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Khalid, Fakhar and Babb, Renee (2008) Hazard and risk assessment from Hurricane Ivan (2004) in Grenada using Geographical Information Systems and remote sensing. *Journal of Maps Student Edition*. pp. 4-10. ISSN 1755-2958

Publisher's version available at:

http://journalofmaps.com/student/08_12_Khalid.pdf

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Hazard and Risk Assessment from Hurricane Ivan (2004) in Grenada using Geographical Information Systems and Remote Sensing

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(Received 30th May 2008; Revised 16th December 2008; Accepted 18th December 2008)

Abstract: Hurricanes are destructive storms with strong winds, intense storm surges, and heavy rainfall. The resulting impact from a hurricane can include structural damage to buildings and infrastructure, flooding, and ultimately loss of human life. This paper seeks to identify the impact of Hurricane Ivan on the affected population of Grenada, one of the Caribbean islands. Hurricane Ivan made landfall on 7th September 2004 and resulted in 80% of the population being adversely affected. The methods that were used to model these impacts involved performing hazard and risk assessments using GIS and remote sensing techniques. Spatial analyses were used to create a hazard and a risk map. Hazards were identified initially as those caused by storm surges, severe winds speeds, and flooding events related to Hurricane Ivan. These estimated hazards were then used to create a risk map. An innovative approach was adopted, including the use of hillshading to assess the damage caused by high wind speeds. This paper explains in detail the methodology used and the results produced.



1. Introduction

Tropical cyclones are defined as “non-frontal synoptic scale low-pressure systems over tropical or sub-tropical waters with organised convection and definite cyclonic surface wind circulation” ([Atlantic Oceanographic and Meteorological Laboratory, 2007](#)). Hurricane is the name given to tropical cyclones formed over the North Atlantic, North-east Pacific, and South Pacific oceans ([Atlantic Oceanographic and Meteorological Laboratory, 2007](#)).

The conditions for hurricane formation are sea surface temperatures of at least 27°C, regions of relatively low surface air pressures, a Coriolis Force resulting from the rotation of the earth, unstable conditions within the troposphere, an absence of strong vertical wind shear, and the release of latent heat within clusters of clouds.

Hurricanes are typically 600 km wide with sustained wind speeds of over 119 kph. They rotate in an anti-clockwise direction in the Northern Hemisphere and a clockwise direction in the Southern Hemisphere. The distinctive features of a hurricane are the eye, eye walls, and the spiral bands ([Aguado and Burt, 2007](#)).

Hazards have either the potential to, or after occurring, do in fact disrupt the normal functioning of social systems and can result in human injury or death ([Showalter, 2001](#)). The primary impact from hurricanes is immediate and direct resulting from the effects of strong winds, heavy rainfall, and storm surge.

Risk is defined as that which involves the likelihood of harm or other form of loss ([Carson, 1996](#)). There is a relationship between hazard and risk which is dependent on vulnerability. There is no risk if there are hazards but no vulnerability, or if there is vulnerability but no hazard ([Blaikie et al., 2003](#)). Risk is therefore a product of both hazard and vulnerability.

1.1 Study area

Grenada is a small Caribbean island located between latitudes 11° 59' and 12° 20' N and longitudes 61° 36' and 61° 48' W. The island is 18 km wide

and 34 km long with a total land area of 312 km² ([Organisation of Eastern Caribbean States, 2004](#)).

Grenada has a population of 102,632 as taken from the Grenada Population and Housing Census in 2001 ([Organisation of Eastern Caribbean States, 2004](#)). This population is mainly distributed on the coastal fringes and covers 110 km² of land, with the population mainly distributed along the coastal fringes. The remainder of the island is unoccupied and comprises steep mountainous terrain covered in vegetation.

On 7th September 2004, Hurricane Ivan ravaged Grenada for 6 daylight hours ([World Bank, 2004](#)). With wind speeds in excess of 217 kph, this hurricane was rated a Category 3 on the Saffir-Simpson Hurricane Scale ([Organisation of Eastern Caribbean States, 2004](#)).

After the complete passing of Hurricane Ivan, a national assessment was performed, which indicated that 80% of the population had been affected and that the cost of the damage was estimated to be twice the annual national Gross Domestic Product of Grenada ([Organisation of Eastern Caribbean States, 2004](#)).

