An Estimate of Population Impacted by Climate Change Along the U. S. Coast

N. S.-N. Lam†, H. Arenas‡, Z. Li∞, and K.-B. Liu§

† Department of Environmental Sciences, Louisiana State University, Baton Rouge, LA 70803, USA. nlam@lsu.edu

‡ Department of Environmental Sciences, Louisiana State University, Baton Rouge, LA 70803, USA. harena1@lsu.edu

∞ Department of Environmental Sciences, Louisiana State University, Baton Rouge, LA 70803, USA. zli4@lsu.edu

§ Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA 70803, USA. kliu1@lsu.edu

ABSTRACT

LAM, N.S.-N., ARENAS, H., LI, Z. and LIU, K.B. 2009. An estimate of population impacted by climate change along the U. S. coast. Journal of Coastal Research, SI 56 (Proceedings of the 10th International Coastal Symposium), 1522 – 1526. Lisbon, Portugal, ISSN 0749-0258.

In estimating the climate change impacts on coastal regions, critical questions such as how many people live within one kilometer or below three-meter elevation along the coast are often raised. Surprisingly, answers to these questions are not available in the literature. This type of fine-scale estimates of population along the coast is necessary to provide a realistic measure of the population most vulnerable to hurricanes and sea-level rise. This paper utilized four published datasets and geographic information system (GIS) methods to retrieve the answers for the 23 coastal states in the conterminous United States. The results show that about 19 million people reside within one kilometer from the shoreline in the conterminous U.S., whereas about 11.6 million people live below three-meter elevation. The state-by-state estimates reveal that Florida has the highest percentage of population living in areas below three meters (32.5%; 5.9 million people), followed by Louisiana (27.6%; 1.2 million people). The same methodology can be applied worldwide to estimate the most vulnerable coastal population to global climate change.

ADDITIONAL INDEX WORDS: *Geographic information systems (GIS), social economic vulnerability, hurricane, sea-level rise*

INTRODUCTION

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 2007 Intergovernmental Panel on Climate Change (IPCC) Report documents a global average sea-level rise rate of 1.8±0.5 mm per year from 1961 to 2003 (SOLOMON *et al.*, 2007). Further paleoclimatic evidence suggests that future sea-level rise could be more rapid, producing a predicted average of 4-6 m rise in the next millennium (SOLOMON *et al.*, 2007; OVERPECK *et al.*, 2006). Likewise, global warming has been suggested to lead to increased hurricane activity (EMANUEL, 2005; WEBSTER *et al.*, 2005), though the subject remains controversial and without consensus and projections (PIELKE, 2005; LANDSEA *et al.*, 2006). No matter which scenarios we adopt, coastal communities around the globe will be most vulnerable, facing the threats from climate change impacts as well as the stresses arisen from development and environmental pollution (FIELD *et al.*, 2007). Sustainable adaptation strategies are needed to reduce vulnerability to climate change as well as other social-environmental stresses (PARRY *et al.*, 2007).

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 (which include both wind damages and storm surges) along the coast. Such estimates would need to be realistic and sufficiently detailed in order to bring attention to the stakeholders. In the United States, 673 counties, out of a total of 3,141, have been defined as coastal counties. These coastal counties comprised 53% of the total population and 42% of the total employment of the United States in 2000 (BUREAU OF THE CENSUS, 2000). However, population estimates based on county units are too coarse and too general to be useful. A detailed, fine-scale estimate of population residing in the most vulnerable coastal areas is needed to facilitate better and realistic planning. Answers to critical questions 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.

Surprisingly, such fine-scale but basic population estimates are not available from the literature. Using published data on population and elevation, we employed geographic information system (GIS) methods to derive population estimates along the U.S. coast under four scenarios: within one kilometer, below three-meter elevation, below six-meter elevation, and within one-kilometer distance and three-meter elevation. The population estimation results as well as the GIS methodology can be extended in the future to estimate on a global basis the most vulnerable population along the coast that will most likely be impacted by climate change.

DATA

Four 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 dataset 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 the case of the United States, other population data such as the census data can be used. We used this global data set here to demonstrate that the same procedure employed in this paper can be extended easily to derive estimates of impacted population for all the coastal regions in the world.

