Impacts of climate change on the tourism sector of a Small Island Developing State: A case study for the Bahamas

Arsum Pathak\textsuperscript{a,}\textsuperscript{*}, Philip E. van Beynen\textsuperscript{a}, Fenda A. Akiwumi\textsuperscript{a}, Kenyon C. Lindeman\textsuperscript{b}

\textsuperscript{a} Geography, Environmental Science and Policy Program, School of Geosciences, University of South Florida, Tampa, FL, 33620, USA
\textsuperscript{b} Program in Sustainability, Florida Institute of Technology, Melbourne, FL, 32901, USA

\textbf{ARTICLE INFO}

\textbf{Keywords:}
Climate change impact
Hurricanes
Tourism
Sea level rise
Small Island Developing States (SIDS)

\textbf{ABSTRACT}

This study examines the direct and indirect impacts of climate change to the tourism sector on the islands of New Providence and adjacent Paradise Island in the Bahamas. The assessment was carried out by conducting a geospatial analysis of tourism establishments at risk using Geographic Information Systems (GIS). We combined the geospatial analysis with publicly available databases to assess the integrated climate-related impacts pertaining to a Small Island Developing State (SIDS) economy. Our study estimated that many tourism properties currently lie in a storm surge zone and the extent of properties at risk increases with a future scenario of a 1 m rise in sea level. While sea level rise (SLR) by itself only threatens a small number of properties, when combined with weak (Category 1), moderate (Category 3) and strong (Category 5) storms the resulting coastal flooding impacts 34\%, 69\%, and 83\% of the tourism infrastructure (hotels and resorts), respectively. In addition to flooding, properties are also susceptible to coastal erosion with 28\% of the total hotels and resorts on the two islands being situated within 0–50 m and 60\% of the tourism infrastructure within 0–100 m of the coastline. Considering the economic importance of the sector, the potential impacts on the tourism infrastructure will cause significant losses in revenue and employment for the two islands. Furthermore, the majority of the tourism on these islands is beach-based and visitor expenditures will decline due to their vulnerability. These losses will have far-reaching social-economic consequences for the Bahamas. Our findings reveal a need for integrated coastal zone management that incorporates tourism management strategies with adaptation measures to deal with climate change.

\textbf{1. Introduction}

While many recent studies have identified the impacts of climate change on coastal tourism (Becken, 2013; Fang et al., 2018), there has been a lack of focus on integrated assessments that analyze the full range of potential climate-induced impacts on a specific destination (Nurse et al., 2014; Scott et al., 2016; Scott and Verkoeyen, 2017). In particular, there is a dearth of research on the cumulative effects of these complex impacts on the tourism sector of Small Island Developing States (SIDS), on which many are economically dependent (Scott et al., 2016; Scott and Verkoeyen, 2017). Our paper examines the multiple direct and indirect

\* Corresponding author. Geography, Environmental Science and Policy Program, School of Geosciences, University of South Florida, 4202 E Fowler Ave, Tampa, FL, 33620, USA.

\textit{E-mail addresses:} arsumpathak@usf.edu (A. Pathak), vanbeyne@usf.edu (P.E. van Beynen), fakiwumi@usf.edu (F.A. Akiwumi), lindeman@fit.edu (K.C. Lindeman).

https://doi.org/10.1016/j.envdev.2020.100556

Received 18 March 2020; Received in revised form 4 August 2020; Accepted 19 August 2020
Available online 28 August 2020
2211-4645/© 2020 Elsevier B.V. All rights reserved.

Please cite this article as: Arsum Pathak, \textit{Environmental Development}, https://doi.org/10.1016/j.envdev.2020.100556
climate-induced impacts on one of the tourism-reliant SIDS – the Bahamas. We evaluate the implications of these impacts at the national level. Taking into consideration the multi-dimensionality of climate change impacts on the prospects of tourism for SIDS sets the foundation for both an integrated vulnerability assessment and potential adaptation measures (Scott and Verkoeyen, 2017).

Agenda 21 of the Earth Summit held in Rio De Janeiro, Brazil, June 1992 recognized SIDS as a group of countries with special environment and development challenges. At present, there are fifty-eight SIDS designated by the United Nations (UN), out of which 38 are UN members while 20 are non-UN members or associate members of regional commissions. These SIDS are spread over three regions – the Caribbean, the Pacific, and AIMS (Atlantic, Indian Ocean, Mediterranean, and the South China Sea) (UN-OHRLLS, 2020). The countries vary in terms of their physical size as well as economic, social, and environmental conditions. Most, however, share a common vulnerability to climate change-induced sea level rise (SLR), changes in sea surface temperature, precipitation, and extreme events (Church et al., 2013; Nurse et al., 2014; Oppenheimer et al., 2019). This vulnerability mostly stems from their low elevation and densely populated coastal areas.

Climate change manifests itself in many ways such as changes in sea levels, storm surges, and sea surface temperatures (Church et al., 2013). A growing number of studies focus on the combined impacts of SLR and storm surge in coastal areas (Frazier et al., 2010; Kleinosky et al., 2007; Neumann et al., 2015; Silver et al., 2019). In the Bahamas, Silver et al. (2019) found an increase in shoreline exposure and population to coastal hazards with an increase in SLR. However, concerning coastal tourism, relatively few studies have attempted to investigate such combined effects of SLR and storm surge for SIDS. To the best of our knowledge, the only quantitative analysis of the combined impacts of SLR and storm surge in the coastal tourism sector have been conducted in China (see Fang et al., 2016). Considering the recent catastrophic damages from the Atlantic Ocean hurricanes Irma and Dorian on several Caribbean SIDS, assessing the risk posed by storm surge coupled with the projected SLR to tourism infrastructure is essential for these developing nations.

