural population on LFAL
Developing country	**288.2**	**7.8%**	**21.9%**
East Asia & Pacific	164.7	11.8%	25.5%
Europe & C. Asia	12.0	6.9%	12.4%
Latin America & Caribbean	12.8	4.3%	13.5%
Middle East & N. Africa	6.8	3.5%	15.1%
South Asia	42.6	3.9%	15.8%
Sub-Saharan Africa	49.3	8.9%	30.0%
Developed country	**10.2**	**2.5%**	**6.0%**
World	**298.4**	**7.3%**	**20.1%**

Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Estimated for 184 countries; one country was indeterminate due to changing political boundaries, and 20 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Table 3. Rural population on less favored agricultural lands and areas, 2010

	Population in 2010 (millions)				
	Rural population (1)	Rural population on less favored agricultural land (LFAL) (2)	% share (2)/(1)	Rural population in less favored agricultural areas (LFAA) (3)	% share (3)/(1)
Developing country	**4,248.6**	**1,499.7**	**35.3%**	**1,579.8**	**37.2%**
East Asia & Pacific	1,499.1	709.4	47.3%	739.7	49.3%
Europe & C. Asia	180.7	97.7	54.1%	98.4	54.5%
Latin America & Caribbean	336.1	109.2	32.5%	111.7	33.2%
Middle East & N. Africa	237.2	50.4	21.3%	50.9	21.4%
South Asia	1,284.0	309.7	24.1%	335.3	26.1%
Sub-Saharan Africa	711.4	223.2	31.4%	243.8	34.3%
Developed country	**415.3**	**166.9**	**40.2%**	**168.7**	**40.6%**
World	**4,663.9**	**1,666.6**	**35.7%**	**1,748.6**	**37.5%**

Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 4. Distribution of rural population of developing countries on less favored agricultural land, 2010

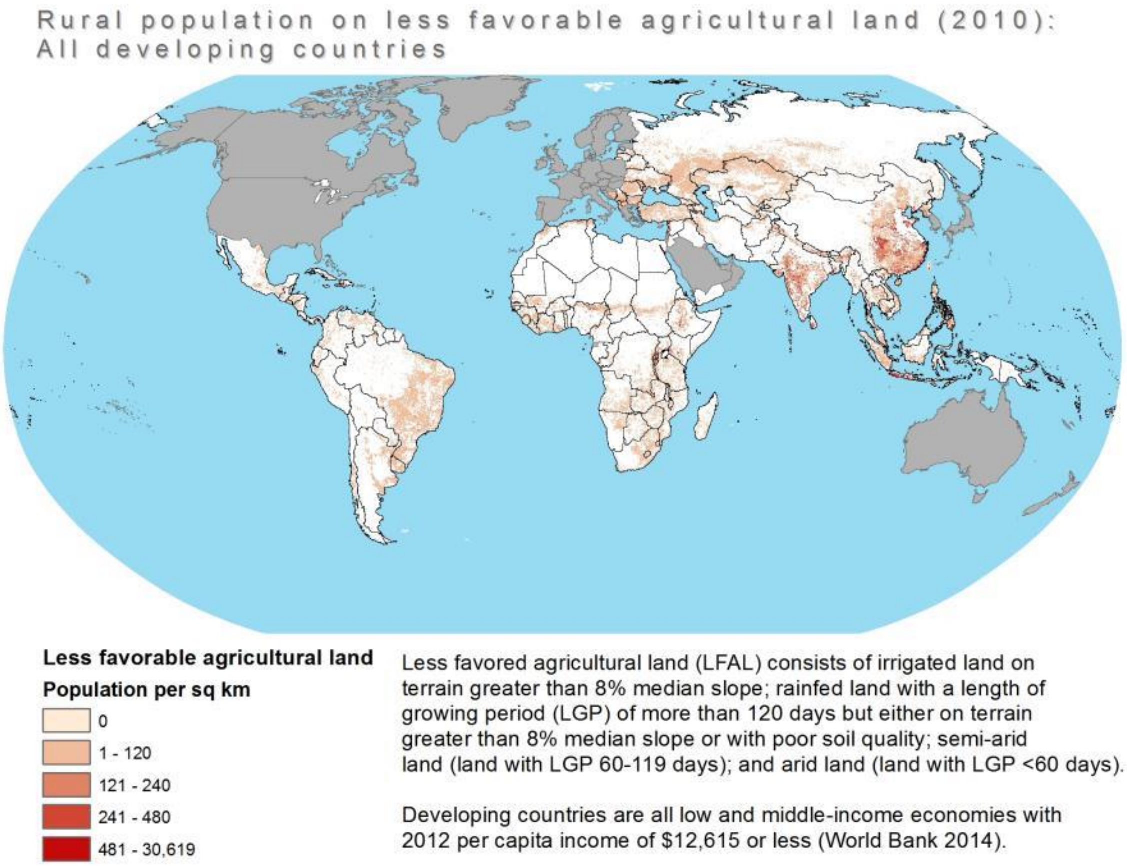


Figure 5. Distribution of rural population of developing countries in less favored agricultural areas, 2010

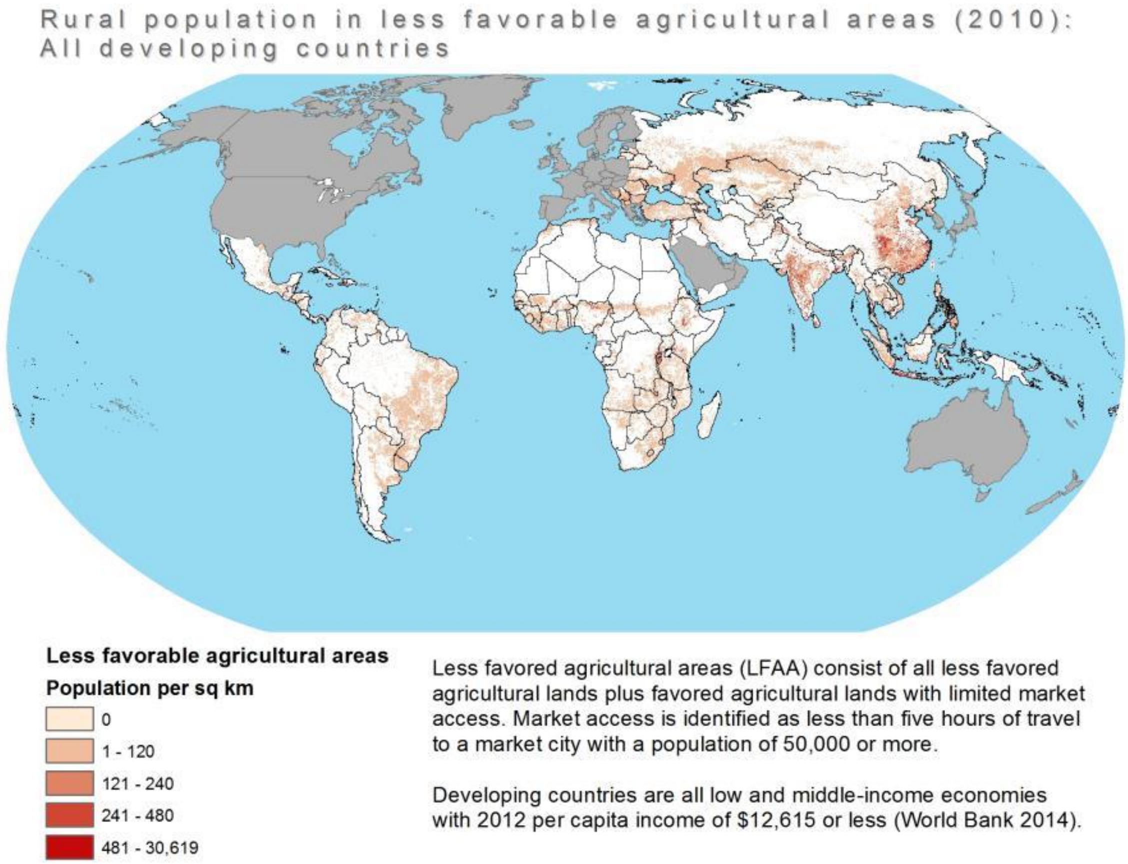


Table 4. Rural population on remote less favored agricultural lands, 2010

	Population in 2010 (millions)		
	Rural population on remote less favored agricultural land (LFAL)	% share of rural population	% share of rural population on LFAL
Developing country	**322.5**	**7.6%**	**21.5%**
East Asia & Pacific	173.1	11.5%	24.4%
Europe & C. Asia	12.4	6.8%	12.6%
Latin America & Caribbean	14.8	4.4%	13.5%
Middle East & N. Africa	7.2	3.0%	14.2%
South Asia	49.7	3.9%	16.0%
Sub-Saharan Africa	65.5	9.2%	29.4%
Developed country	**9.9**	**2.4%**	**5.9%**
World	**332.4**	**7.1%**	**19.9%**

Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Table 5 indicates the changes in the distribution of rural populations on less favored agricultural land and areas from 2000 to 2010. Over this period, rural population rose nearly 13% globally, around 3% in high-income economies and almost 15% in developing countries. However, in high-income countries, the rural populations on less favored agricultural lands, in less favored agricultural areas and on remote less favored agricultural lands fell by 3%. In contrast, in low and middle-income economies, the rural populations on marginal agricultural lands and in less favored agricultural areas grew at 14%, keeping pace with the overall growth in rural populations. The rural population on remote less favored agricultural lands grew at a slightly slower pace, just over 11%. However, from 2000 to 2010, this critical population group expanded over 15% in Latin America & Caribbean, nearly 17% in South Asia and 33% in Sub-Saharan Africa.

