ASSESSING THE COASTAL POPULATION AT RISK TO SEA LEVEL RISE IN THE CARIBBEAN REGION

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Abstract

Climate change impacts such as accelerated sea-level rise and increased hurricane activity pose a serious challenge to the sustainable development along coastal regions. The pan-Caribbean region including Central America, the Caribbean islands, and the U.S. Gulf coast is one of the most disaster-prone regions of the world, with threats of hurricane strikes repeated every year and the impending danger of sea-level rise. Although studies on climate change impacts on the coast have been conducted and impact scenarios have been generated, very few of them have focused on the social-economic impacts. We utilized published data sets and employed GIS method to derive population estimates that would be impacted by sea-level rise for the countries in the Caribbean region using scenarios of 3-meter and 6-meter rise. The results show that a few small island countries in the Caribbean would be inundated even with a 3-meter sea level rise. For the Gulf coast states of the United States, a 6-meter sea-level rise would impact 53.5% and 42.1% of the populations in Florida and Louisiana, respectively. The Bahamas, Belize, and Guadeloupe will have at least 20% of their populations impacted if sea level rises 6 meters. These crude estimates and the GIS maps produced in this paper are the first step towards the development of a more comprehensive vulnerability assessment to be conducted for the region in the near future.

Introduction

Sea-level rise as a result of global warming has posed a serious threat to the coastal communities, especially those located in the low-lying coastal areas. The 2007

Intergovernmental Panel on Climate Change (IPCC) documents a global average rate of sea-level rise of 1.8±0.5 mm per year from 1961 to 2003 (Solomon *et al*., 2007). However, more and more recent scientific evidence points to a more rapid sea-level rise, with a predicted average of 4-6 m rise in the next millennium (Solomon *et al*., 2007; Overpeck *et al*., 2006). In addition to accelerated sea-level rise, increased hurricane activities due to climate change may also be a concern, though a consensus on whether global warming would lead to increased hurricane activities has not yet been reached (Emanuel, 2005; Landsea *et al*., 2006; Pielke, 2005; Webster *et al*., 2005). Together, sea-level rise and potential increase in hurricane activities due to climate change would make the coastal communities even more vulnerable in the future.

The pan-Caribbean region including Central America, the Caribbean islands, and the U.S. Gulf coast is one of the most disaster-prone regions of the world, with threats of hurricane strikes repeated every year and the impending danger of increasing sea level (Figure 1). For example, in 1998 Hurricane Mitch devastated several Central American nations and caused a death toll of over 10,000 people and economic losses in the billions of US dollars. Climate change impacts to this region will be detrimental especially considering its overall vulnerability and resilience in which the ability to respond and adapt is crucial to decreasing vulnerability and increasing resilience (Cutter *et al*., 2003; Lam *et al*., 2009a). There is a need to assess the overall vulnerability to climate change in this coastal region, and there is a need to develop a useful methodology to assess vulnerability that is applicable to most regions in the world (Field *et al*., 2007; Parry *et al*., 2007; Yusuf and Francisco, 2009).

As pointed out previously (Lam *et al*., 2009b), although studies on climate change impacts on the coast have been conducted and impact scenarios have been generated, very few of them have focused on the social-economic impacts. A fundamental social-economic measure of climate change impacts on coastal regions is how many people would be directly affected by sea-level rise and/or hurricane strikes along the coast. Such estimates would need to be realistic and sufficiently detailed in order to bring attention to the stakeholders. For example, estimates such as how many people live within one kilometer or below three-meter elevation along the coast would be most useful, as these fine-scale population estimates depict the number of people who would be most directly affected by hurricanes or sea-level rise.

Very few published studies have actually derived such fine-scale, basic population estimates. In one of our previous studies, we utilized four published data sets and GIS methods to estimate the number of people within one kilometer or below three-meter elevation along the U.S. coast (Lam *et al*., 2009b). The results from this previous study show that of the 23 coastal states within the conterminous United States, about 19 million people resided within one kilometer from the shoreline, whereas about 11.6 million people lived below three-meter elevation based on a 2006 population estimate. Findings from the previous study also suggest that the same methodology can be applied worldwide to estimate the most vulnerable coastal population to global climate change.