(2) National elevation data: This digital elevation data set (also called Digital Elevation Models; DEM's) was produced by the U.S. Geological Survey (USGS) using a map scale of 1:24,000 for the conterminous U.S. Its spatial resolution is 1 arc second (approximately 30 m) while its elevation unit is in meters. The horizontal datum used in this data set is NAD83, while the vertical datum is NAVD88. The data were obtained from the USGS website using the Seamless Data Distribution System (http://seamless.usgs.gov). For most states, the elevation data were split into several files because of its size.

(3) Shoreline data: The shoreline data were collected from NOAA's Coastal Geospatial Data website (http://coastalgeospatial.noaa.gov/data_gis.html). The map scale for the shoreline data is 1:70,000 (medium scale).

(4) Census boundary and population data: The state boundaries and other census unit boundaries and their corresponding population data were obtained from the Census 2000 TIGER/Line shapefiles from their website: (http://arcdata.esri.com/data/tiger2000/tiger_download.cfm). In addition to population number, the census data contain a host of social-economic variables that can also be retreived using the same procedure as documented below.

METHODS

The software used in this study includes both ArcGIS 9.2 and ERDAS/Imagine. The following steps were carried out to retrieve areas (and their corresponding populations) that are below 3 meters, 6 meters, and within 1-km along the U.S. coast. (1) The elevation data (DEM) obtained from the USGS came in many files. The first step was to mosaik these files and then divide them into files of optimal size for different parts of the coast. The division into different files is necessary to avoid processing huge data files and prevent computing problems. For example, Florida was divided into three files for subsequent processing. (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) Converted the recoded DEM's into a vector dataset, composed of polygons. (4) The polygon file was overlaid with the census state boundaries datasets to identify the areas that fit the criteria by state. (5) The final step was the overlay of the criterion areas by state (e.g. 3 meters, 6 meters, or 1-km buffer zones) with the LandScan dataset. The result was a set of statistical measures (e.g., population) for each of the coastal states. (6) To generate the 1-km population, a 1-km buffer zone (in the form of polygons) was generated for the shoreline data, then Step 5 was repeated to tabulate the zonal statistics (e.g., population).

An alternative procedure in Step 3 would be to not transforming the raster flood risk areas into vector polygons but rather to perform all the operations using only raster data. Two problems were identified with this alternative: first there were errors in the recoded DEM's due to the mosaic process that were easier to correct using vectors polygons; and second, the file size of the raster data is very large, making them more difficult to handle.

RESULTS AND DISCUSSION

Based on the LandScan 2006 population data, the results show that about 19 million people are residing within one kilometer from the shoreline in the conterminous U.S., whereas about 11.6 million people are living below 3-meter elevation (Figure 1 and Table 1). Furthermore, there are about 6.3 million people in the U.S. who would fit into both criteria, that is, residing in areas below 3-meter elevation as well as within one kilometer from the coast. This group of people represents the group that would most likely be impacted by both hurricane strikes and sea-level rise. For the 6-meter sea-level rise scenario, the number of people that would most likely be affected would double to 22 millions. Similarly, the number of people that would be impacted is expected to dramatically increase as we increase the distance from the coast to 2, 3, or 4 km, and so on.

Based on the state-by-state tabulation, it is of no surprise that Florida and Louisiana yield the highest percentages of population (32.5% and 27.6%, respectively) that would most likely be affected if sea-level rises by 3 meters (Figures 2&3). These two states also have very high percentages of population (27.6%, 18.0%) residing within one kilometer from the coast. The coastal states in the Northeast could also be impacted severely by hurricanes and storm surges, as evidenced from the number and percentage of people living within one kilometer from the Atlantic coast and waterways, including District of Columbia (26.8%), Rhode Island (24.8%), Maine (23.0%), Delaware (20.5%), New Jersey (19.0%), New York (18.8%), Massachusetts (16.2%), Virginia (12%), and Maryland (10.5%).

