Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran

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Flood is one of the most devastating natural disasters with socio-economic and environmental consequences. Thus, comprehensive flood management is essential to reduce the flood effects on human lives and livelihoods. The main goal of this study was to investigate the application of the frequency ratio (FR) and weights-of-evidence (WoE) models for flood susceptibility mapping in the Golastan Province, Iran. At first, a flood inventory map was prepared using Iranian Water Resources Department and extensive field surveys. In total, 144 flood locations were identified in the study area. Of these, 101 (70\%) floods were randomly selected as training data and the remaining 43 (30\%) cases were used for the validation purposes. In the next step, flood conditioning factors such as lithology, land-use, distance from rivers, soil texture, slope angle, slope aspect, plan curvature, topographic wetness index (TWI) and altitude were prepared from the spatial database. Subsequently, the receiver operating characteristic (ROC) curves were drawn for produced flood susceptibility maps and the area under the curves (AUCs) was computed. The final results indicated that the FR (AUC = 76.47\%) and WoE (AUC = 74.74\%) models have almost similar and reasonable results. Therefore, these flood susceptibility maps can be useful for researchers and planner in flood mitigation strategies.

Keywords: flood susceptibility mapping; frequency ratio; weights-of-evidence; GIS; Iran

1. Introduction

Floods are the most common natural disaster affecting more people in the worldwide (140 million people per year) than all other disasters (WHO 2003). Floods can cause to socio-economic and environmental consequences, and thus, comprehensive flood management is very vital (Markantonis et al. 2013). Because of the great potential damages to natural resources, agriculture, transportation, bridges and many other aspects of urban infrastructure, flood control and prevention measures are urgently needed (Billa et al. 2006; Huang et al. 2008; Dang et al. 2011; Alvarado-Aguilar et al. 2012).

From sustainable development viewpoint, the flood hazard management is essential, so that governments can prevent as much damage as possible (Kumar et al. 2010; Feng & Wang 2011; Esteves 2013; Schober et al. 2015). In addition, flash floods considered as a major obstacle to the local development programmes. However, negative consequences of

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flood can be applied by integrated approaches to flood hazard management (Masood & Takeuchi 2012; Jourde et al. 2014). Dewan et al. (2007) proposed comprehensive flood hazard management strategies for land-use planning due to the efficient management of future flood disasters in Greater Dhaka using Synthetic Aperture Radar data and geographical information system (GIS). However, determining the benefits of flood reduction is difficult because there are intangible realities and requires a long time to be revealed (Yi et al. 2010).

Remote sensing techniques coupling with GIS tools can provide a good platform to combine, manipulate and analyse the information for the determination of potential hazard areas very quickly and more efficiently (Saha et al. 2005; Pradhan et al. 2011; Devkota et al. 2013; Wang et al. 2013; Pourghasemi et al. 2013a, 2014). On the other hand, GIS has also been used extensively to study flood and associated damages (Sanyal & Lu 2004; Pradhan 2010; Youssef et al. 2011; Kia et al. 2012; Patel & Srivastava 2013).

Different methods were developed for natural hazard mapping using statistical methods and GIS techniques in the last decade (van Westen et al. 2003; Ayalew et al. 2004; Althuwaynee et al. 2014). The most common approaches proposed in the literature are frequency ratio (FR) (Pareek et al. 2010; Pradhan & Lee 2010; Pradhan & Youssef 2010; Pradhan et al. 2011; Lee et al. 2012a; Shafapour Tehrany et al. 2014a), logistic regression (Ayalew & Yamagishi 2005; Lee et al. 2007; Gorum et al. 2008; Pradhan et al. 2008; Choi et al. 2012; Akgun et al. 2012; Ozdemir & Altural 2013; Felicisimo et al. 2013), artificial neural networks (Lee et al. 2003; Choi et al. 2010; Poudyal et al. 2010; Pradhan & Buchroithner 2010; Pradhan et al. 2010b; Park et al. 2013; Zare et al. 2013; Conforti et al. 2014) and spatial multicriteria evaluation (Sinha et al. 2008; Yalcin 2008; Fernández & Lutz 2010; Ghanbarpour et al. 2013; Pourghasemi et al. 2014). Also, other approaches have been applied in several studies including Dempster–Shafer (Tangestani 2009; Park 2011; Mohammady et al. 2012; Pourghasemi et al. 2013c), decision tree (Yeon et al. 2010; Shafapour Tehrany et al. 2013), fuzzy logic (Bui et al. 2012; Pourghasemi et al. 2012b; Sharma et al. 2013; Ramazi & Amini 2014), index-of-entropy (Bednarik et al. 2010; Pourghasemi et al. 2012a, 2012c; Jafafari et al. 2014; Naghibi et al. 2015), analytical hierarchy process (AHP) (Meyer et al. 2009; Pourghasemi et al. 2012b; Zou et al. 2013; Papaioannou et al. 2015) and weights-of-evidence (WofE) (Bonham-Carter 1991; Oh & Lee 2010; Pradhan, Oh and Buchroithner, 2010a; Regmi et al. 2010; Mohammady et al. 2012; Pourghasemi et al. 2013c; Fu et al. 2013; Dube et al. 2014; Regmi et al. 2014). During the past decades, traditional optimization techniques, such as linear, nonlinear and dynamic programming, have been applied for flood hazard assessment (Needham et al. 2000; Olsen et al. 2000; Travis & Mays 2008; Nagesh Kumar et al. 2010; Yazdi & Neyshabouri 2012). However, the main shortcoming of these approaches is related to assumptions in the flood modelling because obtained results are too unrealistic (Yazdi et al. 2013).