Objectives

Our ultimate goal of the project is to develop methodology to better assess the overall vulnerability of the Caribbean region to climate change. GIS and spatial analytical methods will be heavily employed. For this paper, however, we focus on the vulnerability of coastal communities to future sea-level rise as a first step in illustrating the complexity of the problem, such as issues of scale and resolution and the difficulty in obtaining reliable and

consistent data for most developing countries. Specifically, this paper will demonstrate the use of GIS in integrating different data sets to derive estimates of population for each country in the Caribbean region that are most vulnerable to sea-level rise at different levels. We will utilize published data sets and GIS method to derive population estimates of the countries in the Caribbean region using two scenarios: below three-meter elevation and below six-meter elevation. These initial population estimates would serve as the most direct measure of socio-economic impacts of sea-level rise due to climate change.
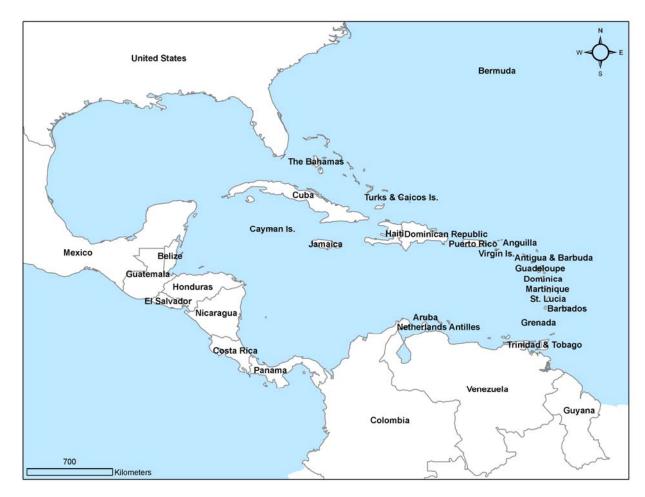

Figure 1. Map of the study area.

Figure 2. The Landscan population map of the study area.

Methodology

Three sets of published data were used in this study: (1) LandScan population data: The LandScan data were obtained from the Oak Ridge National Laboratory through its website (http://www.ornl.gov/landscan/index.html). The specific data set used was LandScan Global 2006, which contains residential population distribution of the world, defined in a 30"x30" (approximately 1-km) raster data format. It is noted that for many other developed countries such as the United States, more detailed and accurate population data for individual countries such as the census data may be used. However, to enable global comparison, we used this global data set here to demonstrate that the same procedure can be extended to derive estimates of impacted population for all the coastal regions in the world. (2) Elevation data: This digital elevation data set called GTOPO30 was produced by the U.S. Geological Survey (see http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html). It is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1-kilometer pixel size). GTOPO30, completed in 1996, was derived from several raster and vector sources of topographic information and the data was divided into tiles for easier distribution. This means different files will need to be merged to create the coverage for the study area. (3) Political boundary data: The political boundaries at the subnational level were obtained in a vector form, from ESRI (published in 2005). According to its metadata, the original source is ArcWorld Supplement, created in 1996 with a scale equal to 1:3,000,000.
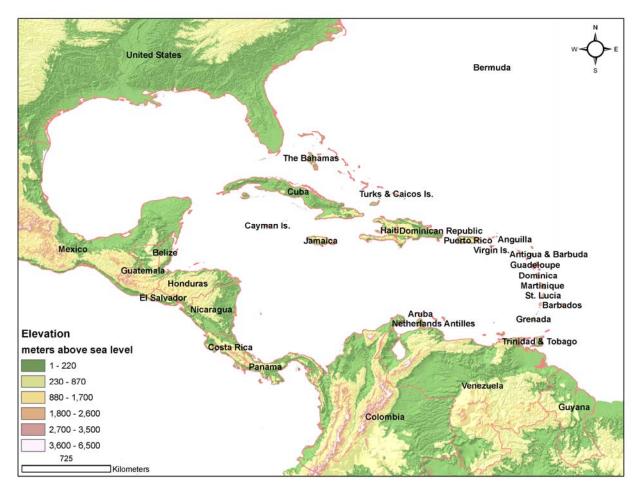
Figure 3. Map of elevation map for the study area.

