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Flood susceptibility mapping using novel ensembles of adaptive neuro fuzzy inference system and metaheuristic algorithms

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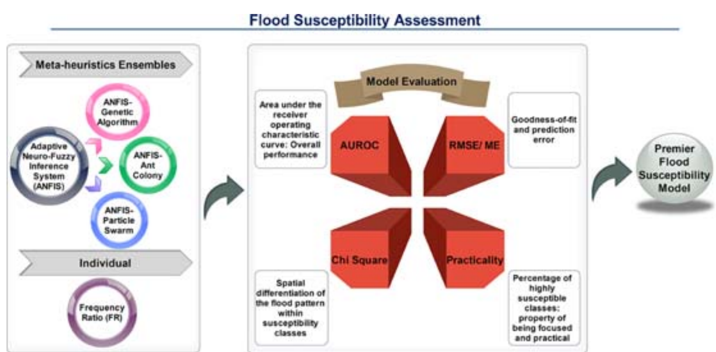
HIGHLIGHTS

- The performance of meta-heuristics was assessed in flood susceptibility mapping.
- ANFIS-PSO adopted faster convergence algorithm and outperformed other models.
- ANFIS-PSO showed practical and robust results compared to other models.

GRAPHICAL ABSTRACT



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ABSTRACT

Flood is one of the most destructive natural disasters which cause great financial and life losses per year. Therefore, producing susceptibility maps for flood management are necessary in order to reduce its harmful effects. The aim of the present study is to map flood hazard over the Jahrom Township in Fars Province using a combination of adaptive neuro-fuzzy inference systems (ANFIS) with different metaheuristics algorithms such as ant colony optimization (ACO), genetic algorithm (GA), and particle swarm optimization (PSO) and comparing their accuracy. A total number of 53 flood locations areas were identified, 35 locations of which were randomly selected in order to model flood susceptibility and the remaining 16 locations were used to validate the models. Learning vector quantization (LVQ), as one of the supervised neural network methods, was employed in order to estimate factors' importance. Nine flood conditioning factors namely: slope degree, plan curvature, altitude, topographic wetness index (TWI), stream power index (SPI), distance from river, land use/land cover, rainfall, and lithology were selected and the corresponding maps were prepared in ArcGIS. The frequency ratio (FR) model was used to assign weights to each class within particular controlling factor, then the weights was transferred into MATLAB software for further analyses and to combine with metaheuristic models. The ANFIS-PSO was found to be the most practical model in term of producing the highly focused flood susceptibility map with lesser spatial distribution related to highly susceptible classes. The chi-square result attests the same, where the ANFIS-PSO had the highest spatial differentiation within flood susceptibility classes over the study area. The area under the curve (AUC) obtained from ROC curve indicated the accuracy of 91.4%, 91.8%, 92.6% and 94.5% for the respective models of FR, ANFIS-ACO, ANFIS-GA, and ANFIS-PSO ensembles. So, the ensemble of ANFIS-PSO was

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introduced as the premier model in the study area. Furthermore, LVQ results revealed that slope degree, rainfall, and altitude were the most effective factors. As regards the premier model, a total area of 44.74% was recognized as highly susceptible to flooding. The results of this study can be used as a platform for better land use planning in order to manage the highly susceptible zones to flooding and reduce the anticipated losses.

1. Introduction

Among different types of natural disasters such as earthquakes, landslides, soil erosion, tsunami, volcanic eruptions, and so on, flood is considered as the Earth's most common–and most destructive–phenomena (Doocy et al., 2013). Iran has been faced with immense floods each year considering its vast extent, climate variability, and spatio-temporal changes in rainfall in the most basins. Over the past decades, economic damages caused by floods have reached to 1705 thousand dollars (Khosravi et al., 2016a, 2016b; Norouzi and Taslimi, 2012). Each year floods are the leading cause of intense financial losses and fatalities in the worldwide and capable of causing serious damages to transport, cultural heritage, natural ecosystems, economics, and human lives (Messner and Meyer, 2006). Although, it is impossible to prevent flood; but, use of appropriate methods and analyses can anticipate the disaster and to somewhat compensate it (Cloke and Pappenberger, 2009). Besides, it seems important to measure and understand the process of occurrence in order predict, prevent, and reduce the adverse effects in advance (Billa et al., 2006; Huang et al., 2008). One of these measures is to prepare flood hazard and its susceptibility mapping.