Pradhan (2010) applied multivariate logistic regression to risk area delineation and flood susceptibility mapping in Kelantan River Basin, Malaysia. The results showed that logistic regression model had reasonable accuracy. Lee et al. (2012a) applied FR model for flood susceptibility mapping in Busan, South Korea. The results showed that FR model is very efficient for flood susceptibility modelling. Chormanski et al. (2011) utilized RS and GIS techniques and water chemistry analysis for flood extent mapping in Biebrza River Lower Basin, Poland. They stated that the new methodology is effective in recognizing inundated areas. Shafapour Tehrany et al. (2014a) used integrated bivariate and multivariate statistical models for flood susceptibility mapping in Busan,
South Korea. The results showed the efficiency of logistic regression in flood susceptibility modelling, and it can be improved in the combination with the bivariate probability methods. Shafapour Tehrany et al. (2014b) also applied a novel ensemble WofE and support vector machine (SVM) models for flood susceptibility mapping in Terengganu, Malaysia. Their results proved the efficiency of the ensemble WofE and SVM methods over the individual methods.

In general, FR and WofE models are mostly used in landslide susceptibility mapping and other natural hazards, so it is relatively new in flood susceptibility modelling.

The Golestan Province in Iran is always exposed to flood hazard, because of climatic and physiographic conditions and anthropogenic activities (Omidvar & Khodaei 2008; Saghaftian et al. 2008; Ardalan et al. 2009; Abdolhay et al. 2012). On 10 August 2001, an exceptionally flash flood occurred in the Golestan basin and inundated large areas that claimed a total of 300 lives, and 4000 buildings was sustained heavy damage (Sharifi et al. 2012). Moreover, according to official government reports, the direct damage of this flood was estimated at over USD 400 million dollars (Sharifi & Mahdavi 2001). From 1990 to 2005, Golestan Province has faced to 64 floods and the total number of people directly affected by the flood was estimated to be more than 217,000 (Sharifi et al. 2012). So, the purpose of current research was to assess and compare flood susceptibility maps produced using two bivariate statistical GIS-based approaches, i.e. FR and WofE models in the Golestan Province, Iran.

2. Study area
This study is located in the Golestan Province which is situated in the north-eastern part of Iran. The study area lies between the latitudes of 36° 34′ to 37° 50′ N and the longitudes of 54° 5′ to 56° 8′ E (Figure 1). The total area is almost 11,888 km² inhabited by population number of 1.4 million. Topographically, this region has mountainous area and flat land. Elevation of the study area ranges between −147 and 3349 m. The study area is considered to have climate diversity with an average annual precipitation of 450 mm (WRCG 2013). The central and northern regions have a temperate Mediterranean climate, and the southern section has a typical mountain climate. The average daily minimum temperature is −5.5 °C in the winter, and daily maximum temperature is 33 °C in the summer (WRCG 2013).

In last decade, this area has faced with destructive floods, which was chosen as a suitable application site for flood susceptibility mapping.

3. Methodology
Figure 2 shows the applied methodology in this study as a flowchart.

3.1. Flood inventory map
The future flood event in an area can be estimated using analysing the past records of its occurrence (Manandhar 2010). Therefore, a flood inventory map is considered as the most important factor for prediction of future flood occurrence. In this study, a flood inventory map containing 144 flood locations was prepared for Golestan Province using documentary sources of Iranian Water Resources Department (IWRD) and extensive field surveys, i.e. GPS points (period between 2001 and 2009).