In conclusion, our spatial analysis confirms that the concentration of rural populations on less favored agricultural lands and less favored agricultural areas is predominantly a developing country problem. The number of people in these locations has increased significantly from 2000 to 2010, both globally and in each major developing country region. Of particular concern is the continuing expansion in the number of rural people in developing countries on less favored agricultural land without market access, from nearly 300 million in 2000 to over 330 million in 2010. This critical population group appears to be increasing by over 1% annually across the developing world, and at annual rates approaching 2% in Latin America & Caribbean and South Asia and over 3% in Sub-Saharan Africa (see Table 5).

Table 5. Rural population on less favored agricultural lands and areas, 2000-2010 changes

	Percentage (%) change from 2000 to 2010			
	Rural population (1)	Rural population on less favored agricultural land (LFAL) (2)	Rural population in less favored agricultural areas (LFAA) (3)	Rural population on remote less favored agricultural land (LFAL) (4)
Developing country	**14.6%**	**14.1%**	**14.3%**	**11.4%**
East Asia & Pacific	7.2%	10.0%	9.9%	5.1%
Europe & C. Asia	4.0%	1.4%	1.4%	3.3%
Latin America & Caribbean	14.3%	15.1%	15.2%	15.4%
Middle East & N. Africa	21.3%	12.3%	12.4%	5.6%
South Asia	17.8%	15.1%	15.2%	16.6%
Sub-Saharan Africa	28.3%	35.9%	35.8%	32.9%
Developed country	**2.6%**	**-2.9%**	**-2.9%**	**-3.1%**
World	**13.4%**	**12.1%**	**12.3%**	**11.9%**

Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days). Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2), (3) and (4) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

3. Rural Populations on Degrading and Improving Agricultural Land

Our approach to the spatial analysis of rural populations on degrading and improving agricultural land over 1981-2000 follows closely that of Bai et al. (2008 and 2010), who depict global change in the normalized difference vegetation (NDVI), scaled in terms of net primary productivity (NPP) change. Thus, in our analysis, *degrading agricultural land* consists of agricultural land with a negative change in net primary productivity from 1981-2000, where NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses. Consequently, *improving agricultural land* is agricultural land with a non-negative change in NPP from 1981-2000. Market accessibility was also used to identify *remote degrading* and *remote improving agricultural land*, where market access is less than five hours of travel to a market city with a population of 50,000 or more.

Using a variety of global spatially referenced datasets, we analyze the spatial distribution of rural population across developing countries in 2000 and 2010 on degrading versus improving agricultural land over 1981-2000 (See the technical notes in Appendix for further details). Degrading or improving land was determined using University of Maryland's Global Land Cover Facility's AVHRR Global Production Efficiency Model (GloPEM), which is available from 1981-2000 with annual summations of net primary production (NPP) change measured in grams of carbon sequestered per square meter per year (gC/m^2/yr). Agricultural land extent was obtained from the Pilot Analysis of Global Ecosystems (PAGE) (http://www.ifpri.org/dataset/pilot-analysis-global-ecosystems-page), and rural populations determined from the rural-urban extent dataset that was published as part of CIESIN Global Rural Urban Mapping Project (GRUMPv1). Market accessibility was used to identify remote areas using Nelson (2008) as released by the Global Environment Monitoring Unit of the Joint Research Centre of the European Commission.

Table 6 summarizes the estimates of the rural population on all degrading agricultural land in 2000. Globally, over 1.3 billion people lived in these areas in 2000, nearly all in developing countries. Around 32% of the rural population of low and middle-income economies was on degrading agricultural lands, and 34% of the global population. This share ranges from 13% in Latin America & the Caribbean to 51% in East Asia & Pacific. Almost all the world's 200 million people on remote degrading agricultural land were in developing countries. This accounts for 5% of the rural population globally and about 6% in low and middle-income economies. The proportion is less than 2% in Latin America & the Caribbean and 9% in East Asia & Pacific.

Figure 6 shows the global distribution per km^2 of the rural population in developing countries in 2000 on all degrading agricultural land.

Table 6. Rural population on all degrading agricultural lands, 2000

	Population in 2000 (millions)				
	Rural population (1)	Rural population on all degrading agricultural land (DAL) (2)	% share (2)/(1)	Rural population on all remote degrading agricultural land (3)	% share (3)/(1)
Developing country	**3,706.8**	**1,258.7**	**32.4%**	**202.2**	**5.5%**
East Asia & Pacific	1,398.4	710.3	50.8%	125.2	9.0%
Europe & C. Asia	173.8	67.0	38.5%	6.2	3.6%
Latin America & Caribbean	294.1	38.3	13.0%	5.6	1.9%
Middle East & N. Africa	195.6	43.7	22.3%	5.4	2.8%
South Asia	1,090.4	285.2	26.2%	27.4	2.5%
Sub-Saharan Africa	554.6	114.1	20.6%	32.4	5.8%
Developed country	**404.7**	**72.6**	**17.9%**	**3.2**	**0.8%**
World	**4,111.5**	**1,331.3**	**34.0%**	**205.4**	**5.0%**

Degrading agricultural land (DAL) consists of agricultural land with a negative change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses. Market accessibility is used to identify remote DAL, where market access is defined as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 6. Distribution of rural population of developing countries on all degrading agricultural land, 2000

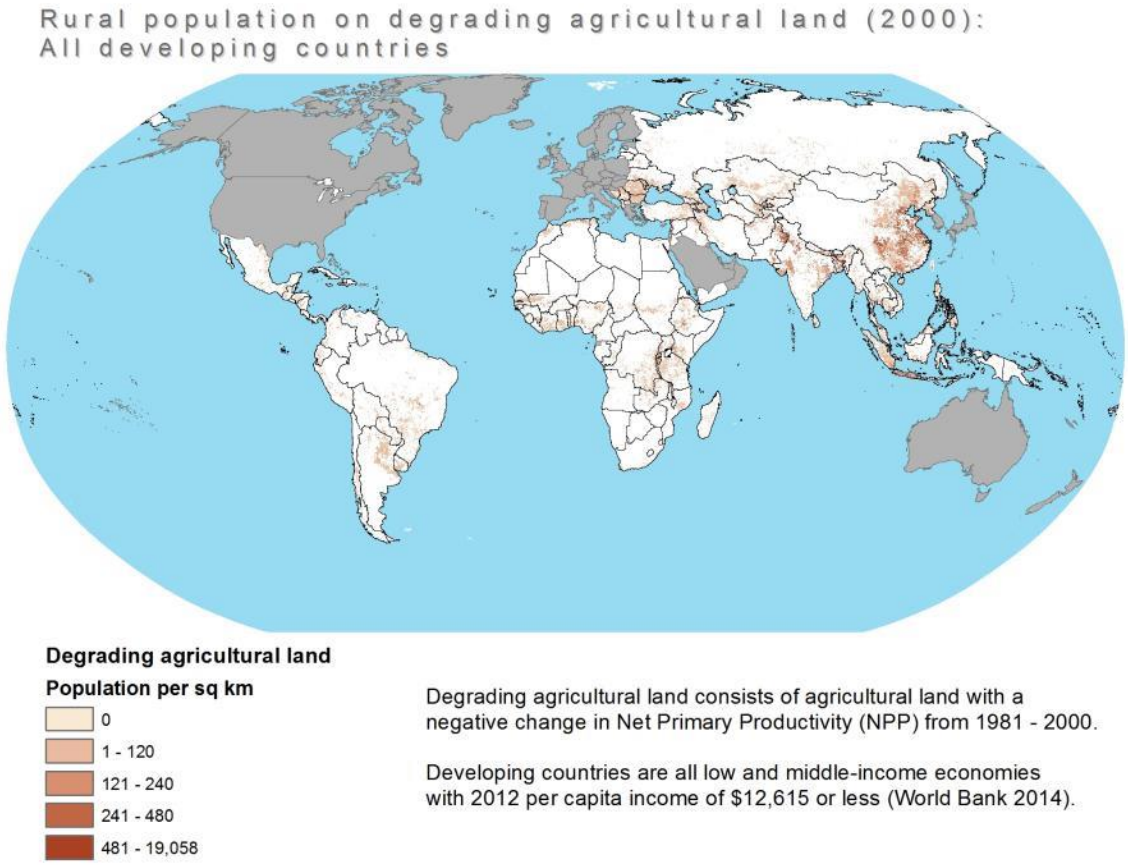


Table 7 indicates the distribution of the rural population on all improving agricultural land in 2000. Around 1.5 billion are on such lands globally, with 1.3 billion in developing countries. People on improving agricultural lands constitute 37% of the rural population worldwide and 36% in low and middle-income economies. Just over 160 million people globally are on improving agricultural lands without market access, almost all in developing countries. They account for about 4% of rural populations globally and in low and middle-income economies.