1.2 Purpose of study

This paper seeks to identify the impact of Hurricane Ivan on the population of Grenada through hazard and risk assessments. The results of these assessments indicate how much of the population of Grenada was affected by the physical impact from Hurricane Ivan (see main map), and does not include other impacts such as socio-economic and psychological, which were all assessed by the Organisation of Eastern Caribbean States in 2004.

2. Methods

2.1 Hazard mapping

There were three types of hazards that were mapped: floods, storm surge, and wind exposure. The hazard mapping involved spatial analysis techniques which utilised a Shuttle Radar Topography Mission (SRTM) 90-metre digital elevation model (DEM) to delineate the flood-prone areas within Grenada. The SRTM DEM was used initially to calculate the flow direction of surface water. As water flowed down the slopes, flow direction was measured by changing elevation values in the DEM. The flow direction surface was then used to measure the overland flow accumulation. The flow accumulation surface represented the total amount of water flowing into each cell of the DEM. This accumulated amount of water in each cell was calculated by using the direction of the flow of water from one cell to another. Combination of flow direction and flow accumulation surfaces were then used to produce an estimation of the current stream network. These results were used to delineate watershed areas for the entire island to estimate the sizes of the catchment areas of the surface waters. Storm surge mapping involved combining average tidal predictions with the various storm surge values to create a total storm surge calculation, from which they were then identified on the island using the DEM.

Finally, wind exposure mapping was performed by using the hillshading technique. A hillshade tool was created to identify locations on a digital elevation model that would be in the direct path of sun rays and those areas that would fall in shadow. This tool was applied to wind blowing over land enforcing the theory that there would be no areas sheltered from hurricane winds. The analysis therefore involved wind blowing from all compass directions and altitudes producing many maps showing varying degrees of possible wind damage to the entire island.

2.2 Risk mapping

The first step involved in risk mapping was determining the vulnerable regions within the island. This was accomplished by extracting the populated areas from the high resolution satellite imagery. The risk areas

were then created by intercepting those vulnerable areas with the hazard areas to produce flood risk, storm surge, and wind damage maps for Grenada. The main map shows four maps depicting the locations of the vulnerable populations.

3. Conclusions

The results from this research, as seen in the maps, show that the areas affected from severe flooding totals 91 km², which is approximately 82% of the total populated areas of the country. A total area of 0.25 km² was inundated by storm surges for terrain elevations up to and including 18 m. The entire country experienced wind damage because the wind was not from one direction alone, nor from one altitude, thereby causing catastrophic damage island-wide. These figures indicate the degree of the damage caused after the passing of Hurricane Ivan.

The map is quite important to future hurricane hazard planning for Grenada because it highlights that populated areas located along the coastal fringes of the island and along natural water courses are the most vulnerable areas to flooding, storm surges, and wind damage. The map is a useful tool that can be used to show the locations and magnitudes of damage caused by a Category 3 hurricane, as well as estimate the damage that would be caused by hurricanes of lesser strengths.

With respect to alleviating damage from hurricane winds, building regulations should be created and enforced to ensure a minimal level of defence against hurricane force winds. It is therefore necessary to use these findings as a benchmark for preparations to be made for disaster mitigation, management, and preparedness. Further analysis can be performed using higher resolution DEMs as well as including drainage elements within the country such as suck wells, which are used to collect surface run-off, to obtain a more accurate depiction of flood areas.

Software

The software used to obtain the results of this research included Erdas Imagine 9.1, ER Mapper, ArcGIS 9.2 and Microsoft Office Excel. Erdas Imagine 9.1 and ER Mapper were used to perform corrections to the SRTM 90 m DEM data, which was used in the flood and storm surge delineation models and the wind exposure model. ArcGIS' Spatial Analyst was used to extract the inundation areas from flooding and storm surge and the possible degree of exposure from the wind forces. Microsoft Excel was used to create charts showing the relationship between the various heights of the storm surge, the maximum distance inland from the coast that inundation will occur, and the terrain elevation.

Acknowledgements

We wish to thank the University of Greenwich, Medway Campus, GeoOrbis, Inc., the United Nations Development Programme (UNDP) and DigitalGlobe for providing us with the resources needed to complete this paper.

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