During the Atlantic hurricane season in 2016, Hurricane Matthew hit the South coast of New Providence Island with a storm surge height of more than 2 m causing estimated damages of USD 600 million in the Bahamas (Stewart and Berg, 2017). Tourism-related infrastructure such as Nassau airport and surrounding roads were flooded or damaged (Stewart and Berg, 2017). Researchers predict an increase in the frequency of such severe Category (Cat) 4 and 5 storms like Matthew and more recent Dorian in the 21st century (Bender et al., 2010; Walsh et al., 2016). From the point of view of this study, hurricane Dorian is the most recent and prominent example of extreme events and their impacts on the wider social-economic and environmental conditions of the Bahamas (IDB, 2019). Pacific SIDS that rely on tourism have also been severely impacted during the South Pacific cyclone season. One recent example from 2018 is Cyclone Gita, a Cat 4 storm, that made landfall in Tonga causing widespread infrastructural damages. With an increase in the frequency of more severe storms worldwide over the coming years combined with SLR, potential damages could be exacerbated.

Many SIDS are dependent on single economic sectors such as tourism that provide the main source of employment and economic growth. In the Caribbean region, tourism created one in four new jobs and contributed to 20% of the total visitor exports in 2019 (WTTC, 2020). The tourism sector generated USD 3678 million accounting for 81.6% of the Bahamas visitor exports. In addition to foreign exchange, this sector, in particular hotels and restaurants, is a significant area of interest for foreign direct investments in the Caribbean SIDS. A well-managed tourism sector can also provide opportunities for the growth of other sectors such as fisheries (UNCTAD, 2014). While the tourism sector constitutes part of regional assessments, specific destination-focused research is essential to understand the multifaceted nature of climate change impacts on tourism. The Economic Commission for Latin America and the Caribbean (ECLAC) has produced some country-level assessments of climate change impacts on tourism for several Caribbean SIDS (ECLAC, 2011). However, the assessments lack consideration of multiple impacts. For example, the ECLAC report for the Bahamas “An Assessment of the Economic Impact of Climate Change on the Tourism Sector in the Bahamas” used a Tourism Climate Index (TCI) to model changes in tourist demand but lacked a clear focus of the direct changes on the source market due to climate change.

For this study, we examine the risks posed by climate change to the Bahamas tourism sector. We consider different direct and indirect impacts that may affect the tourism sector in particular and the Bahamas, in general. Specifically, we used integrated impact pathways adapted from the conceptual framework of Scott et al. (2008), Scott, Hall, and Stefan (2012a), and Scott and Verkoeyen (2017) that may affect the tourism sector in the SIDS. Our main research objectives are to 1) assess the inundation and coastal flooding related impacts on coastal tourism by a 1 m SLR and storm surge, 2) assess the impacts on tourism due to flooding and erosion exacerbated by a future SLR scenario and, 3) quantitatively assess the major social-economic and environmental losses stemming from these projected impacts. The overall goal is to timely identify climate risks which can then support decision-making and adaptation planning for tourism stakeholders subjected to these changing climatic conditions.

Many SIDS have developed national strategies in the form of National Adaptation Programmes of Action (NAPAs) and National Communications (NCs) to plan for future climatic changes. While the tourism sector constitutes a part of these reports, most SIDS lack specific planning for climate change while ensuring the growth and management of their main economic sector, tourism. A few exceptions such as the Barbados and Belize have developed dedicated departments for coastal zone management and devised Integrated Coastal Zone Management (ICZM) plans and policies. However, the examples of such integrated responses are relatively limited in most SIDS.

Our selection of the Bahamas is based on the following: a) it faces similar vulnerabilities to climate change as other SIDS, b) it is a heavily tourism reliant economy that provides an avenue for understanding the spillover effects of climate change at the country level, and c) the recent encounters of high-intensity hurricane events in the country. The Bahamas is a large archipelago with a land area of 10,010 km² comprising of 700 islands of which 30 are inhabited (CIA, 2018). The islands are dominated by two carbonate platforms with less than 10 m depth (Buchan, 2000). In the SIDS, the Bahamas has the highest share of the population, 82.8%, living in the Low Elevation Coastal Zones (LECZ), the contiguous area along the coast that is less than 10 m above sea level (Myccoo and Donovan, 2017). One hundred percent of the population in the country lives within 25 km of coastline (Myccoo and Donovan, 2017). In 2019, tourism in
the Bahamas contributed to 43.3% of the GDP (WTTC, 2020). A total of 52.2% of the jobs are supported by tourism and the sector generated 81.6% of the total visitor export-related revenue in 2019 (WTTC, 2020). The Bahamas have experienced five major hurricanes over the past five years. These include a Cat 5 hurricane in 2019, Dorian, after facing a Cat 4 hurricane Matthew in 2016. Other major hurricanes such as Maria and Irma caused damages to some smaller islands in the Bahamas. Nevertheless, all hurricane events, regardless of their magnitude, disrupt the national government, alter visitor’s perception, and decrease tourism-related revenue. The Bahamas, therefore, is a good example of a SIDS to achieve our research objectives. The paper is structured as follows. In section 2, we describe the methodology of our study beginning with a thorough description of our study area. This is followed by the explanation of our findings in Section 3. We discuss our most important findings in section 4 and finally, section 5 concludes our study.

2. Materials and methods

2.1. Study area

Two islands of the Bahamas – New Providence (NP) and the adjacent Paradise Island (PI), hereafter NP and PI (Fig. 1) were chosen for this study because they have the highest room count of tourism accommodations (62.04%), and a large number of employees, visitors and related expenditures in the sector. The Bahamas’ Ministry of Tourism (MOT) lists NP as generating more than 90% of the jobs in the accommodation and food service sector from 1999 to 2012 (MOT, 2019). Out of the 1.63 million visitors in the Bahamas in 2018, 67.2% (1.09 million) stayed on these two islands. The islands have consistently contributed the most to the visitor expenditure since 1989 (the earliest data available at the MOT). Based on the visitor expenditure data provided by the MOT, 67–68% of the visitor expenditures in 2015-16 came from NP and PI (MOT, 2016). Out of this total expenditure on the islands, stopover visitors (who stay at least one night) contributed as high as 86.8% to the total visitor expenditure while cruise visitors and day visitors who do not stay overnight contributed to 13.08% and 0.09% respectively. Many family islands in the Bahamas Archipelago such as Abaco and Eleuthera as well as Grand Bahama Island are growing as tourism destinations, but NP/PI combined dominate the sector (see Fig. 2 for comparative statistics).