Figure 7 shows the global distribution per km^2 of the rural population in developing countries in 2000 on all improving agricultural land.

The results of the 2010 distribution of rural population on all degrading agricultural land are displayed in Table 8. By 2010, there were 1.5 billion on such lands globally and 1.4 billion in developing countries. They comprised 32% of the rural population worldwide and nearly 34% in low and middle-income economies. This share varies from nearly 14% in Latin America & Caribbean to 51% in East Asia & Pacific. The number of people globally on remote degrading agricultural land in 2010 was over 230 million, and located almost entirely in developing countries. They accounted for around 5% of the rural population worldwide and in low and middle-income economies. This proportion was 2% in Latin America & Caribbean compared to 9% in East Asia & Pacific. Figure 8 shows the global distribution per km^2 of the rural population in developing countries in 2100 on all degrading agricultural land.

By 2010, there were also 1.7 billion people worldwide on improving agricultural land, of which approximately 1.5 billion were in developing countries (see Table 9). The number of people on improving agricultural land without market access increased to nearly 180 million in 2010, with 170 million in developing countries. The global and regional shares of the rural population on all and remote improving agricultural land did not change significantly from 2000. Figure 9 depicts the global distribution per km^2 of the rural population in developing countries in 2010 on all improving agricultural land.

Table 7. Rural population on all improving agricultural lands, 2000

	Population in 2000 (millions)				
	Rural population (1)	Rural population on all improving agricultural land (IAL) (2)	% share (2)/(1)	Rural population on all remote improving agricultural land (3)	% share (3)/(1)
Developing country	**3,706.8**	**1,340.7**	**36.2%**	**155.3**	**4.2%**
East Asia & Pacific	1,398.4	398.7	28.5%	67.9	4.9%
Europe & C. Asia	173.8	66.7	38.4%	6.6	3.8%
Latin America & Caribbean	294.1	90.6	30.8%	9.3	3.2%
Middle East & N. Africa	195.6	28.1	14.4%	1.7	0.9%
South Asia	1,090.4	641.8	58.9%	37.3	3.4%
Sub-Saharan Africa	554.6	114.8	20.7%	32.5	5.9%
Developed country	**404.7**	**196.4**	**48.5%**	**9.0**	**2.2%**
World	**4,111.5**	**1,537.1**	**37.4%**	**164.3**	**4.0%**

Improving agricultural land (IAL) consists of agricultural land with a positive change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses. Market accessibility is used to identify remote IAL, where market access is defined as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 7. Distribution of rural population of developing countries on all improving agricultural land, 2000

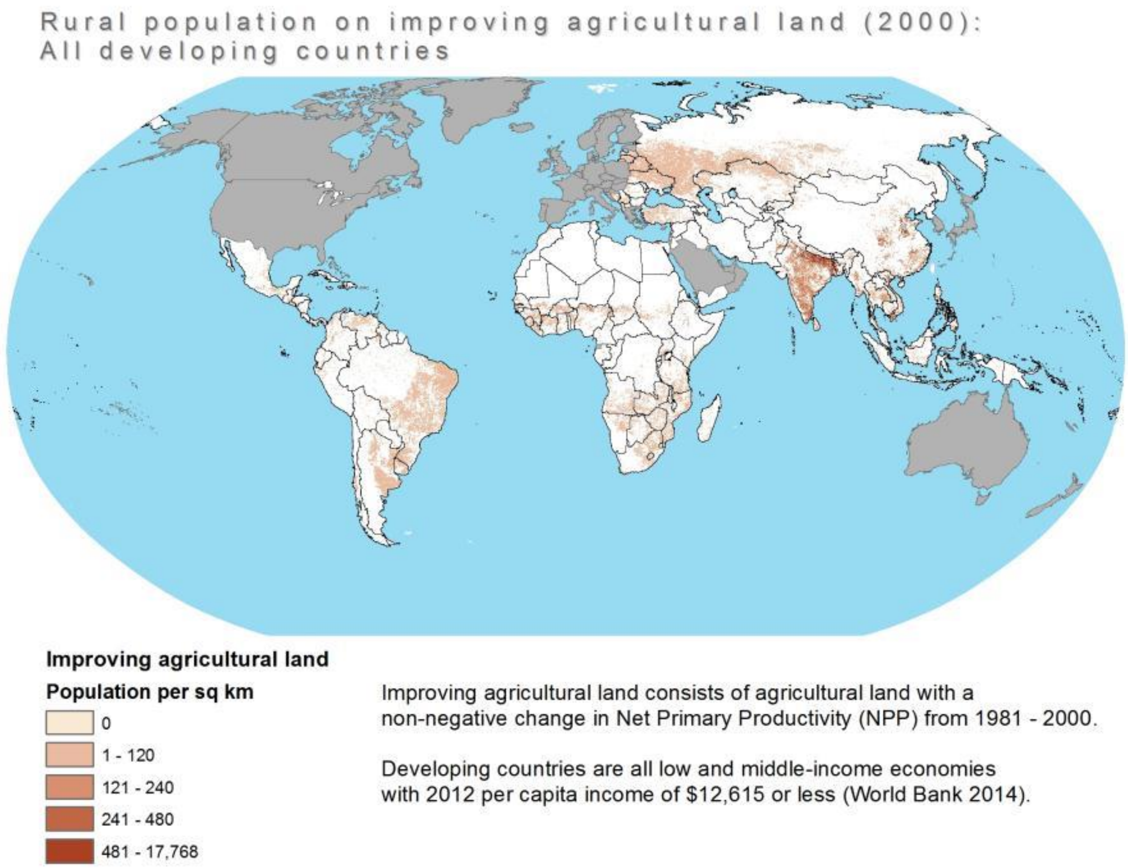


Table 8. Rural population on all degrading agricultural lands, 2010

	Population in 2010 (millions)				
	Rural population (1)	Rural population on all degrading agricultural land (DAL) (2)	% share (2)/(1)	Rural population on all remote degrading agricultural land (3)	% share (3)/(1)
Developing country	**4,248.6**	**1,426.3**	**33.6%**	**230.2**	**5.4%**
East Asia & Pacific	1,499.1	770.1	51.4%	133.6	8.9%
Europe & C. Asia	180.7	67.7	37.4%	6.5	3.6%
Latin America & Caribbean	336.1	45.3	13.5%	6.6	2.0%
Middle East & N. Africa	237.2	49.9	21.1%	5.8	2.4%
South Asia	1,284.0	336.1	26.2%	32.6	2.5%
Sub-Saharan Africa	711.4	157.2	22.1%	45.1	5.4%
Developed country	**415.3**	**70.6**	**17.0%**	**3.1**	**0.7%**
World	**4,663.9**	**1,496.9**	**32.1%**	**233.2**	**5.0%**

Degrading agricultural land (DAL) consists of agricultural land with a negative change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses. Market accessibility is used to identify remote DAL, where market access is defined as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 8. Distribution of rural population of developing countries on all degrading agricultural land, 2010

