Chapter

Vulnerability and Sea Level Rise in the Coastal Tourism City of Playa del Carmen, Quintana Roo, Mexico

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Abstract

The coastal tourism city of Playa del Carmen is located in the heart of the Mexican Caribbean's Riviera Maya. This attractive sun and beach destination has the largest number of hotel rooms in the country (i.e. 10,000 more than Cancún), which has made it Mexico's main magnet for tourists from the United States (US), Canada and Europe. Playa del Carmen is the second biggest city in the state of Quintana Roo and the fastest-growing metropolis in Mexico and Latin America. Rapid urbanisation and tourism development have altered the city's natural ecosystems, among them mangroves and wetlands. These changes have disturbed the sedimentary dynamics of the coastal dunes and put more pressure on the barrier reef system. The area's vulnerability was analysed based on flood scenarios of a 1 metre (m), 2 m and 3 m sea level rise to estimate the total property damage in US dollars.

Keywords: climate change, coastal tourism city, coastal vulnerability, Mexican Caribbean, sea level rise

1. Introduction

The coastal tourism city of Playa del Carmen is the seat of the municipality of Solidaridad, in the Mexican state of Quintana Roo, south of Cancún. The discontinuous chain of barrier reefs that runs parallel to the coast is part of the Mesoamerican Barrier Reef System (i.e. the second longest barrier reef in the world at approximately 600 kilometres [km]). The system rests on the quite narrow continental shelf that runs along the region's coast, ending to the northeast of the Yucatan Peninsula and, at the other extreme, at the Gulf of Honduras's southernmost point c–3].

Quintana Roo's main economic activity is tourism as this state receives more than 16 million tourists each year. Playa del Carmen has become the jewel in the crown of Mexico's tourism destinations because its hotels offer 98,000 rooms and generate many construction and service industry jobs, making it the focal city of the Riviera Maya [4, 5]. As a result, Playa del Carmen's population of Mexican and foreign residents has expanded so rapidly that the city now has the highest growth rate in Mexico and Latin America **Figure 1** [6].

Playa del Carmen has been studied considering its vulnerability in other areas, such as the perceptions of stakeholders about the vulnerability and future

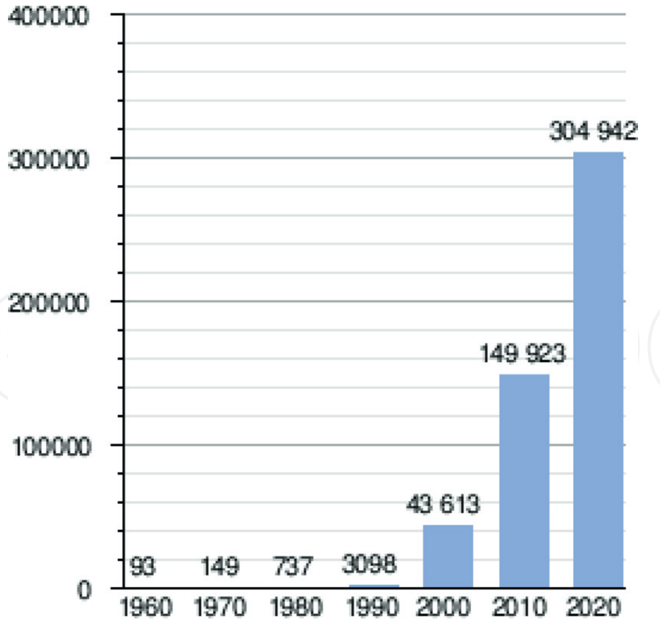

Figure 1.
Playa del Carmen's demographic trends from 1960 to 2020 [6].

sustainability of tourist destinations through the relevance of the policies, plans and strategies adopted in response to climate change [7]; access to housing for the most vulnerable social groups, due to conflicts over the appropriation of space throughout the development of the city, due to accelerated demographic growth and the intense phenomenon of real estate speculation, which have repercussions on urban dynamics [8]; in the contamination of urbanised coastal karstic aquifers, the most vulnerable being those for residential and mixed tourist land use [9]; through ecological indicators that reveal the total absence of vegetation cover in the coastal dune [10]; in the reduction of vulnerability in urban development, through the formation of skills of Architecture and Civil Engineering students for the design of sustainable coastal cities [11].

