Urbanization trajectories and population exposure to sea elevation climate risk in Mexico

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Long abstract

Climate change is the leading environmental problem of the XXI century. Ecosystem services and urban water systems will become increasingly stressed from climate change impacts, population growth, and resource limitations (Ferguson et al., 2013b). Another consequence of climate change is sea-level rise, which will cause inundations in low-elevation coastal zones (LECZ) (less than 10 m above sea level) (McGranahan et al., 2007). This is relevant because nowadays, 40% of the world's population is settled in coastal areas due to economic activities (Barragán & de Andrés, 2015). Cities are places of continuous spatial transformation, the concentration of population, and economic activities; however, urban expansion has adverse effects such as dependency on cars, social segregation, and environmental problems (Hogan & Ojima, 2008; González & Larralde, 2019). The urban consolidation process in the coasts generates pressure in fragile ecosystems such as mangroves, which help to reduce impacts from extreme events such as hurricanes (Mata-Zayas et al., 2017). Greater urbanization on the coast will bring growing environmental and social challenges (Güneralp & Seto, 2013). Not only absolute growth is essential, but the form of urban expansion also is relevant, compact cities are related to high densities and an *infill* use of space (Acheampong et al., 2017)*. However*, more fragmented cities are associated with a *leapfrog development*, rising economic costs, low densities, and more significant ecosystem degradation in the natural surroundings (Hogan & Ojima, 2008). Urban expansion worldwide has been messy, informal, and without planning, the contemporary model of urbanization is unsustainable (Angel et al., 2016).

In Latin America, studies show that urban expansion in coastal areas has been rising, entailing coastal and marine ecosystem degradation (Barragán y de Andrés 2016; UNEP, 2006). Contrary to the global trend, Mexico did not use to have its population located by the sea, although it has 11,122 km of the seashore (INEGI, 2017). However, recently, population size is rapidly expanding because of internal migration pushed by economic dynamism. Studies suggest that population growth in Mexico is closely linked to tourism and trade activities on the coast and that it is mainly taking place in urban settlements (Pérez-Campuzano & Santos-Cerquera, 2016). However, existing studies for Mexico have not paid attention to where within the coast population is locating nor to what extent it is associated with greater exposure to climate risks. Moreover, urbanization implies not only a change in population concentration, but a land change, a transformation of the built environment that could impacts how much and how people are exposed to environmental hazards (McGranahan et al., 2008; Romero-Lankao & Gnatz, 2016; Seto et al., 2010).

Therefore, this paper examines the extent of urbanization and the form it takes in coastal areas in Mexico. It asks if urban areas with higher land expansion rates and more expansive forms translate in more population expose to sea-level rise in low-elevation zones. It argues that places with expansive urbanization trajectories in Mexico are linked to high demographic growth but also reflect fewer environmental protections in coastal lines. As such, population exposed to sea-elevation risks will be higher.

Data and methods

To understand better these feature of urbanization trajectories, we require higher temporal and spatial resolution data that allows tracking changes in land use at small scales and different points in times. Remote sensing data offer such possibilities and can be used to evaluate population concentration, urban expansion, exposure to climate risks, and disaster management (Balk, et al., 2018; Balk, et al. 2019; JRC, 2020; McGranahan et al., 2007; McGranahan et al., 2008).

This research will use remote sensing data and geocoded census data. To examine the extent of urbanization in coastal areas, we use the remote sensing data GHS-Built product (Pasaresi et al., 2015). It is a raster dataset that provides information on the percentage of the built-up area by pixel, with a resolution of 250m. We identify as urban any places with at least 25% of built up and use that physical transformations of coastal zones as a proxy of urbanization. Using the data from 1990, 2000, and 2014, we estimate absolute and relative urban growth. We estimate such measures for coastal municipalities and for the coastal line (12 miles from the seashore) because it is more susceptible to extreme events (Barragán & de Andrés, 2015). To evaluate the urban form, we estimate from the raster data a Cohesion index, which measures the connection among the fragments of an urban area: the more physical connection, the more compact an urban area will be. The Cohesion index value goes from 0 to 100, where 0 is the most fragmented area and 100 the most compacted area (Jia et al., 2019).

To quantify urban built in LECZ, we use a digital elevation model (DEM) to identify low-elevation zones, which are considered as flood risk areas. We use the DEM MERIT, which is a raster dataset of 10 m resolution that minimizes errors in coastal zones (Yamazaki et al., 2017).

Finally, to estimate the population in prone areas to sea-level rise, we use 2020 Population Census data at the block level, produce by the Mexican National Statistics Office (INEGI). We identify those residing in low-elevation areas as a measure of exposure to sea-level rise. We examine the association between the proportion of the exposed population (2020) in the urban area, the urbanization growth (1990-2014) and urban form (2014)

Preliminary results

The data analysis shows an accelerated urbanization of the Mexican coast between 1990 and 2014, particularly in the seashore. On a national scale, the built-up area on the coastal strip went from 933 km2 in 1990 to 1,592 km2 in 2014, which means an increase of 71%. While in the coastal municipalities the figure went from 1,633 km2 to 2,858 km2, which meant an increase of 75%. In both cases, the percentage increase was greater than the population increase (67%). Also, the occupation of the land in the seashore has been greater than in the rest of the coastal municipality (table 1).