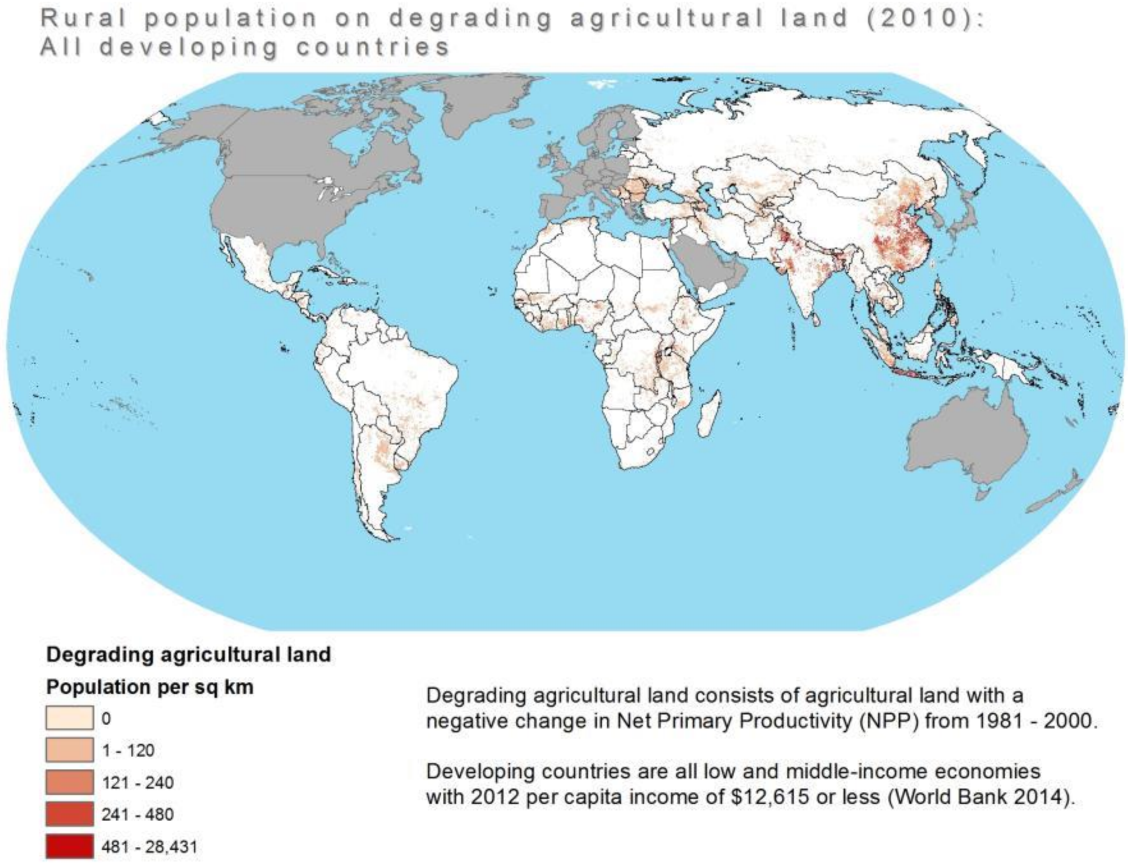


Table 9. Rural population on all improving agricultural lands, 2010

	Population in 2010 (millions)				
	Rural population (1)	Rural population on all improving agricultural land (IAL) (2)	% share (2)/(1)	Rural population on all remote improving agricultural land (3)	% share (3)/(1)
Developing country	**4,248.6**	**1,539.4**	**36.2%**	**169.2**	**4.0%**
East Asia & Pacific	1,499.1	446.3	2.8%	68.2	4.5%
Europe & C. Asia	180.7	66.3	36.7%	7.0	3.9%
Latin America & Caribbean	336.1	103.3	30.7%	10.5	3.1%
Middle East & N. Africa	237.2	34.6	14.6%	2.5	1.1%
South Asia	1,284.0	734.5	57.2%	43.8	3.4%
Sub-Saharan Africa	711.4	154.3	21.7%	37.2	5.2%
Developed country	**415.3**	**190.5**	**45.9%**	**9.0**	**2.2%**
World	**4,663.9**	**1,729.9**	**37.1%**	**178.2**	**3.8%**

Improving agricultural land (IAL) consists of agricultural land with a positive change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses. Market accessibility is used to identify remote IAL, where market access is defined as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

Figure 9. Distribution of rural population of developing countries on all improving agricultural land, 2010

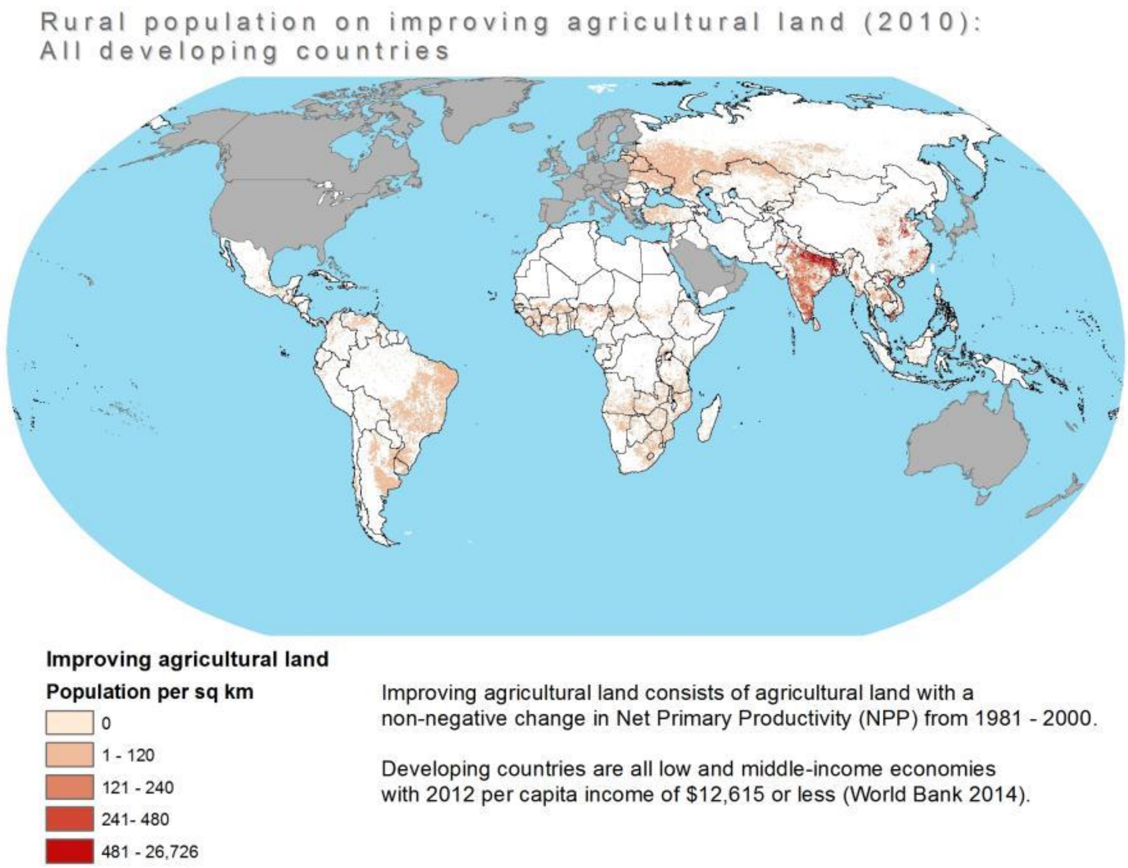


Table 10 indicates the changes in the distribution of rural populations on degrading and improving agricultural land from 2000 to 2010. Recall that, over this period, rural population rose nearly 13% globally, 3% in high-income economies and almost 15% in developing countries. However, in high-income countries, the rural populations on all degrading and improving agricultural land fell by 3%, and declined by 2% on remote degrading agricultural land. On remote improving lands, the population was almost unchanged. In contrast, in low and middle-income economies, the rural populations in all degrading, remote degrading and improving agricultural lands grew 13%, 14% and 15% respectively, keeping pace with the overall growth in rural populations. However, in Sub-Saharan Africa people on all remote and degrading agricultural lands grew 38% and 39% respectively, in Latin America & Caribbean 18% and 17%, and in South Asia 18% and 19%. In developing countries, from 2000 to 2010, the rural population on remote improving agricultural lands grew at a slower pace, around 9%. The fastest growth (49%) occurred in the Middle East & North Africa, but in East Asia & Pacific the population was largely unchanged.

In conclusion, our spatial analysis confirms that the concentration of rural populations on degrading agricultural lands is overwhelmingly a developing country problem. The number of people in these locations has increased significantly from 2000 to 2010, both globally and in each major developing country region. However, an encouraging trend is the growth in the population of developing countries on all improving agricultural land, even in some remote areas. But there should also be concern over the growth in the rural population of developing countries on degraded agricultural land without market access, which increased from just over 200 million in 2000 to 230 million in 2010. This critical population group appears to be expanding by over 1% annually across the developing world, and at annual rates approaching 2% in Latin America & Caribbean and South Asia and 4% in Sub-Saharan Africa (see Table 10).

Table 10. Rural population on degrading and improving agricultural lands, 2000-2010 changes

	Percentage (%) change from 2000 to 2010				
	Rural population (1)	Rural population on all degrading agricultural land (DAL) (2)	Rural population on remote DAL (3)	Rural population on all improving agricultural land (IAL) (4)	Rural population on remote IAL (5)
Developing country	**14.6%**	**13.3%**	**13.8%**	**14.8%**	**8.9%**
East Asia & Pacific	7.2%	8.4%	6.8%	11.9%	0.4%
Europe & C. Asia	4.0%	1.0%	4.4%	-0.6%	6.4%
Latin America & Caribbean	14.3%	18.4%	17.1%	14.1%	12.6%
Middle East & N. Africa	21.3%	14.3%	5.9%	23.0%	49.1%
South Asia	17.8%	17.8%	18.9%	14.4%	17.3%
Sub-Saharan Africa	28.3%	37.8%	39.3%	34.5%	14.6%
Developed country	**2.6%**	**-2.8%**	**-1.8%**	**-3.0%**	**0.1%**
World	**13.4%**	**12.4%**	**13.6%**	**12.5%**	**8.5%**

Degrading agricultural land (DAL) consists of agricultural land with a negative change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses.