Tourism development and urbanisation have clearly put pressure on the Mexican Caribbean, especially on coastal ecosystems. More specifically, these trends have resulted in water pollution, damaged landscapes and the destruction and disappearance of flora and fauna due to the occupation of dynamic zones (e.g. beaches). These coastal ecosystems' vulnerability has been increased by tourism in particular because of the infrastructure needed for visitor transport, energy consumption, waste products generated and required water reserves, which are already scarce in some areas of the Mexican Caribbean [12].

2. Coastal ecosystems

The literature also indicates that coastal ecosystems such as coral reefs, salt marshes, mangroves, submerged aquatic vegetation and dune plants will be affected by rising sea levels and surface temperatures. Any changes in the frequency and intensity of future storms and hurricanes will have a further impact on coastal communities [13–16]. Prior sea level rise research has thus confirmed that these ecosystems' spatial distribution, species diversity and natural productivity will be affected. Some examples of these possible effects are discussed in the following subsections.

2.1 Mangroves

Mangroves' survival will depend on the rate at which the sea level rises in relation to vertical accretion and spaces left for mangroves' horizontal migration. Any movement along the shore within mangroves could be limited by urban and tourism development on the coast [14]. The expansion or compression of the areas available or any mangrove species' preferential distribution will depend on the enclosed land's topographical features, the coast's geomorphological origin and the region's combination of climate patterns [17].

2.2 Seagrass beds

The quantity of light available will be reduced in the ecosystem due to the sediment mixture on the seabed. Changes will occur in these beds' productivity and functional values that will alter the structure of these features and favour their horizontal displacement to new shallow areas created by flooding in coastal areas. The sediment mixture and warming seawater could cause variations in the species composition as the most tolerant types will become dominant [18–21].

2.3 Reefs

Sea level rise will alter erosion and accretion processes along the coast, thereby increasing these areas' vulnerability to hurricanes and storms. Repeated flooding could have a detrimental effect on water quality and thus affect the coral reef biota's development because of sediment mixture, distance from the coast and currents produced in reef lagoons. The Intergovernmental Panel on Climate Change (IPCC) [19] notes that acidity will rise more in areas with eutrophication due to human settlements, which will have a negative impact on coral calcification. The combination of warming and acidification will provoke coral bleaching, increase coral mortality and reduce reef-building capacity, making coral reefs more vulnerable and less adaptable [19, 21]. All the processes and events that limit coral calcification or decrease the coral reef cover can seriously compromise barrier reefs' carbon balance, thereby reducing their biodiversity and contribution to society [3].

3. Hurricanes

Storms and hurricanes' effects are one of the main economic and health threats for urban tourism centres in Quintana Roo. Playa del Carmen has been, over the last 35 years, in the direct or indirect path of 15 tropical cyclones, beginning with Gilberto in 1988—a category 5 on the Saffir-Simpson scale—and ending with Grace in 2021—a category 1 [22–24].

Hurricane Wilma, in October 2005, alone caused 18,772 million Mexican pesos in property damage and affected 540,000 people, according to the Dirección General de Protección Civil del Gobierno Federal (Federal Government's Directorate General of Civil Defence). The tourism industry was affected the most because this hurricane destroyed hotel complexes—13,522 out of 57,830 rooms damaged—and the local airport, as well as eroding beaches, which are the area's main attraction. Wilma's impacts resulted in the relocation of thousands of tourists to 265 contingency shelters [22, 25].

4. Sea level rise in the Mexican Caribbean

Since 1990, the IPCC has warned of sea level rise's effect on low lying coastal areas and islands [26–28] and urged the relevant authorities to implement local strategies that reduce the risks to human well-being. Efforts must be made to conserve and intervene in natural systems, regardless of their current condition, in order to reduce their vulnerability and ensure their recovery so that their environmental functions can continue [29].

Researchers in Quintana Roo have analysed the local tendency towards increased sea levels by checking tide charts [30]. In addition, scholars have examined the regional sea level rise trends for the Caribbean Sea based on altimeter data from TOPEX/Poseidon, Jason-1 and OSTM/Jason-2. The latest rate reported is 2.8 millimetres^{-1} during the 1993—2015 period [31, 32]. Previous studies of the Mexican Caribbean [3, 13, 33–36] have found that a rise of 50 centimetres to 1 metre (m) could be devasting for coastal areas, especially for tourism infrastructure in zones prone to flooding and beach erosion by swells, which would have a strong impact on the region's economy and tourism services.