The ESRI/ArcGIS software was used for GIS analysis and mapping. The following steps were carried out to retrieve areas and their corresponding populations that are below 3 and 6 meters for the countries in the Caribbean region. (1) The elevation data obtained from the USGS came in one file, partly because of its large pixel size of 1-km, so there were no need to mosaik these files, which was the case in the previous U.S. study. (2) The second step was the identification of flood risk areas within a threshold (below 3 or 6 meters) by recoding each pixel that falls within the threshold, thus transforming the dataset into a thematic raster dataset. (3) The recoded elevation file (the thematic raster dataset) was converted into a vector dataset, composed of polygons. (4) The polygon file was overlaid with the political boundaries datasets to identify the areas that fit the criteria by country or subdivision. (5) The final step was the overlay of the criterion areas (below 3 meters or 6 meters) with the LandScan dataset. The result was a set of statistical measures (e.g., population) for each of the countries or subdivisions.
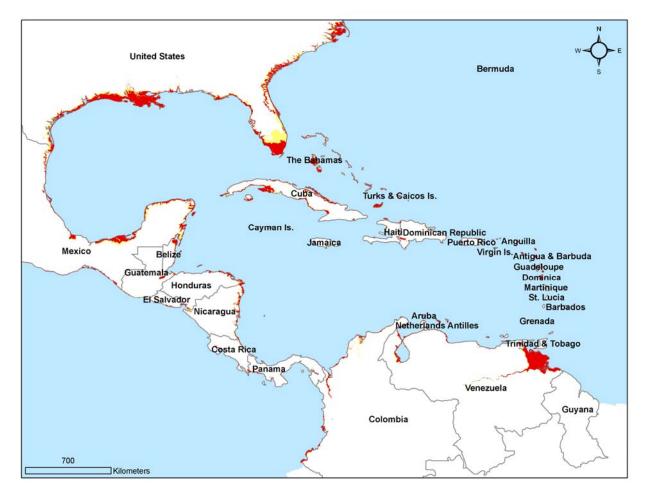
Figure 4. Areas below 3- and 6-meter elevation

Results

The population distribution in the Caribbean region based on the 2006 Landscan data is shown in Figure 2. Figure 3 maps the elevation, and Figure 4 shows the final result. Table 1 summarizes the population estimates under 3-m and 6-m by country and by the Gulf Coast states of the United States. Results for Barbados and Guyana were not included due to missing data. Three countries, Antigua & Barbuda, Dominica, and Turks & Caico Islands, yielded a total population value smaller than the population number who live below 3-m elevation. This is possible because of the use of coarse-resolution raster data sets for measuring tiny island areas. In these cases, we changed the percentage values to 100%, assuming all the population in these countries would be impacted. Also, only the Gulf coast side of Mexico was included in this study.

The results show that about 14 million and 22 million people live below 3- and 6-meter elevation, respectively, in the study region. Within the United States, Florida and Louisiana would be the most seriously impacted. If sea level rises 6 meters, over half of the population (53.5%) in Florida will be affected, whereas in Louisiana, the percentage is 42%. A few island countries will be inundated even with a 3 meter sea-level rise, and these include Anguilla, Antigua & Barbuda, Dominica, St. Kitts & Nevis, Turks & Caicos Is, and possibly Netherlands Antilles. Other countries that would be seriously impacted (for the scenario of a

6-m sea level rise and with over 10% population impacted) include Aruba, Belize, British Virgin Island, Cayman Island, Guadeloupe, Puerto Rico (U.S.A.), St. Lucia, The Bahamas, Trinidad & Tobago, and Venezuela.