Improving agricultural land (IAL) consists of agricultural land with a positive change in Net Primary Productivity (NPP) from 1981-2000. NPP is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses.

Market accessibility is used to identify remote DAL and IAL, where market access is defined as less than five hours of travel to a market city with a population of 50,000 or more.

Developing countries are all low and middle-income economies with 2012 per capita income of $12,615 or less (World Bank 2014).

Column (1) is estimated for 205 countries. Columns (2) and (3) are estimated for 183 countries; one country was indeterminate due to changing political boundaries, and 21 countries had missing data or insufficient spatial resolution denoting agricultural land. Columns (4) and (5) are estimated for 182 countries; one country was indeterminate due to changing political boundaries, and 22 countries had missing data or insufficient spatial resolution denoting agricultural land.

See technical notes in Appendix for further details.

4. Poverty and the Spatial Distribution of Rural Populations

Our poverty analysis examines whether the 2000 spatial distribution of rural populations in developing countries on degraded and improving agricultural land, less favored agricultural lands and less favored agricultural areas have a direct influence on changes in poverty over 2000-2012 or an indirect influence through attenuating the poverty-reducing impact of income growth. We test these hypotheses through examining how the spatial distribution of rural populations in 2000 influences poverty changes from 2000 to 2012 in 83 developing countries.

As indicated in Tables 1-5, we have estimated four spatial distribution variables for the rural population in 2000 on marginal agricultural land and less favored areas for low and middle-income economies. These variables are:

- the share (%) of the rural population on less favored agricultural land (henceforth s_1),
- the share (%) of the rural population on less favored agricultural areas (s_2),
- the share (%) of the rural population on remote less favored agricultural land (s_3), and
- the share (%) of the rural population on less favored agricultural lands on remote land (s_4).

In addition, from Tables 6-10, we have four spatial distribution variables for the rural population in 2000 on degrading and improving agricultural land and remote areas for developing countries:

- the share (%) of rural population located on all degrading agricultural land (d_1),
- the share (%) of rural population located on all remote degrading agricultural (d_2),
- the share (%) of rural population located on all improving agricultural land (i_1), and
- the share (%) of rural population located on all remote improving agricultural (i_2).

We obtain our cross-country measures of a given poverty line z, the poverty headcount index H, and mean income μ from PovcalNet, the on-line tool for poverty measurement developed by the Development Research Group of the World Bank (Available online at http://iresearch.worldbank.org/PovcalNet/). PovcalNet produces internationally comparable country level poverty and income distribution estimates based on more than 850 standardized household surveys across 127 developing countries. From this database, we identify 83 low and middle-income economies with at least two suitable household surveys from 2000 to 2012. The longest available spell between surveys is used for each country, and both surveys use the same welfare indicator, either consumption or income per person. The median interval between surveys is eight years, and it varies from two to eleven years.[1] All monetary measures are in constant 2005 prices and are at Purchasing Power Parity (PPP).

[1] As far as possible, the initial survey year chosen was 2000, or for the soonest subsequent year. However, for Burundi, Gambia, Ghana, Iran, Maldives and Yemen, the initial survey year was 1998, and for Kenya 1997.

The poverty headcount index H is the percentage of the population living in households with consumption per capita (or income when consumption is not available) below the poverty line. We follow Ravallion (2012) and choose a poverty line z of \$2.00 per person per day at 2005 PPP, which is the median poverty line among developing countries. In the initial survey year, the median poverty headcount index across all 83 countries was 42.85%, but ranged widely from 0.29% to 95.44%. By the final survey year, the median poverty headcount was 27.86%, and it varied from 0.08% to 93.49%.

Mean income μ is the average monthly (2005 PPP \$) per capita income or consumption expenditure from the household surveys for each country in the relevant year. In the initial survey year, the median per capita monthly income was \$100 across all 83 countries, and ranged from \$24 to \$2,003. In the final survey year, median income was \$115, and varied from \$28 to \$2,012. Finally, inequality is measured by the usual Gini index, which was also obtained from the PovcalNet cross-country household surveys for the relevant years.

We also employ a number of control variables in our analysis, following the approach of similar poverty analyses.[2] The controls are inflation, government consumption as a share of GDP, arable land per capita, agricultural value added as a share of GDP and per worker, investment as a share of GDP, trade openness, primary school enrollment, and life expectancy. These variables were obtained from the World Development Indicators (World Bank 2014), and as far as possible, for 2000 and our sample of 83 countries. Other controls include a dummy for landlocked country as defined by UNDP (http://unctad.org/en/pages/aldc/Landlocked%20Developing%20Countries/List-of-land-locked-developing-countries.aspx), for small island developing states as defined by UNESCO (http://www.unesco.org/new/en/natural-sciences/priority-areas/sids/about-unesco-and-sids/sids-list/), and distance from equator for each country. We also employ rule of law and democracy (voice and accountability) indices, from the Worldwide Governance Indicators (http://data.worldbank.org/data-catalog/worldwide-governance-indicators), which were averaged over 1996-2000 for each country. Finally, we use regional dummies for the six main developing country regions.

To analyze the possible direct and indirect influences of our spatial distribution variables s_k, d_k and i_k in 2000 on poverty changes from 2000 to 2012 in our 83 sample countries, we follow a similar estimation strategy to Ravallion (2012). Thus, our basic regression is

$$g_i\left(H_{it}\right) = a_0 + a_1 \ln\left(v_{it-t}\right) + \left(b_0 + b_1 v_{it-t}\right) g_i\left(m_{it}\right) + w_{it}, \qquad (1)$$

where i is each country observation, t is the final survey date, τ is the length of spell between surveys, and w_{it} is the error term. The annualized growth rate in the poverty headcount between surveys is $\gamma_i\left(H_{it}\right) \equiv \ln\left(H_{it}/H_{it-\tau}\right)/\tau$, and $g_i\left(m_{it}\right)$ is similarly defined as the annualized growth

[2] See, for example, Adams and Page (2005); Dollar and Kraay (2002); Kraay (2006) and Ravallion (2012).

rate in mean income. The initial level of the variable of interest is v_{it-t}, which in Ravallion (2012) is the initial poverty level $H_{it-\tau}$, whereas in much of our analysis, it is one of the eight spatial distribution variables in 2000, i.e. s_{kit-t} for marginal agricultural lands and remote areas, d_{kit-t} for degrading agricultural land and i_{kit-t} for improving agricultural land.

Two tests of restrictions on the various parameters estimated by (1) determine the direct and indirect influence of v_{it-t} on the annualized change in poverty. For example, rejection of the null hypothesis $\alpha_1 = 0$ indicates that initial poverty or spatial distribution levels have a direct influence on changes in poverty over time, and subsequently, the magnitude of α_1 determines whether this influence is positive or negative. Failure to reject the null hypothesis of homogeneity, i.e. $b_0 + b_1 = 0$ in the case of $H_{it-\tau}$, s_{kit-t} or d_{kit-t} and $b_0 - b_1 = 0$ in the case of i_{kit-t}, confirms that initial poverty or spatial distribution levels have an indirect influence through "adjusting" the growth elasticity of poverty reduction. That is, these restrictions imply that the correct regressor in (1) is $(1 - v_{it-t})g_i(m_{it})$ in the case of $H_{it-\tau}$, s_{kit-t} or d_{kit-t} and $(1 + v_{it-t})g_i(m_{it})$ in the case of i_{kit-t}. Because even growth adjusted for initial poverty or spatial distribution is expected to reduce poverty, the expected signs of the coefficients of these two regressors are negative.

We test these hypotheses by estimating various versions of (1), with v_{it-t} represented by each of our eight spatial distribution variables in 2000, i.e. s_{kit-t} for marginal agricultural lands and remote areas, d_{kit-t} for degrading agricultural land and i_{kit-t} for improving agricultural land. We estimate the regressions both with and without additional control variables. In none of the specifications could we reject the null hypothesis $\alpha_1 = 0$ that initial spatial distribution levels in 2000 have a direct influence on changes from 2000 to 2012 in our sample of 83 developing countries. These results suggest that the 2000 spatial distribution of rural populations in developing countries on degrading and improving agricultural land, less favored agricultural lands and less favored agricultural areas does not have a direct influence on changes in poverty over 2000-2012.