5. Sea level rise in Playa del Carmen

A digital elevation model (DEM) created by INEGI was used to define flood-prone areas for the urbanised zones of this coastal tourism city. The model was based on lidar measurements on land in a map format, with a scale of 1:10,000 and resolution of 5 m per pixel. The DEM was indexed to the International Terrestrial Reference Frame's horizontal datum for 1992 Epoch 1988.0 (i.e. ITRF92) and the ellipsoid-based Geodetic Reference System 1980 (see www.inegi.org.mx). The coordinates that define the DEM's limits are given in **Table 1**.

The DEM's topographic profile is shown in **Figure 2**, with A and B designating the transect line that begins on the coastline and runs inland. This profile reveals a surrounding zone of 500 m in length with an elevation of less than 3 m. Beginning 500 m from the coastline, the land rises to an elevation of over 7 m for about 1 km. The coordinates are 20.62° North and 87.07° West. **Table 2** provides the profile's statistics.

UTM reference system	DEM Playa del Carmen
West	–87,11268
East	–87,05401
North	20,68874
South	20,62325
Source: Author.	

Table 1.
Coordinates of the digital elevation model for Playa del Carmen.

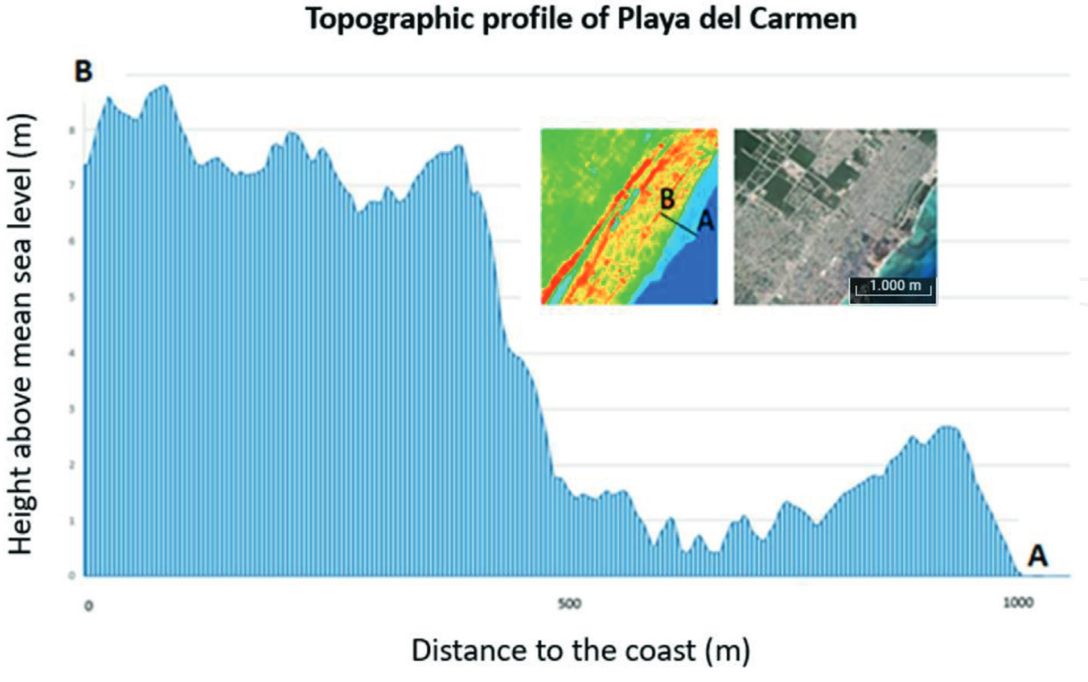

Figure 2.
Topographic profile of Playa del Carmen's terrain for transect line highlighted in the square. Source: Author.

Playa del Carmen DEM statistics			
Number of points: 386	**Minimum value: 0**	**Average value: 2.5**	**Variation: 9.66**
Profile length: 963.9	Maximum value: 8.79	Corrected sum of squares: 9833.29	Standard deviation: 3.1
Source: Author.			

Table 2.
Transect statistics for Playa del Carmen digital elevation model (DEM).