	<3m	<6m	2006 Pop	%pop <3m	%pop <6m
Anguilla	12,763	12,763	13,189	96.8	96.8
Antigua & Barbuda*	67,361	67,361	66,385	100.0	100.0
Aruba	7,198	12,500	63,160	11.4	19.8
Belize	59,542	96,479	285,755	20.8	33.8
British Virgin Is.	2,198	3,069	20,648	10.7	14.9
Cayman Is.	6,013	24,007	26,362	22.8	91.1
Colombia	237,100	627,689	43,272,192	0.6	1.5
Costa Rica	55,640	105,457	4,081,710	1.4	2.6
Cuba	353,583	758,310	11,252,400	3.1	6.7
Dominica*	57,581	57,581	52,013	100.0	100.0
Dominican Republic	246,793	489,751	9,128,740	2.7	5.4
El Salvador	30,634	51,540	6,763,820	0.5	0.8
Grenada	2,593	3,134	75,431	3.4	4.2
Guadeloupe	68,636	80,273	358,922	19.1	22.4
Guatemala	51,736	118,703	12,439,400	0.4	1.0
Haiti	186,175	404,037	7,926,530	2.4	5.1
Honduras	138,693	220,881	7,209,400	1.9	3.1
Jamaica	128,467	193,321	2,673,910	4.8	7.2
Martinique	9,429	19,109	425,544	2.2	4.5
Mexico	1,569,248	2,744,423	106,575,000	1.5	2.6
Montserrat	78	78	8,142	1.0	1.0
Netherlands Antilles	164,797	165,393	177,227	93.0	93.3
Nicaragua	18,371	41,417	5,528,770	0.3	0.8
Panama	160,810	261,484	3,136,500	5.1	8.3
Puerto Rico	238,579	469,563	3,853,650	6.2	12.2
St. Kitts & Nevis	28,938	28,938	28,992	99.8	99.8
St. Lucia	19,851	20,925	163,134	12.2	12.8
St. Vincent & the Grenadines	200	1,192	78,819	0.3	1.5
The Bahamas	45,889	149,452	271,812	16.9	55.0
Trinidad & Tobago	61,745	91,652	945,242	6.5	9.7
Turks & Caicos Is.*	8,256	8,256	4,441	100.0	100.0
Venezuela	1,563,072	2,392,669	25,180,976	6.2	9.5
Virgin Is.	4,676	5,093	96,159	4.9	5.3
Alabama	82,078	89,796	4,622,060	1.8	1.9
Florida	6,567,360	9,215,760	17,232,100	38.1	53.5
Louisiana	1,266,690	1,799,890	4,272,030	29.7	42.1
Mississippi	98,805	154,123	2,886,660	3.4	5.3
Texas	412,486	835,564	23,256,600	1.8	3.6
Total	14,009,383	21,693,389	304,197,124	4.6	7.1

Table 1. Preliminary estimates of population impacted by sea-level rise.

Conclusion

We have demonstrated that through the use of GIS and a number of published data sets, crude estimates of population who would most likely be impacted by sea-level rise can be obtained. The same methodology can be applied to compute population estimates for the world. As in many studies, however, the results of the study will be affected by the accuracy of the datasets, especially the issue of scale and resolution.

Sea-level rise is inevitable and will directly impact the low-lying coastal areas. In many countries, the low-lying coastal areas are the key economic production regions with rich natural resources, attracting businesses, tourism, and people. Some of the low-lying coastal areas are densely populated cities such as New Orleans in the United States, Amsterdam in Netherlands, and Bangkok in Thailand, just to name a few. With sea-level rise, these low-lying areas will be inundated, and a series of consequences can be anticipated. These include for example issues such as how and when to move the population to higher grounds; how to protect the natural resources such as wetlands; how to modify the infrastructure such as road networks, bridges, telecommunication, levees, and dams; whether certain land use regulations or building codes should be enforced; and what is the cost-benefit ratio of all these mitigation plans. Effective strategies will need to be developed to help mitigate the impacts of sea-level rise. These strategies, in order to be sustainable, must also be developed with an understanding of the complexity of the broader environment including how the change of one element could affect another element in a system. The crude population estimates and the GIS maps produced in this paper are the first step towards the development of a more comprehensive plan.

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