However, in all estimations of (1) the null hypothesis of homogeneity could not be rejected either. Imposing the resulting restrictions on (1) suggest that the correct regressor is $(1 - v_{it-t})g_i(m_{it})$ in the case of s_{kit-t} or d_{kit-t} and $(1 + v_{it-t})g_i(m_{it})$ in the case of i_{kit-t}. In all versions of these estimations, both with and without controls, the relevant coefficient was significant and negative. These results confirm that initial spatial distribution levels have an indirect influence through "adjusting" the growth elasticity of poverty reduction.

Table 11 summarizes the results of this analysis for the four s_k spatial distribution variables for the rural population on less favored agricultural land and in less favored agricultural areas. For comparison, the table also shows the impacts on changes in poverty from an increase in income growth only, an increase in poverty adjusted growth and an increase in initial poverty levels. For example, in the absence of any change in the spatial distribution of rural populations or in initial poverty levels, a one-standard-deviation increase of 3.52% in average income growth in our sample of developing countries, from 3.36% to 6.88%, would reduce the annual poverty rate by 4.97%.

For our sample of countries, a one-standard-deviation change in the share of rural population on less favored agricultural lands (s_1) is equivalent to increasing this spatial distribution by 21% (e.g., at the mean, this share of rural population would rise from 38% to 59%). This has the effect of increasing the annual poverty rate by 0.92% to 0.99%. A one-standard-deviation change (also 21%) in the share of rural population located in less favored agricultural areas (s_2) increases poverty from 0.97% to 1.11% per year. A one-standard-deviation change in the share of rural population located on remote less favored agricultural land (s_3), which is 8.4%, would increase poverty by 0.35% to 0.47%. Finally, a one-standard-deviation change in the share of rural population on less favored agricultural land located on remote land (s_4) by 19% increases annual poverty rates by 0.95% to 1.32%.

Table 12 indicates the results of our poverty analysis for the two d_k spatial distribution variables for rural populations on degrading agricultural land and for the two i_k distribution variables for populations on improving agricultural land. For our sample of countries, a one-standard-deviation change in the share of rural population on degrading agricultural land (d_1) is equivalent to increasing this spatial distribution by 21% (e.g., at the mean, this share of rural population would rise from 27% to 48%). This has the effect of increasing the annual poverty rate by 0.98% to 1.04%. A one-standard-deviation change (4%) in the share of rural population located on remote degrading agricultural land (d_2) increases poverty from 0.18% to 0.25% per year. However, a one-standard-deviation change in the share of rural population located on all improving agricultural land (i_1), which is 21%, would reduce poverty by 0.57% to 0.76%. Finally, a one-standard-deviation change in the share of rural population on remote improving agricultural land (i_2) by 19% reduces annual poverty rates by 0.55% to 0.74%.

Table 11. Effects of key less favored agricultural land and less favored agricultural area variables on annualized change in poverty (%)

	Descriptive Statistics			% change in poverty of one standard deviation change
Key variables, $v_{it-\tau}$	Mean	Median	Standard Deviation	
Annualized growth (%) in the poverty rate ($2/day), $\gamma(H_{it})$	-7.70	-4.26	10.28	--
Annualized growth (%) in the mean survey income, $\gamma(\mu_{it})$	3.36	3.32	3.52	-4.97
Annualized poverty-adjusted growth (%) in the mean survey income, $\gamma(\mu_{it})(1- H_{it-\tau})$	1.74	1.11	2.41	-6.82
Initial headcount poverty rate (% of population), $H_{it-\tau}$	46.41	42.85	29.56	2.81
% of rural population on less favored agricultural land (2000), $s_{1it-\tau}$	38.15	38.37	20.95	0.92 to 0.99
% of rural population in less favored agricultural areas (2000), $s_{2it-\tau}$	40.04	41.37	20.79	0.97 to 1.11
% of rural population located on remote less favored agricultural land (2000), $s_{3it-\tau}$	8.50	7.06	8.40	0.35 to 0.47
% of rural population on less favored agricultural land located on remote land (2000), $s_{4it-\tau}$	24.74	23.55	18.81	0.95 to 1.32

The last column reports the impact on the annualized growth (%) in the poverty rate via a one standard-deviation change in each of the relevant $v_{it-\tau}$ variables listed in the far-left column. The penultimate column shows the one-standard-deviation change for each variable from the sample of 83 countries. For the spatial distribution variables, the lower estimate is for estimations without additional control variables whereas the higher estimate includes controls.

Table 12. Effects of key degrading and improving agricultural land variables on annualized change in poverty (%)

Key variables, $v_{it-\tau}$	Descriptive Statistics: Mean	Median	Standard Deviation	% change in poverty of one standard deviation change
Annualized growth (%) in the poverty rate ($2/day), $\gamma(H_{it})$	-7.70	-4.26	10.28	--
Annualized growth (%) in the mean survey income, $\gamma(\mu_{it})$	3.36	3.32	3.52	-4.97
Annualized poverty-adjusted growth (%) in the mean survey income, $\gamma(\mu_{it})(1- H_{it-\tau})$	1.74	1.11	2.41	-6.82
Initial headcount poverty rate (% of population), $H_{it-\tau}$	46.41	42.85	29.56	2.81
% of rural population on all degrading agricultural land (2000), $d_{1it-\tau}$	27.11	22.44	21.04	0.98 to 1.04
% of rural population on all remote degrading agricultural land (2000), $d_{2it-\tau}$	5.02	3.81	4.43	0.18 to 0.25
% of rural population on all improving agricultural land (2000), $i_{1it-\tau}$	31.89	29.6	21.05	-0.57 to -0.76
% of rural population on all remote improving agricultural land (2000), $i_{2it-\tau}$	13.45	5.21	18.83	-0.55 to -0.74

The last column reports the impact on the annualized growth (%) in the poverty rate via a one standard-deviation change in each of the relevant $v_{it-\tau}$ variables listed in the far-left column. The penultimate column shows the one-standard-deviation change for each variable from the sample of 83 countries. For the spatial distribution variables, the lower estimate is for estimations without additional control variables whereas the higher estimate includes controls.

To summarize the results of our poverty analysis, we find no evidence of a direct impact on poverty changes from the spatial distribution of rural populations on less favored agricultural land, less favored agricultural areas or degrading and improving agricultural land, but there is a significant indirect impact of these distributions on the poverty-reducing effects of income growth. Across a wide range of developing countries, as more rural people are located on less-favored and degrading agricultural land, as well as in less favored agricultural areas, the result is an increase in the overall poverty rate. However, if the share of the rural population on improving agricultural land rises, then poverty is reduced. The most critical population groups appear to be rural populations on less favored and degrading agricultural land without market access. If there is a substantial reduction in the share of the rural population on remote less favored and degrading agricultural land, then poverty rates could fall across a wide range of developing countries.

5. Conclusion: Policy Implication and Further Research

This study has shown that a sizable proportion of the rural population in developing countries is concentrated on less favored agricultural lands, which are subject to low productivity and degradation due to steep slopes, poor soil quality or limited rainfall (Figure 1, boxes A and B). In 2000, over 1.3 billion rural people in developing countries, almost 36% of the rural population, were located on these lands, and their numbers increased to 1.5 billion in 2010 (35% of the rural population).

A large segment of the rural population is also located in less favored agricultural areas, which include less favored agricultural lands plus favorable land that is remote, due to long distances to markets and limited access to infrastructure (Figure 1, boxes A, B and D). In 2000, nearly 1.4 billion people (37% of the rural population) lived in these areas in developing countries, increasing to nearly 1.6 billion (still 37% of the rural population) in 2010.

Perhaps most critical may be the rural population located on less favored agricultural lands that are also remote due to poor access to infrastructure and markets (Figure 1, box B). In 2000, this population in developing countries consisted of 288 million people. Although they comprised less than 8% of the rural population, they accounted for 22% of the rural population on less favored agricultural land. By 2010, the rural population on remote less favored agricultural land had increased to 323 million people.

We also find that large numbers of the rural population in developing countries are located on agricultural land that has been degrading over 1981 to 2000. In 2000, nearly 1.3 billion were located on all degrading agricultural land (32% of the rural population), which included 202 million without market access (around 6% of the rural population). By 2010, over 1.4 billion people were located on degrading agricultural land (34% of the rural population), which included 230 million people in remote areas (over 5% of the rural population).

In addition, large segments of the rural population in developing countries are located on agricultural land that has been improving in terms of net primary productivity over 1981-2000. In 2000, there were 1.3 billion people on improving agricultural land, or 36% of the rural population. They included 155 million people without market access, or 4% of the rural population. By 2010, there were over 1.5 billion people on improving agricultural land in developing countries, and the numbers in remote areas increased to 169 million people.

