International Journal of Disaster Risk Reduction 22 (2017) 345–354

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Tropical cyclone disaster management using remote sensing and spatial analysis: A review

Muhammad Al-Amin Hoque[a,b,*], Stuart Phinn[a], Chris Roelfsema[a], Iraphne Childs[c]

[a] Remote Sensing Research Centre, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD 4072, Australia
[b] Department of Geography and Environment, Jagannath University, Dhaka 1100, Bangladesh
[c] Queensland Centre for Population Research, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD 4072, Australia

ARTICLE INFO

Keywords:
Remote sensing
Tropical cyclone
Hazard
Vulnerability
Risk
Climate change

ABSTRACT

Tropical cyclones and their often devastating impacts are common in many coastal areas across the world. Many techniques and dataset have been designed to gather information helping to manage natural disasters using satellite remote sensing and spatial analysis. With a multitude of techniques and potential data types, it is very challenging to select the most appropriate processing techniques and datasets for managing cyclone disasters. This review provides guidance to select the most appropriate datasets and processing techniques for tropical cyclone disaster management. It reviews commonly used remote sensing and spatial analysis approaches and their applications for impacts assessment and recovery, risk assessment and risk modelling. The study recommends the post-classification change detection approach through object-based image analysis using optical imagery up to 30 m resolution for cyclone impact assessment and recovery. Spatial multi-criteria decision making approach using analytical hierarchy process (AHP) is suggested for cyclone risk assessment. However, it is difficult to recommend how many risk assessment criteria should be processed as it depends on study context. The study suggests the geographic information system (GIS) based storm surge model to use as a basic input in the cyclone risk modelling process due to its simplicity. Digital elevation model (DEM) accuracy is a vital factor for risk assessment and modelling. The study recommends DEM spatial resolution up to 30 m, but higher spatial resolution DEMs always performs better. This review also evaluates the challenges and future efforts of the approaches and datasets.

1. Introduction

Tropical cyclones are some of the most deadly natural disasters, typically generating sustained high winds, storm surges and intensive rainfall [87]. Globally, many coastal areas are affected regularly by tropical cyclone disasters [49]. The destructive characteristics of tropical cyclones are great threats to coastal people and the environment [88], resulting in the loss of more human lives than all other natural disasters [49]. During 1968–2010, on an average about 88 tropical storms formed each year across the world [80,89]. Out of these, 48 acquired the strength of a tropical cyclone (category 1 and 2) and 21 achieved the intensity of a major tropical cyclone (category 3, 4 and 5) [89]. Over the last two centuries globally around 1.9 million people have lost their lives by cyclone disasters [80]. Tropical cyclones are also responsible for enormous damages in local economy and environment [31,64,80]. The intensity of tropical cyclones will probably increase under likely future climate change scenarios [16,34,46], and thus coastal people and environment will be more vulnerable to tropical cyclones.

Although, it is not possible to stop cyclone disasters, but their impacts can be minimised using a range of management approaches, e.g. response, recovery, prevention/reduction and preparedness [36,44,61]. Remote sensing and spatial analysis are efficient and accurate tools to provide useful information in every phase of cyclone disaster management [32,68,86]. Remote sensing data combined with spatial analyses provide required information on changes to environmental conditions and infrastructure due to cyclonic impacts and are essential tools for reducing the impacts of future tropical cyclones. Developing and implementing appropriate approaches through mapping, monitoring and management, these tools serve to protect people, property and the environment. The most significant contribution of satellite remote sensing is repeated high spatial resolution (< 5 m pixels) satellite imagery both before and after the cyclone event to assess the impacts and monitor the progress of recovery [45,57,86]. Satellite remote sensing and spatial analysis can also be used predictively to assess the cyclonic risk through hazard, vulnerability and mitigation capacity mapping and to model potential future impacts

* Correspondence to: Remote Sensing Research Centre, School of Earth and Environmental Sciences, The University of Queensland, Brisbane, QLD 4072, Australia.
E-mail addresses: m.hoque2@uq.edu.au (M.A.-A. Hoque), s.phinn@uq.edu.au (S. Phinn), c.roelfsema@uq.edu.au (C. Roelfsema), i.childs@uq.edu.au (I. Childs).

http://dx.doi.org/10.1016/j.ijdrr.2017.02.008
Received 6 September 2016; Received in revised form 9 February 2017; Accepted 10 February 2017
Available online 12 February 2017

under likely climate change scenarios [3,74,83,92]. Furthermore, satellite remote sensing also plays an essential role in tracking tropical cyclones and providing accurate forecasting of landfall [23,73]. However, this is not a focus of the current paper. This paper focuses on non-metrological and oceanographic remotely sensed data, for examining changes to environmental conditions and infrastructure as well as assessing future impacts for effective cyclone disaster management.

A great amount of work has already been conducted in different phases of tropical cyclone disaster management using satellite remote sensing and spatial analysis [48,49,65,68,87]. Various kinds of processing techniques and dataset have been incorporated in these studies. Visual interpretation, field transects, data mining and change detection incorporating moderate (5–30 m pixels) to high (< 5 m pixels) spatial resolution satellite imagery are commonly used techniques for assessing tropical cyclone impacts and recovery. Single criterion, multi-criteria and various risk equations have been used for tropical cyclone risk assessment. For assessing the future impacts of a tropical cyclone under a climate change scenario, risk modelling has widely been used by many researchers [49,68,7]. Some of these modelling tools are based on advanced modelling software, while others are simple Geographic Information System (GIS) based models.