NP and PI of the Bahamas Archipelago have the highest contribution to the tourism sector. These islands contributed 47.8% of the total revenue to the Bahamas GDP (USD 4.3 billion) in 2017 (WTTC, 2018). As much as 72.8% of the total exports in the Bahamas are generated as spending by international visitors (WTTC, 2018). The sector is also the largest contributor to employment in NP with 53.1% females and 46.9% males employed in the sector (MOF, 2018). Thus, tourism provides important job opportunities for the local

Fig. 1. Location of the study area (left); DEM of study area showing the location of tourism infrastructure (bottom right); close up view of the populated northern coast and the adjacent Paradise Island (top right).
Considering the importance of the tourism industry in the Bahamas, any potential climate-induced losses to its two main tourism-generating islands will likely have far-reaching social-economic implications. Therefore, these islands together provide an avenue for understanding the potential impacts of climate change and its spillover effects on the entire country.

2.2. Methodology

The four impact pathways through which climate change may affect tourism are – a) direct impacts from changing climate, b) indirect environmental change and cultural heritage impacts, c) indirect impacts associated with societal change and, d) impacts induced by climate change mitigation and adaptation in other sectors (Scott et al., 2008, 2012a; Scott and Verkoeyen, 2017). We operationalized three of these impact pathways by developing specific indicators for the quantification of impacts and potential losses (Fig. 3).

The indicators for different types of impacts were selected based on suitability to the study area, literature review, and the

Fig. 2. Percentage of contribution to the selected tourism-related indicators from three main island groups in the Bahamas in 2018.

Fig. 3. Selected climate change impact pathways for tourism in SIDS.
availability of data. A detailed description of the chosen indicators is provided below (Table 1).

### 2.2.1. Sea level rise and storm surge

In a recent report published by the IPCC, Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC), the rate of Global Mean Sea Level (GMSL) can reach 15 mm/year if the Antarctic contributions to GHGs are taken into account (IPCC, 2019). According to the report, SLR projections vary from a lower bound of 0.43 m (Slangen et al., 2014) to as high as 2.46 m (Le Bars, Drijfhout and de Vries, 2017) depending upon the baseline period and the choice of probabilistic or semi-empirical models (IPCC, 2019).

Local sea level data is not available for the study area. The nearest tide gauge data is available for the Settlement Point in the Bahamas maintained by the Permanent Service for Mean Sea Level (PSMSL, 2020). A time-series analysis of the tide gauge SLR data available from 1986 to 2000 and 2005–2016 shows an upward trend in sea level. However, the discontinuity and gaps in the available measurements make the available GMSL projections a more reliable choice of SLR. Considering the variability in global projections and gaps in the regional dataset, this study uses a conservative 1 m SLR scenario by 2100 that has been commonly used in similar studies that evaluated impacts of SLR on tourism infrastructure (e.g., Fang et al., 2016; Isaac, 2013; Scott et al., 2012b; Simpson et al., 2010).

The Second National Communication document recognizes that the rate of SLR in the Bahamas is slower than vertical land movement. It also suggests that “sea level is rising at a rate of 0.2 mm/yr (the difference between vertical land movement and thermal expansion)” and the future SLR will be in line with the global trends (The Commonwealth of the Bahamas, 2014).

We used the SLOSH (Sea, Lake and Overland Surges from Hurricanes) model to calculate potential surge for an area by using a series of historical or hypothetical hurricanes of various Saffir-Simpson categories, speed, landfall location, and direction (e.g., Frazier et al., 2010; Sealy and Strobl, 2017). Each model run reflects the maximum surge height for a particular grid cell. The outputs from each model run are combined to form a composite Maximum Envelope of Water (MEOWs) for each hurricane category, speed, and direction on the Saffir-Simpson Scale (National Hurricane Center, 2003). A further composite called Maximum of MEOWS (MOM) is generated for all simulated hurricanes for a given Saffir-Simpson scale category regardless of landfall direction and speed (Glahn et al., 2009). Here we use the MOM outputs generated from the SLOSH display in the Bahamas Basin that encompasses the entire study area. Gridded layers as shapefiles were downloaded for three hurricane categories: weak (Cat 1), moderate (Cat 3), and strong (Cat 5). The MOM outputs provide a conservative estimate of surge height as it does not account for wind-driven waves that increase the storm surge height (Frazier et al., 2010). Since storm surge is the most significant concern for the coastal Bahamas, the product is useful for making early decisions by planners and fits the purpose of our study.

### 2.2.2. Tourism infrastructure and cultural heritage sites

We used the tourism infrastructure on the islands of NP and PI for the above analysis. Only formal accommodation providers such as hotels and resorts are included in our analysis as they generate the highest revenue for the entire sector. An initial list of tourism hotels and resorts (n = 57) was obtained from the Directory of Hotels – June 2018 published by the Bahamas Ministry of Tourism (MOT, 2018). This document provides a comprehensive account of tourism type, location, address, and room count. These properties were identified in Google Earth to verify their geographic location. During this step, two properties were eliminated due to missing geographic information on Google Earth or lacking any online records for identification (such as an address, website, etc.). Two more properties were identified in Google Earth to verify their geographic location. During this step, two properties were eliminated due to missing

We used the MOM outputs generated from the SLOSH display in the Bahamas Basin that encompasses the entire study area. Gridded layers as shapefiles were downloaded for three hurricane categories: weak (Cat 1), moderate (Cat 3), and strong (Cat 5). The MOM outputs provide a conservative estimate of surge height as it does not account for wind-driven waves that increase the storm surge height (Frazier et al., 2010). Since storm surge is the most significant concern for the coastal Bahamas, the product is useful for making early decisions by planners and fits the purpose of our study.