As in many other studies, the results of this study will be affected by the accuracy of the datasets. We noted that for states that have many small rivers and waterways, when they are considered as part of the shoreline, the buffering method will follow these rivers inland and include the population within 1-km of these rivers. This results in more inland population being included in the estimates, even though they are quite far from the coast, such as the case of District of Columbia. One might interpret this phenomenon as valid, as rivers and waterways could be impacted by storm surges from hurricane strikes. Alternatively, the GIS method of line generalization can be applied in the future to generalize the shoreline and reduce the number of small rivers and waterways so that only the population near the coast are included.

In this study, we used the LandScan population data instead of the U.S. census data so that the population numbers retreived would be comparable on a global basis. It is important to stress that the U.S. census data have many more variables than just population number, such as number of people in different age groups, income, types of households, and housing characteristics, which can be retreived using the same procedure. This detailed social-economic information would be extremely valuable for emergency planning and policy decisions.

Through the GIS maps, we can further pinpoint the risk areas that deserve most attention, such as those that have high population density. These GIS maps can further be used to overlay with maps of transportation lines and critical infrastructures

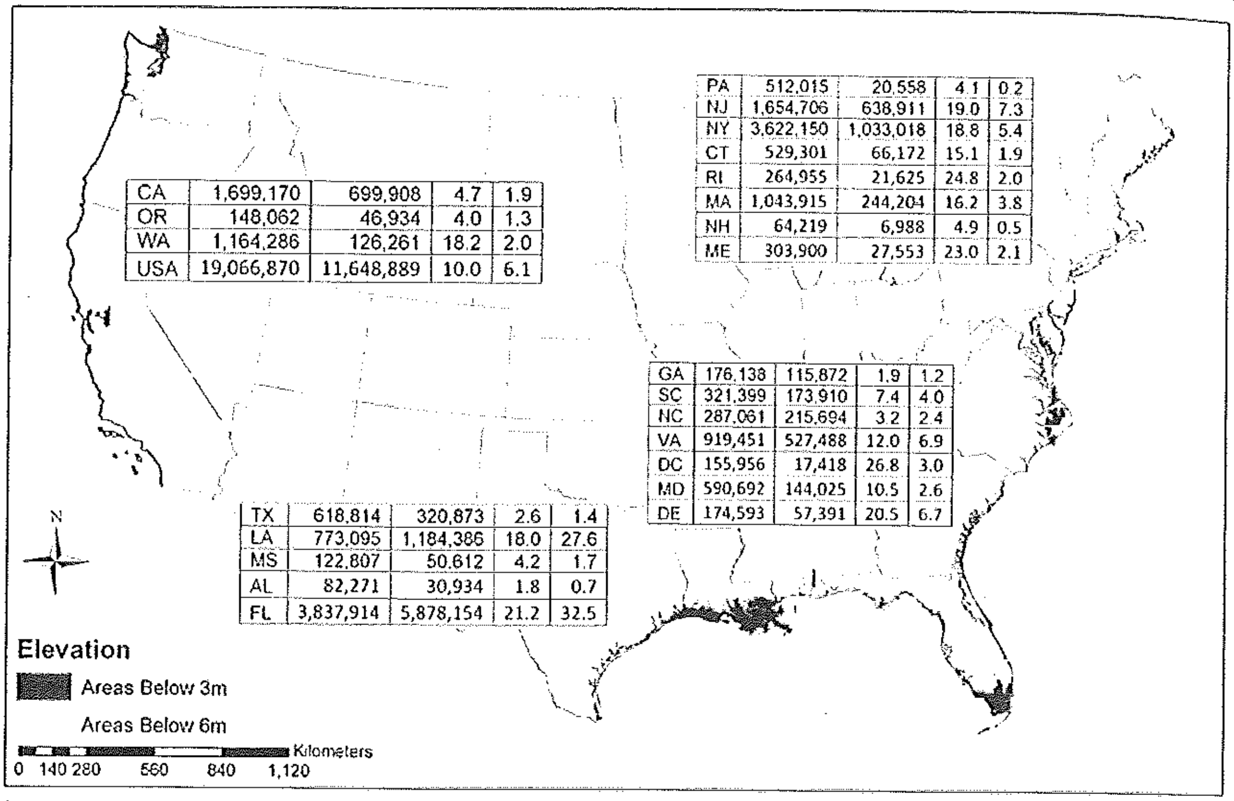
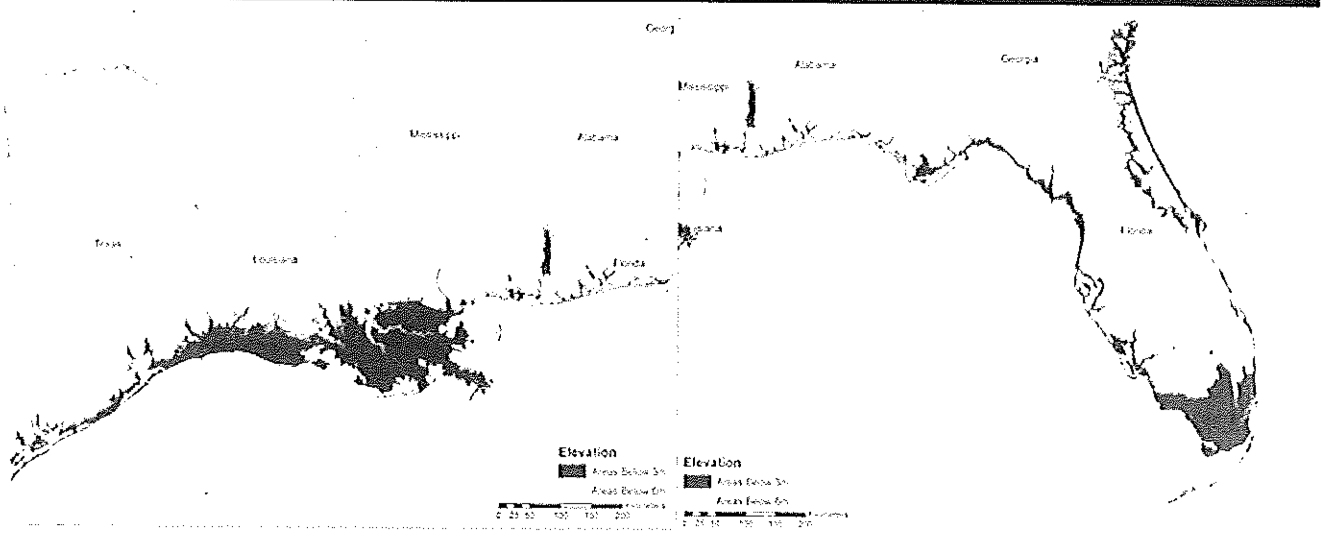