Our poverty analysis reveals that, as more rural people are located on less-favored agricultural land, in less favored agricultural areas and on degrading agricultural land, the result is likely to be an increase in the overall poverty rate. Our analysis also confirms that the most critical rural populations may be people on less favored and degrading agricultural land in remote areas. As these population distributions account for a larger share of rural populations across developing countries, the ability of overall income growth to reduce poverty may be severely affected. However, we also find that a greater share of the rural population on improving agricultural land reduces poverty rates. This suggests that, as more rural people experience improving agricultural land, poverty could be reduced in developing countries.

These results lend credence to recent concerns about the prevalence of geographical poverty traps in the rural areas of developing countries (Barbier 2012; Bird et al. 2002 and 2010; Jalan and Ravallion 2002; Kanbur and Venables 2005). As the World Bank (2008, p. 49) has pointed out, "in such a case, reducing rural poverty requires either a large-scale regional approach or assisting the exit of populations." It may be that both strategies will be required to alleviate the problem of the concentration of rural populations on less favored agricultural lands, degrading agricultural lands and less favored agricultural areas, which as this study has shown appears to be a major obstacle to the poverty-reducing effect of overall income growth in developing countries. In particular, our results suggest that the most critical and vulnerable rural population group are those located on less favored and degrading agricultural lands that are also remote from markets. It is these segments of the rural population that should be the main target of any strategy aimed at encouraging out-migration while investing in improving the livelihoods of those who remain in such areas.

As our study indicates, currently just about the same number of rural people in developing countries (1.4 billion) are on degrading agricultural land as are on improving agricultural land (1.5 billion). Both groups account for approximately one third (around 34% and 36%, respectively) of the rural population. Our results suggest that substantial poverty reduction could occur in developing countries if more of the rural population farmed improving as opposed to degrading agricultural land. Targeting such rural populations in developing countries to overcome biophysical constraints to agriculture and limited market access and infrastructure must be an urgent priority.

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Appendix: Technical Notes

Data sources:

Several geospatial datasets were utilized in this analysis

(1) National boundaries were determined from the Gridded Population of the World, Version 3 (GPWv3): National Administrative Boundaries file as published by the Center for International Earth Science Information Network (CIESIN) and Centro Internacional de Agricultura Tropical (CIAT) in 2005. Country boundaries are denoted by polygons and are identified using unique ISO3V10 3-letter country/state codes. The geographic coordinates of this dataset are in decimal degrees using the World Geodetic System spheroid of 1984 (WGS84). Territories of countries were not included in this analysis.

Center for International Earth Science Information Network (CIESIN), Columbia University; and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World Version 3 (GPWv3): National Boundaries. Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), Columbia University. Available at http://sedac.ciesin.columbia.edu/gpw. (Accessed 17 July 2013).

(2) Populations for 2000 and 2010 were identified using the Gridded Population of the World, Version 3 (GPWv3) dataset published in 2005 by the CIESIN, International Food Policy Research Institute (IFPRI) and CIAT. We chose not to use the higher resolution Global Rural-Urban Mapping Project (GRUMP), Version 1 also published by CIESIN because in addition to 1990, 1995 and 2000 population data, the GPWv3 also offers population projections for 2005, 2010 and 2015. The resolution of this GRID formatted raster is 0.041666667 by 0.041666667 decimal degrees or 2.5 by 2.5 arc-minutes (approximately 5 km^2 cells).

Center for International Earth Science Information Network (CIESIN)/Columbia University, United Nations Food and Agriculture Programme (FAO), and Centro Internacional de Agricultura Tropical (CIAT). 2005. Gridded Population of the World, Version 3 (GPWv3): Population Count Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/gpw-v3-population-count. (Accessed 7 July 2013).

(3) Urban areas were identified using the Urban Extents Grid, Version 1 (1995) from GRUMP V1. This data was published in 2011 by CIESIN, International Food Policy Research Institute (IFPRI), the World Bank and Centro Internacional de Agricultura Tropical (CIAT). The resolution of this GRID formatted raster is 0.0083333333 by 0.0083333333 decimal degrees or 30 arc-seconds (approximately 1 km^2 cells). Rural areas were defined as those that are non-urban.

Center for International Earth Science Information Network (CIESIN)/Columbia University, International Food Policy Research Institute (IFPRI), The World Bank, and Centro Internacional de Agricultura Tropical (CIAT). 2011. Global Rural-Urban Mapping Project, Version 1 (GRUMPv1): Urban Extents Grid. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/grump-v1-urban-extents*. (Accessed 17 July 2013).*

(4) Length of growing period (LGP) data, using a baseline period of 1961-1990, was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the Agro-climatic resources series with the "Growing period" collective title. The resolution of this TIFF formatted raster is 0.083333333 by 0.083333333 decimal degrees or 5 by 5 arc-minutes (approximately 10 km^2 cells).

FAO Global Agro-Ecological Zones Data Portal version 3. Available online: http://gaez.fao.org/ *(Accessed 17 July 2013).*

(5) Terrain data, for median terrain slope classes, was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the land resources series with the "Terrain Resources" collective title. The dataset's eight relevant terrain classes include (i) 0 - 0.5%, (ii) 0.5 - 2%, (iii) 2 – 5%, (iv) 5 – 8%, (v) 8 – 16%, (vi) 16 – 30%, (vii) 30 – 45% and (viii) >45%. The resolution of this TIFF formatted raster is 0.083333333 by 0.083333333 decimal degrees or 5 by 5 arc-minutes (approximately 10 km^2 cells).

FAO Global Agro-Ecological Zones Data Portal version 3. Available online: http://gaez.fao.org/ *(Accessed 17 July 2013).*

(6) Soil constraints are identified from a series of data sources published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the land resources series with the "Soil Resources" collective title. There are seven constraints on soil including (i) nutrient availability, (ii) nutrient retention capacity, (iii) rooting conditions, (iv) oxygen availability to roots, (v) excess salts, (vi) toxicity, and (vii) workability. Within each soil constraint category there are four levels classifying how constrained soil is including (i) No or slight constraints, (ii) Moderate constraints, (iii) Severe constraints and (iv) Very severe constraints. We consider less favored soil where any of these constraints are considered severe or very severe. The resolution of this TIFF formatted raster is 0.083333333 by 0.083333333 decimal degrees or 5 by 5 arc-minutes (approximately 10 km^2 cells).

FAO Global Agro-Ecological Zones Data Portal version 3. Available online: http://gaez.fao.org/ *(Accessed 17 July 2013).*

(7) Irrigated cultivated land data was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the land resources series with the "Water Resources" collective title. The percentage of land equipped for irrigation is given for each pixel in the dataset. Consistent with the Fan and Hazell (1999), we classify land as irrigated if greater than 25% of all cultivated land within a pixel is irrigated. The resolution of this TIFF formatted raster is 0.083333333 by 0.083333333 decimal degrees or 5 by 5 arc-minutes (approximately 10 km^2 cells).

Fan, S., and P. Hazell. 1999. "Are Returns to Public Investment Lower in Less-Favored Rural Areas? An Empirical Analysis of India". Environment and Production Technology Division Discussion Paper 43. International Food Policy Research Institute, Washington, DC.

FAO Global Agro-Ecological Zones Data Portal version 3. Available online: http://gaez.fao.org/ (Accessed 17 July 2013).

(8) Market accessibility was used to identify remote areas using Nelson (2008) *"Travel time to major cities: A global map of accessibility"* as released by the Global Environment Monitoring Unit of the Joint Research Centre of the European Commission. Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more. This dataset was published in seconds of travel to the nearest city and was converted to hours of travel. Additional details on how travel distances and speeds were calculated and accompanying assumptions can be found here

http://bioval.jrc.ec.europa.eu/products/gam/description.htm. The resolution of this GRID formatted raster is 0.0083333333 by 0.0083333333 decimal degrees or 30 arc-seconds (approximately 1 km^2 cells).

Nelson, A. 2008. Travel time to major cities: A global map of Accessibility. Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra Italy. Available at http://gem.jrc.ec.europa.eu/.

(9) Global agricultural lands were identified using the International Food Policy Research Institute's (IFPRI) Pilot Analysis of Global Ecosystem (PAGE) agricultural extent (PAGE v.1).

Pilot Analysis of Global Ecosystems (PAGE): Agroecosystems, 2000. 2005. Washington, DC: World Resources Institute and the International Food Policy Research Institute.(datasets). http://www.ifpri.org/dataset/pilot-analysis-global-ecosystems-page. (Accessed 17 July 2013)

Consistent with the original seasonal land cover region (SLCR) agriculture threshold (see You et al. (2008) for greater detail), we set the percent of land cover area consisting of "cropland, grazing land or irrigated area net of areas with a growing period of zero days" (Sebastian 2006) threshold at thirty percent.

