Int J Appl Earth Obs Geoinformation 68 (2018) 20–30

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

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

Risk assessment of storm surge disaster based on numerical models and remote sensing

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ARTICLE INFO

Keywords:
Storm surge disaster
Numerical simulation
Remote sensing
GIS
Risk assessment

ABSTRACT

Storm surge is one of the most serious ocean disasters in the world. Risk assessment of storm surge disaster for coastal areas has important implications for planning economic development and reducing disaster losses. Based on risk assessment theory, this paper uses coastal hydrological observations, a numerical storm surge model and multi-source remote sensing data, proposes methods for valuing hazard and vulnerability for storm surge and builds a storm surge risk assessment model. Storm surges in different recurrence periods are simulated in numerical models and the flooding areas and depth are calculated, which are used for assessing the hazard of storm surge; remote sensing data and GIS technology are used for extraction of coastal key objects and classification of coastal land use are identified, which is used for vulnerability assessment of storm surge disaster. The storm surge risk assessment model is applied for a typical coastal city, and the result shows the reliability and validity of the risk assessment model. The building and application of storm surge risk assessment model provides some basis reference for the city development plan and strengthens disaster prevention and mitigation.

1. Introduction

A storm surge is a coastal flood of rising water commonly associated with low pressure weather systems (such as tropical cyclones and strong extratropical cyclones), which is the main cause of coastal disaster. Storm surges not only damage harbors, wharves and dams, but also swallow houses, farms and mariculture zones after bursting dams (Heaps, 1983). With expands of economy, coastal areas hold more population and production activities, which increases the potential losses caused by storm surges.

To effectively prevent storm surge disaster, how to assess risk of storm surge disaster is an urgent problem to solve first. The method to assess risk of storm surge disaster is based on the regional disaster system theory, which uses the result of hazard and vulnerability assessment to evaluate the risk of storm surge disaster (FEMA, 2010; Wood et al., 2005). Hazard assessment of storm surge is an important part in risk assessment and risk division of storm surge disaster. The aim of hazard assessment is to evaluate the natural attributes of storm surge (how serious a storm surge is), which usually includes numerical simulations, recurrence interval computation, and probable maximum storm surge. As the diversity of disaster factors and particularity of disaster bearers, storm surge risk assessments have more uncertainty compared with other disasters (Fang et al., 2011; Shi, 2012). National Hurricane Center and other agencies in USA started to assess risk of storm surge since 1990s and they mainly consider storm surge caused by different levels of tropical cyclones and predict the probable maximum storm surge, which provide reference to local governments, insurance companies and community residents (Glahn et al., 2009). TAOS (The Arbiter of Storms) is a high resolution, GIS based system for integrated storm hazard modeling, which simulates hazard factors like wind, precipitation, tide and waves to assess the hazard of storm surge (Watson, 1995).

Vulnerability is one of the most important attributes of disaster systems, which bridges hazard factors and disaster bearers. Vulnerability is a function of two variables, exposure to disasters and response capacity (Adger, 2006). Vulnerability of storm surge is significant correlated to social economy, population and natural environment of coastal areas, which reflects the interactions between society, economy, environment and storm surge. Vulnerability shows the resistant capability of coastal disaster bearers towards to storm surge. Based on storm flood data, the US Army Corps of Engineers built the function between submerged depth and property losses for seven types of buildings (Committee-NFP, 1995). Kleinosky et al. (2007) used SLOSH model to simulate submerged depth of different levels of storm surge and designed submergence scenarios with DEM data and disaster bearer distribution. The result shows the vulnerability curves of disaster bearer, which can be used for vulnerability assessment of storm surge. Jonkman and Vrijling (2008) used disaster data form US, UK, Japan and

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https://doi.org/10.1016/j.jag.2018.01.016
Received 30 September 2017; Received in revised form 9 January 2018; Accepted 29 January 2018