#### Table 1

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Metric</th>
<th>Data Source and Analysis</th>
<th>Rationale for Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure losses and damages</td>
<td>Property count (number of hotels and resorts)</td>
<td>Elevation data (ALOS GDEM) Major tourism properties point shapefile (hotels and resorts) Island boundaries shapefile (Humanitarian Data Exchange) SLOSH gridded shapefile Geospatial analysis</td>
<td>Coastal resort properties in the Caribbean are vulnerable to 1m SLR (Isaac, 2013; Scott, Simpson and Sim, 2012b)</td>
</tr>
<tr>
<td>Loss of revenue</td>
<td>Loss in occupancy</td>
<td>Room count (MOT, 2018)</td>
<td>Tourism sector contributed to 47.8% of total GDP in the Bahamas (WTTC, 2018)</td>
</tr>
<tr>
<td>Loss of beaches and coral reefs</td>
<td>Properties susceptible to erosion</td>
<td>Beach width Distance from the coast, meters Coral reef cover, sq. km (Arkema et al., 2017; Simpson et al., 2012)</td>
<td>Beaches and coral reefs are important factors for tourism destinations (Uyarra et al., 2005)</td>
</tr>
<tr>
<td>Cultural heritage sites</td>
<td>Number of sites susceptible to SLR, storm surge</td>
<td>Heritage site point shapefiles Geospatial analysis</td>
<td>Heritage tourism is growing as a tourism market in the Caribbean (Jordan and Jolliffe, 2013)</td>
</tr>
<tr>
<td>Loss of employment</td>
<td>Ratio of bed capacity to staff</td>
<td>Occupational and wages data (MOF, 2018)</td>
<td>Tourism generated &gt; 3 million jobs in SIDS and supported 55.7% of employment in the Bahamas in 2017 (WTTC, 2018)</td>
</tr>
<tr>
<td>Loss of visitor expenditure</td>
<td>Loss of tourists due to losses in recreational services provided by beaches and coral reefs</td>
<td>Average expenditure per number of tourists (MOT, 2017)</td>
<td>International visitors spent more than USD 2 billion (72.8% of total exports) in the Bahamas in 2017 (WTTC, 2018)</td>
</tr>
</tbody>
</table>
island on NP while 15 properties were located on PI. The properties were further categorized based on their location as designated in the Directory: beachfront \((n = 27)\) and inland \((n = 26)\); and type: budget \((n = 24)\), economy \((n = 13)\) and luxury \((n = 16)\). The geospatial database also contained the following information: geographic coordinates of the property, elevation, and distance from the coast. A point shapefile containing the central point of each resort/hotel was created in ArcGIS version 10.4. A 100 m property buffer was applied to the point feature before conducting geospatial analysis to account for the total area of the properties.

In addition to tourism infrastructure, we also considered several cultural heritage sites on the two islands in our analysis. The official website of the Bahamas lists 17 cultural heritage sites in the Bahamas, nine of which are located on NP and PI. Of these, three cultural sites were historical villages and geographically dispersed over the islands. These villages do not have delineated boundaries and are spread out in a manner that made it difficult for mapping and conducting geospatial analysis, which excluded them from the study. Therefore, five cultural heritage sites were chosen for analysis: three forts, one national park, and one historic tourist attraction. There are other critical infrastructures such as road networks and airports that are relevant to tourism management. A detailed impact analysis of key infrastructures for climate-induced SLR and storm surge in the Caribbean SIDS has already been conducted by Simpson et al. (2010) and therefore, we focused our analysis on the accommodation infrastructure most closely and directly related to generating tourism-related revenues.

### 2.2.3. Coastal flooding scenarios: current and future hazard assessment

The first step in this analysis was the delineation of the flood risk zones due to storm surge in the study area. A methodology similar to Frazier et al. (2010) was adopted. Current exposure of the tourism infrastructure to storm-surge flooding was estimated using SLOSH. The MOM outputs for each hurricane category were compared with a 30-m digital elevation model (DEM) of the study area. The DEM, also known as ALOS (Advanced Land Observing Satellite) DEM, was downloaded from the Japan Aerospace Exploration Agency (JAXA).

ALOS DEM is one of the most recent global DEM’s available and has better vertical accuracy when compared with other comparable DEMs such as SRTM and ASTER GDEM (Grohmann, 2018; Santillan and Makinano-Santillan, 2016). An accuracy assessment is regarded as best practice for elevation centered geospatial analysis such as inundation and flooding (Gesch, 2018). We used the Trimble TSC3 handheld device based on Real-time Kinematic (RTK) surveying to collect ground truth GPS points. The values of elevation at the ground GPS points were compared with different global DEM elevations. We found that ALOS and SRTM GDEM had lower mean differences in the elevation than ASTER GDEM when compared to the GPS points. However, due to more missing values in the SRTM DEM, we chose to use ALOS DEM for our analysis.

ArcGIS was used for creating the flood risk maps and conducting the analysis. The first step was to convert the MOM shapefiles into raster grids using inverse distance weighted (IDW) interpolation. Raster calculator in the spatial analyst toolbox was then used to identify the areas where storm surge height exceeded the DEM elevation. This method generated a binary raster with the flooded and non-flooded cells. This raster was reclassified to create a final storm surge raster i.e. flood risk map containing only the flooded cells for each hurricane category. The cells that were surrounded by higher, non-flooded land and not hydrologically connected to the coastline were manually removed from the risk zones.

To compute future hazard zones enhanced by SLR, the DEM was modulated to represent a future scenario of 1 m SLR by lowering the SRTM DEM, we chose to use ALOS DEM for our analysis.

ArcGIS was used for creating the flood risk maps and conducting the analysis. The first step was to convert the MOM shapefiles into raster grids using inverse distance weighted (IDW) interpolation. Raster calculator in the spatial analyst toolbox was then used to identify the areas where storm surge height exceeded the DEM elevation. This method generated a binary raster with the flooded and non-flooded cells. This raster was reclassified to create a final storm surge raster i.e. flood risk map containing only the flooded cells for each hurricane category. The cells that were surrounded by higher, non-flooded land and not hydrologically connected to the coastline were manually removed from the risk zones.