5.1 Urbanised area

A Google Earth image was selected for the area under study. This true colour image was broken down into its red, green and blue components to be used in an unsupervised classification process [37]. A binary image (1, 0) was created to show the urbanised and tourism development areas (class 1) while omitting vegetation, bodies of water and bare land (class 0). Finally, the results were combined with the DEM to obtain an image divided into three elevation zones: 1 m (>0 m to ≤1 m), 2 m (>1 m to ≤2 m) and 3 m (>2 m to ≤3 m). The total urbanised area was calculated for each zone in square metres (m^2).

5.2 Cost of infrastructure

Property developers' websites were surveyed to estimate the cost per m^2 of building tourism infrastructure in Playa del Carmen on beachfront properties and those located along the coast. The average property value in United States dollars (USD) per m^2 was confirmed by checking these properties' average sales price per m^2, without taking inflation into account. This approach can be used to develop economic growth indicators [38] and tools that help predict housing prices and sales [39].

5.3 Flood scenarios

The values obtained were used to evaluate future economic impacts on the city for the three flood-prone areas identified in the DEM. **Figure 3** highlights the scenarios for the infrastructure shown in red for the 1 m, yellow for the 2 m and green for the 3 m zones.

Playa del Carmen is the second largest metropolis in the state at 304,942 residents, according to INEGI's 2020 census, but the city's population growth rate is higher than that of Cancún. The scenario of 1 m of flooding would affect a surface area of 19,281 m^2, shown in red in **Figure 3**, with an estimated USD77 million in damages. The scenario of 2 m of flooding would cover a surface area of 64,649 m^2, highlighted in yellow, with approximately USD258 million in damages. The final scenario of 3 m of flooding would affect a surface area of 90,895 m^2, shown in green, with an estimated USD363 million in damages (see **Table 3**).