In the context of the wide range of remote sensing and spatial analysis based approaches used for managing tropical cyclone disasters, it is very challenging to select appropriate datasets and processing approaches, since it is critical to understand the spatial and temporal effects of cyclone hazards. Additionally, it is required to ensure that the information produced is accurate and suited to the particular cyclone management task and context [40,45]. This paper provides a comprehensive review of commonly used remote sensing and spatial analysis based approaches, specifically addressing their strengths and weaknesses in relation to data requirements for tropical cyclone disaster management. The paper begins with an overview of cyclone disaster management processes and their information requirements. This is followed by a critical evaluation of remote sensing, spatial analysis techniques and dataset to find out the appropriate processing techniques and dataset best suited to cyclone management tasks. The evaluation focuses on tropical cyclone impacts assessment and recovery, risk assessment and risk modelling approaches. The strengths and weaknesses, procedures and other pertinent issues concerning the different approaches and dataset are compared and discussed. The challenges and future research areas are also evaluated. Lastly, the paper summarises the best approaches and dataset recommended.

2. Tropical cyclone disaster management and its information requirements

Cyclone disaster management has two phases, i.e. post-disaster, response and recovery; and pre-disaster prevention/reduction and preparedness (Fig. 1). Extensive sources of information are required at each of the phases of cyclone disaster management [40].

The response phase includes the actions to reduce the impact of disasters protecting life and property during and immediately after the landfall of tropical cyclones [40]. The activities considered in this phase are evacuation, relief, search and rescue, and management of natural resources [14,44,91]. Spatial location, type and intensity, percentage of area and structures affected constitute the requisite information for supporting these activities. This information is derived through a process of overall impacts assessment [40]. Conversely, the recovery phase includes restoration and reconstruction of the affected areas after the cyclone disaster, in particular, monitoring the progress of debris removal, reconstruction of settlements and structures (buildings, bridges, roads), and vegetation regrowth [40,61]. The required information is obtained through the process of recovery assessment [39].

The prevention/reduction phase involves reducing the likelihood and impacts of cyclone disasters by incorporating required measures

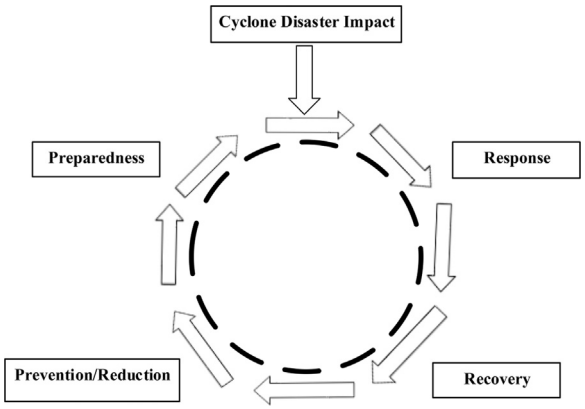

Fig. 1. Cyclone disaster management cycle (adapted from [44]).

and planning [36,79]. The process includes cyclone risk mapping through the mapping of hazards, vulnerability and mitigation capacity for producing required information [40,81]. On the contrary, the preparedness phase includes the development of required systems to manage any tropical cyclone disasters and to reduce their impacts [14,44,61]. Monitoring the cyclone hazards, identifying probable affected areas, developing warning systems, adequately training to the volunteers and evacuation plans are considered part of the preparedness activities [15,40]. Cyclone risk modelling is an important process in this stage which can provide realistic scenarios identifying areas that may be affected in the future [32]. Table 1 summarises the type of information and data required at each stage of cyclone disaster management.

Identification of a suitable dataset is a pre-requisite to derive accurate information by appropriate processing techniques for effective cyclone disaster management [3,38]. Considering the wide ranges of available sources to produce the data types required for cyclone disaster management, it is yet challenging to identify the most suitable dataset [50]. There are several criteria, which can be considered in the selection of appropriate datasets. Spatial resolution, scale, accuracy, and the suitability of datasets in terms of particular processing techniques are the most remarkable ones [39,50,78].

3. Evaluation of remote sensing and spatial analysis techniques and the datasets appropriate for tropical cyclone disaster management

A range of studies has been conducted for managing tropical cyclone disasters using satellite remote sensing and spatial analysis techniques, and dataset with different degrees of success. Appropriate dataset and processing techniques are required for deriving more accurate and useful information for effective cyclone disaster management [40]. The procedures, dataset, applications, strengths and weaknesses, and other issues concerning the various approaches are discussed and compared here to find out the most appropriate dataset and relevant processing techniques. The discussion is followed by tropical cyclone disaster management phases: response and recovery, prevention/reduction and preparedness.

3.1. Response and recovery

Response and recovery are two essential phases of tropical cyclone disaster management. The location, amount, rate, type and percentage of the area and structures affected are required information for the response phase whereas area, type and rate of recovery in the landscape are essential for recovery phase [44]. Overall impact and recovery assessment are required processing in these two phases of management to generate supporting information. Various techniques and wide ranges of remote sensing data have been used for assessing the impacts