To compute future hazard zones enhanced by SLR, the DEM was modulated to represent a future scenario of 1 m SLR by lowering the elevation of the DEM by a meter through a raster calculator. The mapping process, described above, was used for newly created DEM to delineate enhanced areas with SLR and storm surge.

### 2.2.4. Calculating impact assessments

These flood risk maps were overlaid with the point shapefile of tourism infrastructure to assess properties at risk. To further quantify major social-economic and environmental losses associated with tourism, the following secondary datasets were used:

a) **Inundation related losses** - calculated by considering the total loss of revenue in terms of room count and average room rate in USD.

The data on room count was obtained from the Bahamas MOT. While inundation may result in a total loss, a property affected by storm surge may not be completely destroyed. Consistent with other studies in the Caribbean (Moore et al., 2010) and more specifically in the Bahamas (ECLAC, 2011), this study uses a hurricane damage estimate of 10%, 35% and 75% for a Cat 1, 3 and 5 storm respectively. The total loss in room count was adjusted to account for these damage percentages. The most recent average daily rate (USD) of the rooms (ADR = Room Revenues/Rooms Sold), $303 for the Bahamas (STR, 2019), was used for calculating revenue losses. The revenue was calculated at a present-day ADR value i.e. it does not take into account future increases in the hotel prices and new constructions.

b) **Coastal erosion** - calculated using Bruun Rule, a two-dimensional conceptual model for predicting SLR induced erosion, which assumes that the coast retreats 50–100 times the vertical increase in sea level (Bruun, 1962). This rule has been criticized for being too simplistic and omitting important variables such as slope and lithology of the coast (Cooper and Pilkey, 2004). However, Atkinson et al. (2018) found shoreline recession relative to rising water levels falling within 25% of the prediction within the Bruun Rule. The rule has also been used recently in coastal destinations such as Thailand (Rithpring et al., 2018), Gambia (Amuzu et al., 2018) and many SIDS where data on the physical parameters of the coast are still lacking (Mueller and Meindl, 2017; Scott et al., 2012b). It was evident during field observations that the islands have a consistent beach profile with mostly sandy beaches and shallow slopes. Therefore, Bruun rule was used for an approximate estimation of the coastal properties at risk of erosion.

To determine erosion through the Bruun Rule, beach width in the two islands were initially evaluated from Google Earth images, however, it was evident that the width does not exceed 50 m for the two islands. Consequently, property distance from the coast was
Fig. 4. Coastal flooding caused by storm surge and 1 m of sea level rise for a) weak storm (Cat 1) b) moderate storm (Cat 3), and c) strong storm (Cat 5).
used as an indicator of beach loss. If the properties were impacted by coastal erosion, this means that there is essentially no beach remaining after the storm, and the hotel is exposed to erosion related damages.

c) **Coral bleaching** - used as an indicator of loss of coral reefs. Global mean sea surface temperature can rise from 0.73 °C (RCP 2.6) up to 2.58 °C (RCP 8.5) by 2100 placing coral reefs from moderate to very high risks from climate change (Oppenheimer et al., 2019). IPCC’s SR1.5 estimated a decline of 70–90% of coral reefs even with RCP2.6 and more than 99% coral reefs lost beyond a global temperature increase of 2 °C (Hoegh-Guldberg et al., 2018). Further, Burke et al. (2011) estimated 79% of the coral reefs in the Bahamas are threatened due to local and thermal stress. In the absence of more local studies that consider the site-specific risks to coral reefs based on their type, depth, etc., we used a conservative estimate of 70% decline in the coral reefs by the end of the century. Data on the total coral reef area for the Bahamas and reef area in NP is taken from the CARIBSAVE “Climate Change Risk Profile for The Bahamas” report (Simpson et al., 2012).

d) **Loss of employment** - computed by considering the average employee per room. Data on the average employee per room for the three different classes of accommodations as adjusted from the Caribbean Hotel and Tourism Association (CHTA): 2.8 for luxury hotels, 1.5 for moderate hotels, and 0.7 for a budget property. The most recent data on hotel employment (MOF, 2018) is only available for NP and shows 13,863 persons employed in the sector. The average employee to room ratio was extended to PI to estimate the total number of hotel employees on the two islands (n = 23,864).

e) **Loss of tourists and related expenditures** - quantified through the loss of natural resources (beaches and coral reefs) vital for tourism. The following data sources were used: an exit survey conducted by Research and Statistics Department of the Bahamas MOT (2017) that provides data on the visitor’s preference for beaches and coral reef-related activities (snorkeling and scuba diving) in the Bahamas. The exit survey provided the percent of visitors who primarily visited the islands of NP and PI for their beaches. We then used the data from MOT on total stopover visitors to assess the number of beach visitors. These numbers were compared with the total visitors in the Bahamas to calculate the total visitor losses in the country due to lost beaches on the two islands. Similarly, the average expenditure per tourist (USD 1212.098) was calculated using MOT data on stopover visitors and visitor expenditure from 1990 to 2016 (MOT, 2016). Total visitor expenditure in the Bahamas was USD 2663.8 million (WTTC, 2018).

We limited our analysis to stopover visitors (who stay at least one night), deliberately excluded cruise and day visitors who do not stay overnight, and thus, do not contribute to the accommodation sector.

3. Results

Final flood risk maps for Cat 1, Cat 3, and Cat 5 storm at a present SLR scenario showed the changes in storm surge with a future increase of 1 m SLR (Fig. 4). The following section details various climate-related impacts relevant to the study area.

3.1. Direct climatic changes

**Tourism properties at risk of SLR induced inundation:** Results indicate that six properties (11%) are at risk of permanent inundation i.e. complete loss of occupancy due to a 1 m rise in sea level. These include one budget, one luxury, and four economy hotels and resorts. As expected, all of these are coastal beachfront properties. A total room capacity of 756 rooms will be impacted under this scenario.