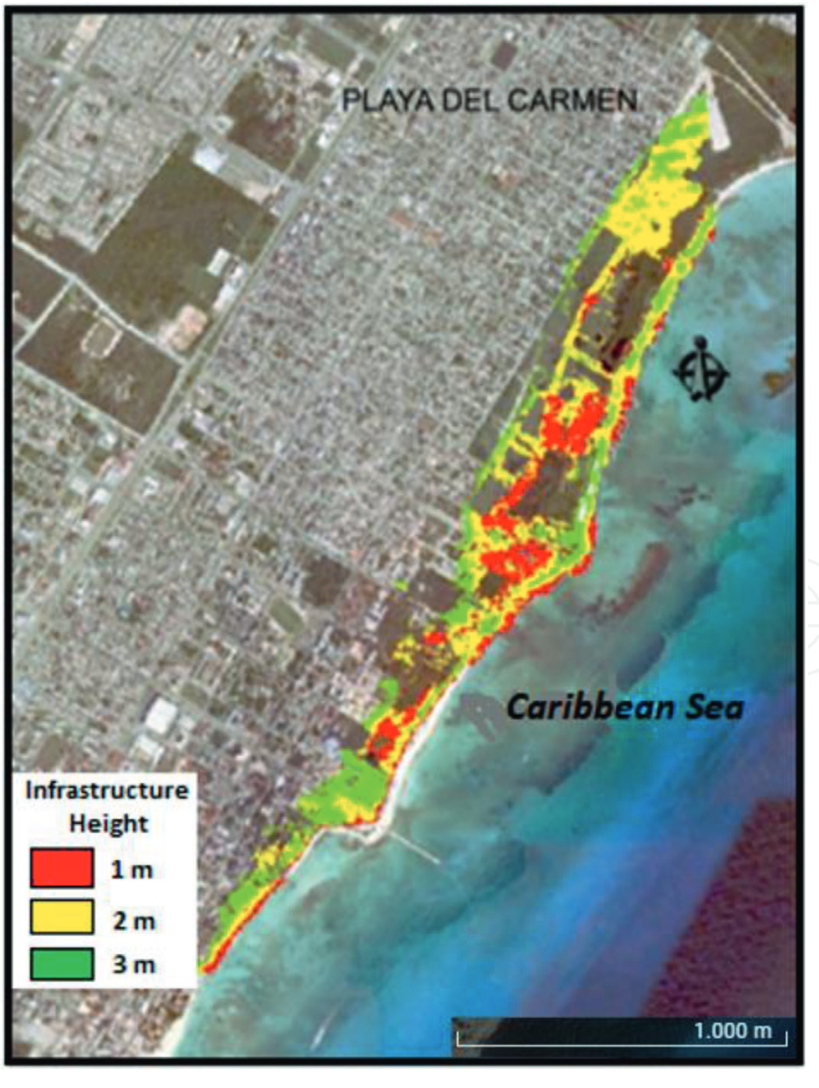

Figure 3.
Playa del Carmen: Google Earth image combined with digital elevation model, with infrastructure at 1 m in red, 2 m in yellow and 3 m in green. Source: Author.

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Playa del Carmen	
Residents	304,942
Price per m^2	USD4,000
1 m	19,281 m^2
	USD77 million
2 m	64,649 m^2
	USD258 million
3 m	90,895 m^2
	USD363 million
Digital elevation model	6.7 metres above sea level
Distance	5.7 kilometres

Source: Adapted from [31, 32].

Table 3.
Cost in United States dollars (USD) for urbanised and tourism areas for three flood scenarios (values calculated based on average sales price per square metre [m^2] for beachfront properties in Playa del Carmen, according to the Asociación Mexicana de Profesionales Inmobiliarios [Association of Mexican Estate Agents]).

The damages in USD for the three scenarios are summarised in **Table 3**. Each option considers urbanised and tourism areas and only the average net construction cost. The calculations thus disregarded the cost of furnishings or other accessories for homes, offices or businesses. These facilities may have special features (i.e. flooring, designer accessories or interiors created by famous architects), so costs can triple or quadruple. Basic services (e.g. water, electricity, cable and Internet) and each building's number of floors were also excluded. The DEM shows an average elevation of 6.7 m above sea level and a stretch of coast 5.7 km long.

In addition, the city's tourism infrastructure is vulnerable each year to storm flooding due to the nortes (north) season's rains. Heavy downpours are also brought by the storms and tropical cyclones that can develop from June to November in the North Atlantic region (see www.nhc.noaa.gov/).

6. Conclusions

Playa del Carmen's vulnerability has gradually increased in three ways: (a) the growing number of national and foreign residents due to the boom in tourism development, (b) a possible increase in the frequency and intensity of tropical cyclones and (c) progressive sea level rise. The Mexican and foreign population growth is strongly connected to the investment boom in tourism facilities and expanding business and service sectors. These trends imply budgetary allocations to defray the cost of providing the necessary housing, infrastructure and basic services such as potable water and sewage disposal. In the last 30 years, the already high freshwater demand has reached a critical level due to the depletion of groundwater (i.e. aquifers), especially in Playa del Carmen [12].

The IPCC reports that, since the 1970s, the frequency and intensity of tropical cyclones has increased in the North Atlantic region. These events are expected to have negative effects on the tourism industry in the future not only in Playa del

Carmen but also throughout the entire Mexican Caribbean as the hurricane season coincides with the summer—and a part of the autumn—holiday season. Hurricanes' consequences depend on their intensity and the property damage they inflict. They can paralyse business activities in any city or tourism centre, as well as decreasing employment and increasing other sectors' vulnerability (e.g. health, energy, transport and education).

The best way to deal with the hurricane season is to provide information and education about these storms. Their impacts on coastal areas can be reduced with a permanent management plan that establishes priorities for the protection of human lives and natural habitats' conservation and restoration (i.e. the Mesoamerican Reef and vegetation on coastal dunes and in mangroves and wetlands) as these features function as physical barriers.

Finally, the IPCC predicts that sea levels will continue to rise. These levels must be monitored in the Caribbean Sea region as they are a continuing threat to ecosystems, tourism centres and coastal towns. Urban and tourism planning for coastal areas has to pay attention to climate change's impacts. Management plans should be able to adapt to—and mitigate the effect of—sea level rise in Playa del Carmen, which requires engineering solutions (i.e. raised roads or bridges, changes in building designs and waterfronts constructed of materials resistant to high temperatures, hurricane winds and elevated salinity). Measures also need to include, among others, limitations on tourism and urban development in high-risk zones and the protection of infrastructure in urban and tourism areas. Any future adaptation programme of action must also be combined with the diffusion of information to society at large and the relevant users in countries with coastlines worldwide.

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