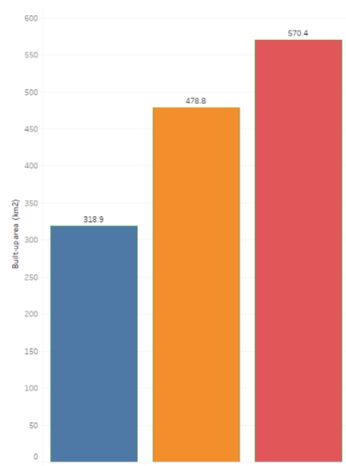
Table 1. Urban growth index in Mexican coastal zones, 1990-2014

	1990	2000	2014	2020
Municipalities				
Population				20,574,799
Total area (km2)	503,894.81	503,894.81	503,894.81	
Built-up area (km2)	1,632.71	2,407.37	2,858.66	
Mean intensity of built-up area (%)	51.94	55.32	55.22	
Urban propotion (%)	0.32	0.48	0.57	
Coastal line				
Total area (km2)	179,549.24	179,549.24	179,549.24	
Built-up area (km2)	933.33	1,348.70	1,592.66	
Mean intensity of built-up area (%)	48.75	53.83	55.14	
Urban propotion (%)	0.52	0.75	0.89	
Coastal line-Municipality relation				
Urbanized area in coastal line in relation to municipality total area (%)	0.19	0.27	0.32	
Urbanized area in coastal line in relation to municipality built-up area (%)	57.16	56.02	55.71	

On the other hand, the intensity built -the average proportion built within each pixel (250 m2) - has similar levels in the strip and in the rest of the coastal municipality, but in the analyzed period, it increased more in the strip where it went from 49 percentage points in 1990 to 55 in 2014, while in the rest of the coastal municipalities the increase was only 3 points. This implies a growing trend of pressure on coastal ecosystems since not only the urbanized area increased, but the intensity of urban land use increased.

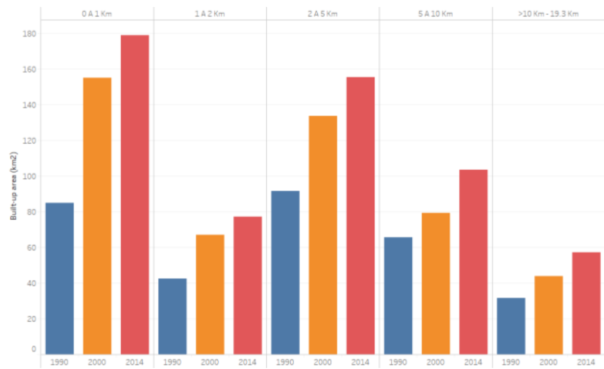
In addition, this urban expansion takin place mainly in LECZ. As we can see in Figure 1, built-up areas in LECZ in Mexico were 319 km2 in 1990, 479 km2 in 2000, and 570 km2 in 2010; this represents an absolute growth rate 78.68% between 1990 and 2010. This implies that a more significant amount of infrastructure is exposed to the consequences of sea-level rise in Mexico.

Figure 1. Built-up growth in low elevation coastal zones, Mexico, 1990-2014



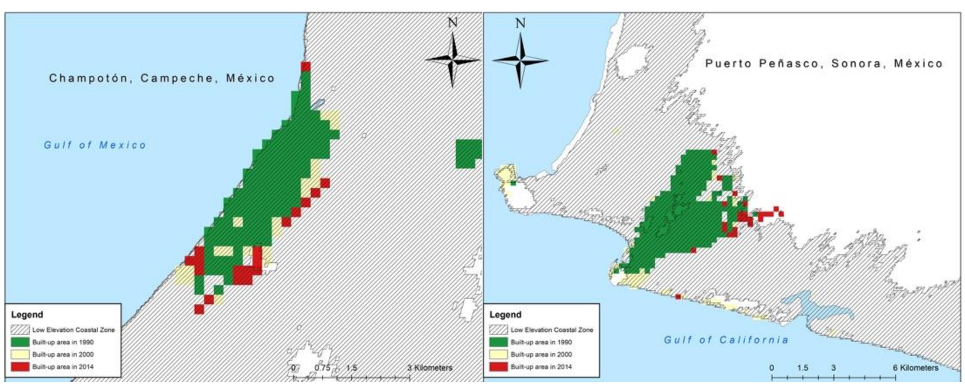
Concerning the localization of this urbanization in the LECZ, Figure 2 shows that, as times goes by low-elevation seashore is becoming more urbanized: there total built area is larger, and urbanization expanded more rapidly that in that other distance range. Overall, data suggest that urban expansion took place in direction to the seashore, exposing infrastructure and people to a greater risk. Data (table 1) also show that urban population in coastal municipalities is rapidly growing, moving from 10.2 millions in 1990 to 20.5 millions in 2020, with a growth rate 1.4 faster than non-coastal municipalities.

Figure 2. Built-up growth in low elevation coastal zones by distance ranges, Mexico, 1990-2014



There were different urban trajectories along the Mexican coastal zone. The following images (figure 3) illustrate two of them. The first one is an urban extension in direction to the seashore, the second one is the localization far from the coastal shore. For instance, Champoton city (left) historically has been in the seashore, and the new areas settle by it. Although Champoton has a more compact form, all the city is exposed to sea-level rise. Conversely, Peñasco Port city has a more fragmented form, and the new urban areas tend to be located far from the seashore, where there is less exposition to sea-level rise.

Figure 3. Urban extension between 1990 and 2014, Champoton City and Peñasco Port City, Mexico



Next steps in the analyzes will systematize those features for ache urban area in the Mexican coast, estimate the total population living in low-elevation areas and seek to establish an association between them by running a regression model.

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