**Tourism properties at risk due to coastal flooding:** Sea level rise considerably increases the extent of storm surge caused by various categories of storms (Fig. 4). Considerably more properties are impacted by storm-surge hazards as compared to permanent inundation. At present, coastal flooding caused by a weak (Cat 1), moderate (Cat 3) and strong (Cat 5) storm can potentially affect 34% (n = 18), 69% (n = 37), 83% (n = 44) of the tourism infrastructure (hotels and resorts), respectively. The percentage of infrastructure at risk increases considerably with the addition of a SLR scenario. For example, the number of properties increases from 18 to 27 when a Cat 1 storm is amplified by a 1 m SLR, resulting in a more than 18% increase of risk. Similarly, a Cat 3 and Cat 5 storm poses risk from
75% \((n = 40)\) to as much as 90% \((n = 48)\) of the tourism properties when enhanced by a meter rise in SLR by 2100.

**Tourism properties at risk due to sea level rise induced coastal erosion:** 96% of the beachfront tourism properties \((n = 27)\) are located within 100 m of the coast. Of these 27 properties, 12 are within 0–50 m of the coastline. For the inland properties \((n = 26)\), six properties lie within 100 m of the coastline and three are within 50 m of the coastline. In summary, 28% of the total properties on the two islands are within 0–50 m while 60% of the tourism infrastructure resides within 0–100 m of the coastline.

**Loss of occupancy and revenue:** Assuming total losses by a 1 m SLR, 7% \((756\) rooms\) of the total room count will be uninhabitable for accommodating visitors on the two islands. In addition, storm surge will also cause potential damage to the tourism infrastructure. A Cat 1 storm coupled with SLR will pose losses of occupancy to around 579 rooms \((10% of a total 5795 rooms)\) whereas a Cat 5 storm surge will damage more than 7777 rooms on the two islands.

Fig. 5 presents the relative losses in room count based on the property type. More economy properties are impacted in the future 1 m SLR and all associated storm surge scenarios as compared to budget and luxury accommodations. Only 3% of luxury properties are at risk of potential SLR induced inundation. For these properties, the occupancy related losses increase from 5.9% to 29.2% when the storm category changes from Cat 1 to Cat 3. Comparatively, 14.4% and 19.8% of the budget and economic properties are at risk from the SLR and these risks increase to 31%–34.9% for Cat 1 and Cat 3 storm categories respectively. In the event of a strong storm, most properties will face a similar level of risks: 71.4% for budget, 75.4% for the economy, and 74.3% for luxury properties.

The decrease in revenues (Fig. 6) was estimated as follows: 7% for SLR, 5.5% for a weak storm (Cat 1), 30% for a moderate storm (Cat 3), and 74% for a strong storm (Cat 5) by 2100. Amongst other business interruptions due to flooding and inundation, the potential losses in occupancy will decrease revenues significantly.

### 3.2. Indirect climate-induced environmental changes and cultural heritage impacts

**Loss of beaches:** At present, the beach width for all the beaches on the two islands do not exceed 50 m putting them at risk of potential erosion caused by rising sea level. The erosion of coastal properties indicates that the beaches will be lost much earlier than the properties themselves. Potentially 60% of the coastal properties are susceptible to damages from erosion in the study area. In terms of occupancy, this damage translates into a room count of more than 92% \((9727\) rooms\) in the two islands.

**Loss of coral reefs:** The Bahamas could possibly lose as much as 1390 sq. km of its coral reefs due to rising ocean temperature. NP consists of 30 sq. km \((approx. 1.5%)\) of the total reef region in the Bahamas. Assuming a 70% decline in coral reef cover, NP could lose 21 sq. km of its coral reef cover. These losses will be exacerbated if the local threats such as overfishing, pollution, and coastal development are also taken into account (Burke et al., 2011). The coral reefs in NP are at high risk of coastal development and dredging while human activities such as pressure from fishing and invasive lionfish add to this risk (Arkema et al., 2017). The losses in the fringing coral reefs, mostly present on the northern side of the island, will alter many ecosystem services such as storm protection, local finfish fisheries, habitat for spiny lobster (main export of the Bahamas), and visitor expenditure (Arkema et al., 2017). It is worth noting that there is some evidence that suggests several reef species demonstrate higher resilience through adaptation and acclimatization to changing climate than others (Palumbi et al., 2014). However, for this study, we assume a total loss of coral reefs because such a fine level analysis is beyond the scope of our study.

**Cultural heritage sites:** Only one of the five cultural heritage sites face risks of inundation due to a meter SLR. This site, Fort Montagu, is also susceptible to all three storm surges and lies within less than 50 m of the coastline. In addition, the Clifton Heritage National Park on NP Island is at risk of flooding by a moderate (Cat 3) and strong (Cat 5) storm at the present SLR levels which obviously increases with the 1 m rise in sea level. The other three sites, due to their high elevation, are not at current or future risks of storm surge and SLR.

---

**Fig. 6.** Losses from SLR and SLR plus differing storm categories as a percent of total revenue and employment opportunities generated by the tourism sector in NP and PI.
3.3. Indirect climate-induced social-economic changes

**Loss of employment:** Sea level rise will directly affect only a small percentage (5.14%) of the total employment in the travel and tourism sector (Fig. 6). However, the number of employees will be significantly impacted due to storm surge with more than 74% of the total employment at risk due to a strong Cat 5 storm by 2100. These values are conservative estimates, as they do not account for future employment growth in the tourism sector.

**Loss of tourist expenditures:** The highest loss of tourism expenditure will result from the loss of beaches. The beaches of NP and PI are listed by 86% of tourists as the main reason why they come to the islands (Exit Survey, Bahamas MOT, 2017). Considering a total loss of beaches by 2100, this will result in a 56.17% decline of the total visitors in the Bahamas and a decrease in visitor expenditure by USD 981.75 million (36.8% of total visitor expenditure).