You, Liangzhi, Stanley Wood, and Kate Sebastian. 2008 "COMPARING AND SYNTHESIZING DIFFERENT GLOBAL AGRICULTURAL LAND DATASETS FOR CROP ALLOCATION MODELING." The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37(B7), 1433-40.

Sebastian, K. 2006b. Global Extent of Agriculture. Dataset derived from Ramankutty (2005 & 2002), Siebert (2006) and IIASA/FAO (2000). International Food Policy Research Institute (IFPRI).Washington, D.C. Unpublished data

Note the thirty percent threshold is slightly more restrictive than the ten percent threshold used in the World Development Report (WDR) 2008 analysis (Sebastian 2007), which will make our estimates of individuals on agricultural land conservative.

Sebastian, K. 2007. GIS/Spatial Analysis Contribution to 2008 WDR. http://siteresources.worldbank.org/INTWDR2008/Resources/2795087-1191427986785/SebastianK_ch2_GIS_input_report.pdf. (Accessed on 16 February 2014).

The source data for the agricultural extent is the 1992-93 Advanced High Resolution Radiometer (AVHRR) dataset, which was used to calculate individuals on agricultural land in the year 2000. Calculations of individuals on agricultural land for 2010 were scaled linearly by the change in agricultural land percentage from 2000 to 2010, respectively. Agricultural land (% of land area) data for 2000 and 2010 is from the World Bank's World Development Indicators (WDI). Regional classifications (both *developing* and *all countries*) and income classifications were also extracted from the most recent version of the WDI. Developing economies are those that were low, lower-middle or upper-middle income as of *18 December 2013.*

World Development Indicators, 1960-2013. The World Bank. Last updated 18-Dec-2013. http://data.worldbank.org/data-catalog/world-development-indicators. (Accessed 16 February 2014).

Degrading or improving land was determined using University of Maryland's Global Land Cover Facility's AVHRR Global Production Efficiency Model (GloPEM) (Prince and Goward 1995; Prince and Small 2003), which is available from 1981-2000 with annual summations of net primary production (NPP) change measured in

Prince, S., J. Small (2003) Global Production Efficiency Model, 1997_npp_latlon, Department of Geography, University of Maryland, College Park, Maryland, 1997.

Prince, Stephen D., and Samuel N. Goward. "Global primary production: a remote sensing approach." Journal of biogeography (1995): 815-835.

grams of carbon sequestered per square meter per year (gC/m^2/yr). Consistent with Bai et al. (2008) and Bai and Dent (2007) annual changes in net primary productivity are taken as an indicator of land degradation or improvement.

Bai, Z.G., D.L. Dent, L. Olsson and M.E. Schaepman. "Proxy global assessment of land degradation." Soil Use and Management 24.3 (2008): 223-234.

Bai ZG and Dent DL 2007. Land Degradation and Improvement in Senegal 1.Iidentification by remote sensing. Report 2007/07, ISRIC – World Soil Information, Wageningen

Raster dataset management: [3]

All of the raster datasets used in these analyses were resampled to 30 arc-second ERDAS IMAGINE (.img) formatted raster layers using the nearest neighbor resampling technique. Raster alignment was ensured by setting the geoprocessing environment to snap all raster datasets to the extent of the LGP dataset (Top 90, Left -180, Right 180, Bottom -90). The population raster datasets from the GPWv3 were resampled (and values converted appropriately) from 2.5 arc-minute resolution to 30 arc-second resolution.

Less Favored Land:

Length of growing period data was reclassified for cells with a LGP from 0 – 119 (Arid and Semi-Arid) having an assigned value of "1" and all other cells having an assigned value of "NoData". Terrain was reclassified for cells with a median slope of 0% - 8% having a value of "NoData" and cells with a slope >8% having a value of "1". The classes that corresponded to steep terrain included class 5 (8% – 16%), class 6 (16% - 30%), class 7 (30% - 45%) and class 8 (>45%).

Irrigated land with poor soil and irrigated land with steep terrains were calculated with a cell value of "1" to create the product of each individual constraint (e.g. Irrigated*Poor Soil, Irrigated*Steep Terrain) for less favored land and "NoData" for those areas not affected by these constraints.

Rainfed land with LGP>120 days on >8% sloped land and rainfed land with LGP>120 days on poor soil quality land were also calculated for the product of each of the constraint. Rainfed land was defined as land that was not irrigated (land with per pixel irrigated cell area coverage of 25% or less).

The four raster constraints on less favored land, (i) irrigated land on > 8% slope, (ii) rainfed land with LGP>120 days on >8% slope (iii) rainfed land with LGP>120 days and poor soil and (iv) arid (LGP<60 days) and semi-arid (LGP 60-119 days) lands, were combined into a single less

[3] All geospatial analysis was conducted using ESRI ArcGIS 10.1 licensed to the University of Wyoming.

favored land mosaic. This less favored land mosaic was masked to include only agricultural land creating a mosaic of less favored agricultural land (LFAL).

All population summations, within the boundaries of countries, were conducted within the extent of the urban-rural raster dataset. Population counts of interest were then calculated using zonal statistics and a mask on rural areas, at the country level, to create our key variables of interest.

Less Favored Areas:

An accessibility mask was created from the market accessibility dataset by reclassifying raster values as “1” if the cell was 5 hour more hours from the nearest market center of 50,000 or more individuals. This mask resembles remote areas. The favored land dataset, defined as those areas that are not less favored, was extracted to include only remote favored locations. The “rural less favored land” raster dataset and the “remote favored land” raster datasets were combined into a single mosaic representing less favored areas. Variables of interest were calculated using zonal statistics as the country level.

Remote agricultural and less favored agricultural land:

Additional refinements (extracting populations from the LFAL and LFAA datasets using the remoteness mask and summarizing those populations) were made to create our remaining indicators.

Degrading and improving lands and areas:

Two decades of land degradation and improvement data are analyzed (1981-2000), using the difference in the annual sum NPP between 2000 and 1981. Degrading land is defined as land with a negative NPP change over these twenty years. Improving land is defined as land that is not degrading (land with a non-negative change in NPP). These degrading and improving lands are dissected in a manner analogous to the divisions in the LFAL and LFAA analyses. Rural individuals on degrading and improving agricultural land were separately summarized using the improving and degrading land masks, respectively. These individuals were then masked, using the remoteness indicator, and summarized to find the rural population located on all remote degrading (and improving) agricultural land.

Maps

All accompanying maps are projected using a standard Robsinson (world) projection.

Definitions

Less Favored Agricultural Land (LFAL): *Less favored agricultural land (LFAL) consists of irrigated land on terrain greater than 8% median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8% median slope or with* *poor soil quality; semi-arid land (land with LGP 60-119 days); and arid land (land with LGP < 60 days).*

Less Favored Agricultural Areas (LFAA): *Less favored agricultural areas (LFAA) include less favored agricultural land as well as favored agricultural land with limited market access (i.e. located in remote areas). Market access is identified as less than five hours of travel to a market city with a population of 50,000 or more.*

Degrading Agricultural Land (DAL): Degrading agricultural land consists of agricultural land with a negative change in Net Primary Productivity (NPP) from 1981-2000.

Improving Agricultural Land (IAL): Improving agricultural land consists of agricultural land with a non-negative change in Net Primary Productivity (NPP) from 1981-2000.

Net Primary Productivity (NPP): Net Primary Productivity (NPP) is measured as the change in grams of carbon sequestered per square meter over the 1981-2000 time period after subtracting respiration losses.

Length of Growing Period (LGP): Length of growing period (LGP) data, using a baseline period of 1961-1990, was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the Agro-climatic resources series with the “Growing period” collective title.

Terrain: Terrain data, for median terrain slope classes, was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the land resources series with the “Terrain Resources” collective title. The dataset’s eight relevant terrain classes include (i) 0 - 0.5%, (ii) 0.5 - 2%, (iii) 2 – 5%, (iv) 5 – 8%, (v) 8 – 16%, (vi) 16 – 30%, (vii) 30 – 45% and (viii) >45%.

Soil Constraints: Soil constraints are identified from a series of data sources published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02. There are seven constraints on soil including (i) nutrient availability, (ii) nutrient retention capacity, (iii) rooting conditions, (iv) oxygen availability to roots, (v) excess salts, (vi) toxicity, and (vii) workability. Within each soil constraint category there are four levels classifying how constrained soil is including (i) No or slight constraints, (ii) Moderate constraints, (iii) Severe constraints and (iv) Very severe constraints. We consider less favored soil where any of these constraints are considered severe or very severe.

Irrigated areas: Irrigated cultivated land data was published by the FAO on the Global Agro-Ecological Zones (GAEZ) Data Portal on 2012-05-02 in the land resources series with the “Water Resources” collective title. The percentage of land equipped for irrigation is given for each pixel in the dataset. Consistent with the Fan and Hazell (1999), we classify land as irrigated if greater than 25% of all cultivated land within a pixel is irrigated.