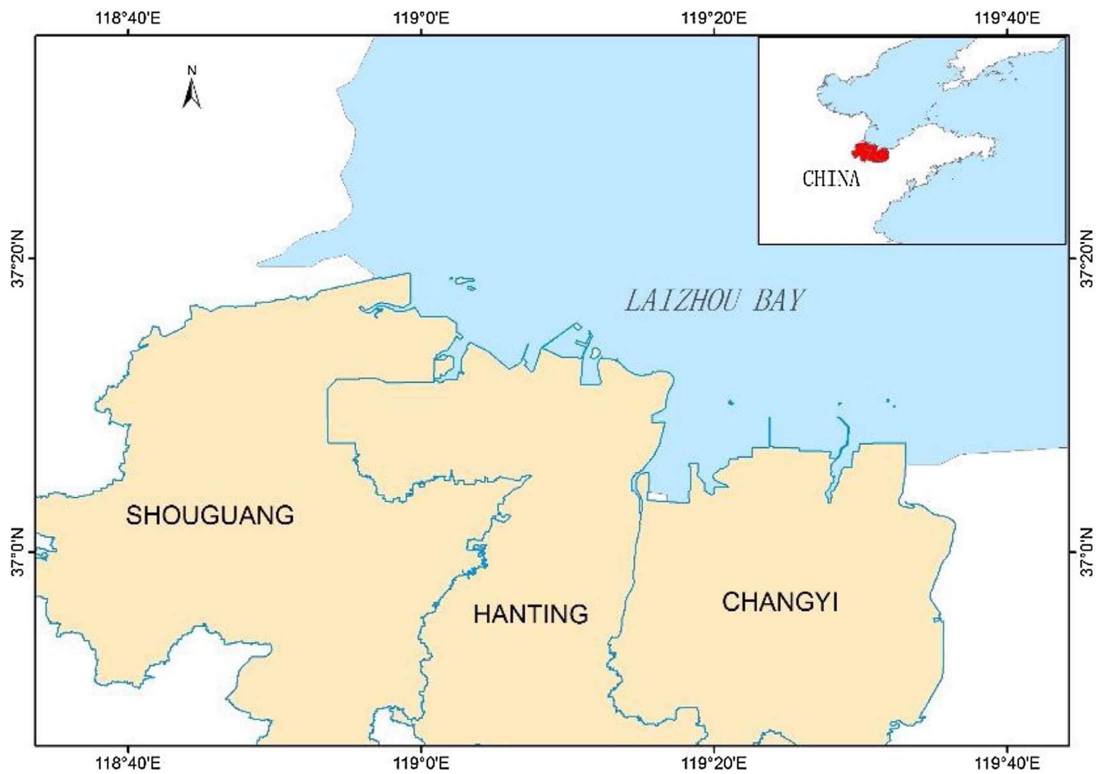

Fig. 1. The map of Weifang.

Table 1
Geography and economy in Weifang and its three coastal county-level cities.

Administrative district	Area (km^2)	Population (million)	Contents
Weifang	16143	9.28	58 subdistricts, 62 towns
Hanting	623	0.41	7 subdistricts
Shouguang	2072	1.07	5 subdistricts, 9 towns
Changyi	1627.5	0.61	3 subdistricts, 6 towns

Netherlands and built the vulnerability model to assess the casualties.

Risk assessment of storm surge is strongly based on the basic data for evaluating hazard and vulnerability. But for a fast developing city, there are two problem for getting the basic data. Firstly, the hydrometeorology observation stations in a developing city are located sparsely, and the observation time is usually quit short. Secondly, great funds are needed to collect land use data for a developing city and even more for the data updating. So how to get these basic data effectively and economically are the problems which the developing city is facing.

To solve the two problems, this paper proposes the following methods: numerical models are used to simulate storm surge, which can provide high resolution coastal hydrometeorology and submergence data based on limited observation; high resolution remote sensing images are used to analyze land use data over different regions, which makes the update of land use economical. These methods are verified by risk assessment of storm surge over Weifang, a developing city in China. Risk assessment of storm surge disaster based on numerical models and remote sensing can provide some basis reference for the city development plan and strengthens disaster prevention and mitigation.

2. Data and methods

2.1. Geography and economy in weifang

Weifang is located in the middle of the Shandong Peninsula and bordering Laizhou Bay in the north, with a higher distribution of leprosy in the south than the north. There are hills and mountains in the south with the altitude of 100–200 m and flood plains in the middle with the altitude of 7–100 m; the altitude of the coastal areas in the north is lower than 5 m. The coastline is 149 km long and arc-shaped. The scale of digital elevation model (DEM) used here is 1:10000, measured during 2010–2012; the bathymetry is from about 40 electronic charts.

There are two large vegetable bases in Weifang, which is the main vegetable producer in the northern China. Weifang has a population of about 9.28 million and has three county-level cities on the coast, namely, Shouguang, Hanting and Changyi (Fig. 1 and Table 1).

2.2. Hazard assessment

2.2.1. Model descriptions

Numerical models have been widely used in storm surge research (Karim and Mimura, 2008; Mcinnes et al., 2003; Weisberg and Zheng, 2008). In this paper, a two-dimensional model is used for numerical studies. The model uses the Galerkin finite element method to discrete in the horizontal space. The explicit upwind difference format is used to discrete momentum equations and transport equations. The dam height will change when the model is simulating the outburst. When the sea water is at the same level of height as the dam, the dam disappear and the altitude decreases to the level of land.

Fig. 2(top) shows the computational area and the depth of water for Weifang. The model uses unstructured triangular grids and the grid is