Figure 1. Areas and population within 1-km and below 3m/6m along the U.S. Coast. For the tables in the figure: column 1-state name; column 2-population within 1 km; column 3-population below 3 meters; column 4-% population within 1 km; Column 5-% population below 3 meters.



Figures 2&3. Enlarged maps of the Louisiana (left) and Florida (right) coasts.

Table 1: Number of People Impacted Under Different Scenarios.

	<1-km	<3m	<6m	1-km& <3m	2006 Pop	%pop <1-km	%pop <3m
Alabama	82,271	30,934	93,452	30,039	4,599,030	1.8%	0.7%
California	1,699,170	699,908	1,846,217	370,782	36,457,549	4.7%	1.9%
Connecticut	529,301	66,172	159,962	61,883	3,504,809	15.1%	1.9%
Delaware	174,593	57,391	108,178	44,482	853,476	20.5%	6.7%
Dist. Columbia	155,956	17,418	38,689	14,609	581,530	26.8%	3.0%
Florida	3,837,914	5,878,154	9,656,798	2,439,590	18,089,888	21.2%	32.5%
Georgia	176,138	115,872	306,025	63,252	9,363,941	1.9%	1.2%
Louisiana	773,095	1,184,386	1,714,392	500,187	4,287,768	18.0%	27.6%
Maine	303,900	27,553	59,327	27,492	1,321,574	23.0%	2.1%
Maryland	590,692	144,025	310,222	114,909	5,615,727	10.5%	2.6%
Massachusetts	1,043,915	244,204	753,563	209,539	6,437,193	16.2%	3.8%
Mississippi	122,807	50,612	142,056	35,706	2,910,540	4.2%	1.7%
New Hampshire	64,219	6,988	17,233	7,851	1,314,895	4.9%	0.5%
New Jersey	1,654,706	638,911	1,314,699	479,041	8,724,560	19.0%	7.3%
New York	3,622,150	1,033,018	1,952,477	945,102	19,306,183	18.8%	5.4%
North Carolina	287,061	215,694	388,179	140,874	8,856,505	3.2%	2.4%
Oregon	148,062	46,934	89,298	14,628	3,700,758	4.0%	1.3%
Pennsylvania	512,015	20,558	164,339	21,177	12,440,621	4.1%	0.2%
Rhode Island	264,955	21,625	69,284	21,630	1,067,610	24.8%	2.0%
South Carolina	321,399	173,910	444,535	128,342	4,321,249	7.4%	4.0%
Texas	618,814	320,873	872,965	173,311	23,507,783	2.6%	1.4%
Virginia	919,451	527,488	1,252,508	374,632	7,642,884	12.0%	6.9%
Washington	1,164,286	126,261	287,316	80,623	6,395,798	18.2%	2.0%
Total	19,066,870	11,648,889	22,041,714	6,299,681	191,301,871	10.0%	6.1%

(e.g., hospitals, schools, industrial plants) to help identify potential threats and develop strategies for mitigation and prevention.

CONCLUSIONS

We have demonstrated that by using the GIS method to integrate a number of published datasets, we can identify the people and areas that are most likely affected by climate change impacts along the U.S. coast. The population estimates provided in this paper are considered conservative estimates. They are basic, yet critical information for developing sustainable adaptation strategies to reduce coastal vulnerability to climate change.

The same method can be extended in a number of ways to provide further information. First, the method can be easily extended to incorporate population projection models to produce estimates of future population. Second, the same methodology can be used worldwide to produce estimates especially for countries that are vulnerable to coastal hazards such as those in the Carribbean region. Third, when additional socio-economic variables become available, such as data on age, income, housing characteristics, and critical infrastructure, the method can be a powerful tool to provide detailed information for policy decisions and planning purposes. Finally, the same method can be applied to overlay with physical-environmental data such as land use/land cover to estimate types of land cover that would most likely be innuadated, and their impacts (e.g., wetland loss) can subsequently be modeled as a feedback loop to the coupled human-natural systems for better evaluation and development of adaptation strategies.

LITERATURE CITED

EMANUEL, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436, 686-688.

FIELD, C.B., MORTSCH, L.D., *et al.* 2007. North America. In: PARRY, M. L., CANZIANI, O.F., *et al.* (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press, pp. 617-652.

LANDSEA, C.W., HARPER, B.A., *et al.*, 2006. Climate change: can we detect trends in extreme tropical cyclones. *Science*, 313(5786), 452-454, doi:10.1126/science.1128448.

OVERPECK J.T., OTTO-BLIESNER, B.L., *et al.* 2006. Paleoclimatic evidence for future ice-sheet instability and rapid sea-level rise. *Science*, 311(24 March), 1747-1750.

PARRY, M. L., CANZIANI, O.F., *et al.* 2007. Technical summary. In: PARRY, M. L., CANZIANI, O.F., *et al.* (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press, pp. 23-78.

PIELKE, R.A. Jr., 2005. Are there trends in hurricane destruction? *Nature*, 438(7071) E11, doi:10.1038/nature.04426.

SOLOMON, S., QIN, D., *et al.*, 2007. Technical summary. In: SOLOMON, S., QIN, D., *et al.* (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press, pp. 21-91.

WEBSTER, P.J., HOLLAND, G.J., *et al.* 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, 309, 1844-1846.

ACKNOWLEDGEMENTS

This research was funded in part by grants from the U.S. National Science Foundation (award number: 0729259), Inter-American Institute for Global Change Research (IAI) (award number: CRN-2050), and the Gulf of Mexico Sea Grant Program (awarded in 02/01/2008).