The 2017 exit survey conducted by the MOT found that coral reef-related activities such as snorkeling, and scuba diving are less preferred by visitors to NP and PI (39% and 7% respectively). The loss of coral reefs described above may induce losses up to 30.04% and 19.71% (USD 525.13 million) in terms of visitors and expenditure lost to the national Bahamas economy.

4. Discussion

Our findings show that the tourism sector on the islands of NP and PI is threatened by SLR and storm surge. Six properties (11%) are located within 1 m SLR and face the risk of inundation. Thirty-four percent (34%) of the coastal tourism businesses on the islands of NP and PI are currently located in a Cat 1 storm surge zone and more than 83% are located in a Cat 5 storm surge zone. With the future projected increase in SLR, the exposure from these storms can significantly increase to as much as 90% of the properties vulnerable if a Cat 5 storm makes landfall on these two islands. Even in a conservative scenario of Cat 1 storm surge, up to 51% of the properties will be vulnerable with a 1 m SLR scenario. It is worth noting that many recent studies have even considered an increase in sea level to as much as 2 m and beyond (Compact, 2015; Le Bars et al., 2017). This will be highly consequential to the tourism sector as well as the Bahamas as a whole. Any adaptation planning needs to consider these higher-end scenarios.

While SLR may pose direct inundation threats to only a small number of properties, the findings from storm surge exposure are pertinent to the Bahamas taking into consideration past hurricane devastation in the country. The Bahamas lost 10% of its GDP (estimated up to USD 551 million) due to hurricanes Frances and Jeanne in 2014 (The Commonwealth of the Bahamas, 2014). Hurricane Matthew in 2016 caused USD 129 million in damages to the tourism sector in the Bahamas (ECLAC, 2019). Even though it caused mild damage to the tourism infrastructure in NP, the island accounted for more than 40 percent of the total losses in the tourism sector of the Bahamas (ECLAC, 2019). The recent catastrophe from Hurricane Dorian, a Cat 5 storm, demonstrated the country’s vulnerability to extreme weather events. Dorian’s impacts were not on NP and PI but the Abaco and Grand Bahama Island to the north which differ in their geology from NP/PI. However, the tourism in NP/PI still suffered due to the consequences of Dorian due to potential tourists assuming that these two southern islands were also physically impacted by the storm. Notwithstanding potential changes in hurricane frequency and intensity of future Atlantic hurricanes (Bender et al., 2010; Walsh et al., 2016), this is a major threat as storm surge risks will be much greater for each hurricane category with rising sea levels. The Bahamas building code (2003) was mandated to provide standards on building design. These findings emphasize the need for further strengthening and updating the building codes to match the intensity of future events. This is a further step towards addressing Sustainable Development Goal (SDG) 13, particularly Target 13.1, which calls for strengthening resilience to climate disasters.

Inter-American Development Bank (IDB) estimated total costs of the impacts of the hurricane Dorian at USD 3.4 billion, accounting for a quarter of the country’s GDP with the tourism sector bearing the highest losses (IDB, 2019). These losses are forecasted to be USD 325 million due to decreases in visitor arrivals and changes in tourist preference due to damaged structures (IDB, 2019). The sector faced damages up to USD 530 million (IDB, 2019). These impacts will be exacerbated by post disasters issues such as disaster debris, contaminated freshwater lenses, and declines in fishery production (EDM, 2019) that further magnify the losses to the tourism industry on the affected islands, as well as the broader social-economic situation in the country.

With regard to property type and increased storm surge, low budget and economy class properties are at greater risk compared to large luxury accommodations. Such properties with limited capital will have greater difficulty recovering from storm damage. Less than half of the small hotels interviewed on the islands of NP and PI could afford hurricane insurance coverage due to low occupancy, high operating costs, and high insurance premiums (Thomas, 2012). An Australian study presented similar findings where small-scale businesses lacked coverage compared to larger tourism enterprises (Cioccio and Michael, 2007). In the Bahamas, insurance premiums are likely to increase further following hurricane Dorian, thus, adding to the vulnerability of smaller tourism businesses.

Natural resources such as beaches and coral reefs are vital to the tourism sector. The vulnerability of beaches is most pertinent to NP and PI as these coastal features buffer hotels and resorts on the southern side of the islands from the full extent of damage that can be wrought by the hurricanes. They also attract the highest number of tourists and therefore revenue. While coral reef-based activities such as snorkeling and diving are comparatively less preferred by tourists, the reefs remain a substantial draw and provide many ecosystem services such as storm protection and fisheries’ habitat. Silver et al. (2019) modeled the coastal protection benefits of ecosystems in the Bahamas and found that these ecosystems were vital in reducing shoreline exposure to coastal hazards for all Bahamian islands. This was also evident in our study where the northern side of the NP Island, where the majority of the tourism infrastructure located, benefits from wave attenuation and storm protection provided by the nearby Cays and the fringing reef. In contrast, the southern side of the island is more exposed due to its lack of physical barriers and the shallow waters of this region of the Great Bahama Bank.

The reefs are also an important habitat for spiny lobster, which is one the main export fisheries of the Bahamas and contributes to
more than 90% of the exports from the country (FAO, Bahamas, 2018). In addition to overexploitation and coastal zone development, lobster and finfish fisheries are sensitive to damages to coral reefs (FAO, Bahamas, 2018). Caribbean Challenge Initiative (CCI) and the Bahamas Protected Areas are involved in the effective management of Marine Protected Areas (MPAs) in the country. In the NP, two MPAs – Southwest NP Marine Managed Area (SWMMA) and Bonefish Pond National Park generate ecosystem services in terms of recreation, tourism, fisheries habitat, and storm protection values (Arkema et al., 2017). However, these areas are threatened by human activities such as dredging, oil leaks, extensive fishing, and tourist pressure (Arkema et al., 2017).

In the Bahamas, coastal ecosystems are tied to the economic development that requires an integrated management approach (Arkema and Ruckelshaus, 2017). Such planning goes towards meeting SDG 14.2 for sustainable management of marine and coastal ecosystems, as well as SDG 14.7 for increasing the economic benefits of tourism to SIDS. In 2002, a preliminary document for the national ICZM planning process for the Bahamas was introduced with the cooperation of the Inter-American Development Bank (IDB). This document assessed the current coastal zone management issues in the country and proposed guidelines such as zoning ordinances and marine protected areas to safeguard the coastal ecosystems and promote sustainable use of resources. More recently, IDB has provided a USD 35 million loan to the Bahamas for Climate-resilient Coastal Management and Infrastructure Program, out of which USD 23.5 million are dedicated towards shoreline stabilization and coastal flood control measures on NP Island (IDB, 2017). The program also calls for natural infrastructure based coastal protection strategies and building national capacity for ICZM. Similarly, Vision 2040, National Development Plan of the Bahamas, highlights researching and implementing climate change adaptation and mitigation measures and integrating disaster risk reduction into development policies as important goals. While ICZM has been in the Bahamas planning process for more than a decade now, there is still no national framework or dedicated unit for ICZM in the country.

In our paper, we evaluated the effects of climate change on two main tourism islands in the Bahamas. It is evident from the findings that a multitude of the impacts that the sector may face will have spillover effects on the whole country. Nonetheless, tourism’s contribution to the social-economic conditions of the Bahamas cannot be neglected. Therefore, integrated management is required to manage sector sustainably while dealing with climate change. Many recent plans and programs in the country have focused on such integrated planning. With a few exceptions such as Barbados and Belize, the scope of ICZM remains a challenge for most SIDS and requires further research. Our findings present the first step to understand the different climate-induced risks and the ways that climate change can affect a specific tourism-based economy. Taking into account the magnitude of these impacts and the increasing storm frequencies in the Bahamas by each passing year, we further emphasize the urgent need for integrated planning. This comes at a time when travel-based revenues for SIDS will be further reduced for at least 1–2 years with other scenarios depending on how the still-developing COVID-19 pandemic disrupts travel and other tourism sectors, which will vary geographically. Currently, the Bahamas is coping with the aftermath of Hurricane Dorian (a Cat 5 storm), and combined with the pandemic, the impacts are particularly unprecedented and challenging. The pandemic provides a snapshot of the fragility of the tourism sector due to its dependence on international markets in SIDS. At the same time, it also focuses attention on the need for integrated planning that pro-actively accounts for external shocks and disruptions.

Even in the face of shocks and challenges discussed in this study and beyond, the tourism industry is no less resilient with the ability to bounce back and continuing to grow. Just from 2017 to 2018, there was a 10.5% increase in tourist arrivals in the Bahamas (Caribbean Tourism Organization, 2019) and WTTC (2018) predicted an increase of more than 3% per annum in tourism’s contribution to the Bahamas’ GDP and employment sector over the next decade, although this was before Hurricane Dorian and COVID-19. Currently, the tourism industry is concentrated on the islands of NP/PI with heavy dependence on direct foreign investments. The country is aiming to develop tourism on family islands and new destinations through strengthening their intra-island airlift and transportation linkages to increase visitation beyond the NP/PI islands (National Development Plan, 2017). Some islands such as San Salvador, Great and Little Inagua, Mayaguana and the Ragged Island Chains have less exposed shorelines due to their higher elevations, rocky shorelines and lower exposure to storm surge as compared to the more vulnerable Abaco, Andros and NP/PI islands (Silver et al., 2019). The potential of extending tourism to these islands needs to be explored to effectively manage the growing industry. In order to do so, the sector needs to improve its value chain by building domestic capacity and improving linkages between foreign and domestic firms. However, the ideal strategies would be those that support climate change adaptation. This will require an integration of public and private stakeholders involved in the tourism sector of the country. Hess and Kelman (2017) suggested mechanisms such as public-private partnerships, building standards and regulations, adaptation taxes and funds, and risk transfer mechanisms for the tourism industry to support adaptation for climate change in SIDS. Specific case studies on the adaptation potential of the SIDS’ tourism sector and their perception towards such measures will also help advance the sustainability of the sector as well as the whole country.

5. Conclusion

In the Bahamas, similar to many other SIDS, there is a clear need for diversification from a single economic base such as tourism that is very climate sensitive. However, the current importance of tourism to these countries with otherwise limited resources cannot be ignored. Our study examines specific risks to tourism from climate change to support efforts for integrated climate risk management in the Bahamas. We find that the multiple and complex issues of many tourism-related impacts in the country warrant an ICZM planning process and associated updates of the Bahamas building codes to better prepare for future extreme weather events. However, it should be noted that other interacting factors may also shape the future of tourism in the Bahamas. These include changes in mitigation and adaptation planning of other sectors such as global aviation policies or the local construction sector, changes in the US economy (the largest visitor expenditure in the Bahamas), and other non-climate stressors. Limiting our study to stopover visitors also excludes other types of tourism such as cruise visitors and day tourists. We also acknowledge that there are factors such as rising groundwater levels and precipitation changes that can induce inland flooding in the country and impact the tourism infrastructure.
However, including all these factors and their implications to the tourism sector is beyond the scope of our research. To improve our understanding of the multitude of the climate-related impacts faced by many SIDS, more country and island-specific studies are needed to draw out comparisons among SIDS. Thus, continuing such analysis on a case-by-case basis in the future will provide opportunities for better coastal management while supporting the growth of tourism for many other SIDS that are economically and socially dependent on the tourism sector.

Author statement


Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We would like to thank the Tharp Research Endowed Scholarship, School of Geosciences, University of South Florida, Tampa, FL, USA, for funding the fieldwork. We thank the Bahamas Ministry of Tourism, in particular, Geneva Cooper and Bonnie Rolle, for facilitating the fieldwork. We thank Dr. Kathleen Sullivan Sealey, University of Miami, for providing helpful initial expertise on the study area. Many thanks to Ela Bialkowska-Jelinksa for her GIS guidance. We also thank the reviewers for their comments that considerably improved the quality of this paper.

References

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Guiot, J., 2018. Global warming of 1.5 °C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Impacts of 1.5°C global warming on natural and human systems.