According to Norouzi and Taslimi (2012), the damage caused by flood is increasing very fast in Iran, so that flood damages have been doubled over the past decades. The annual floods during the rainfall seasons have increased in the Jahrom Township in which the recent events occurred in 2017 costs almost $70 million (CONRWMJT, 2015).[1] That said, the worst is yet to come considering the fastest growing urban agglomerations, the increase in deforestation rate, and intense rainfalls (CONRWMJT, 2015). Therefore, it is crucial to identify flood susceptibility zones (Tehrany et al., 2015). Flood susceptibility mapping has been recognized as the first necessary step in flood prevention and its management (Wu et al., 2010). Various researches on flood susceptibility mapping have been carried out in different countries. Due to the quick access to data and the necessity to improve the commercial satellite products for preparing flood potential maps, the use of Geographic Information System (GIS) has vastly increased. In general, watershed modeling of does not conform to simple and linear hydrological methods, because of its complex inherent (Sahoo et al., 2009). In addition, GIS is a useful tool to study events bearing multi-dimensional behavior such as floods in which various spatial and temporal aspects are considered for modeling. Among different techniques, using GIS (Khosravi et al., 2016b), analytic hierarchy process (Chen et al., 2011), frequency ratio (Lee et al., 2012; Rahmati et al., 2016; Khosravi et al., 2016a), logistic regression (Pradhan, 2010; Kornejady et al., 2014; Kornejady et al., 2015) and fuzzy logic (Pierdicca et al., 2010) are of research interests. Although, conflict of interests is intrinsic to the differences in research scopes. Nowadays, traditional methods are being replaced by more powerful machine learning algorithms including ANFIS (Mukerji et al., 2009; Sezer et al., 2011), artificial neural network (ANN) (Chau et al., 2005; Tiwari and Chatterjee, 2010; Kia et al., 2012), decision trees, and support vector machine (SVM) (Adeli and Hung, 1994). Traditional modeling methods are usually based on hard statistical assumptions and require large amounts of data to run (Clapcott et al., 2013). These models use linear modeling approaches and are not consistent with natural phenomena. Machine learning techniques are used to predict complex nonlinear structures, produce data, and accurate modeling (Olden et al., 2008). Machine learning techniques are not limited to statistical assumptions and are widely used in combination with traditional modeling approaches (Olden et al., 2008). Most importantly, these models have indisputably coped with data scarcity (Rahmati and Pourghasemi, 2017) which can be applicable for the present study area as a region with limited number of rain gauges.

Chau et al. (2005) investigated different flood modeling methods using logistic regression, ANFIS, and ANN in the Yangtze River. Tehrany et al. (2015) used four kernel functions of SVM algorithm to map flood susceptibility in Kuala Terengganu in Malaysia. They noted that radial basis function of SVM (SVM-RBF) method had the highest accuracy. However, many forecasting techniques such as ANFIS especially coupled with metaheuristics have rarely been used for flood susceptibility modeling. However, their performance in predicting other natural disasters such as landslide susceptibility modeling is confirmed (Saito et al., 2009; Yilmaz, 2010; Pradhan, 2013). Therefore, the aim of the present study is to map flood susceptibility over the Jahrom Township in Fars Province using an ensemble of ANFIS with different metaheuristic algorithms including ACO, GA, and PSO and comparison of their performance.

1.1. Study area

The Jahrom Basin is located in the Jahrom Township in southern Fars Province, with an area of about 5737 Km^2. The region is located within 28° 17′ to 29° 8′ N latitudes and 54° 4′ to 52° 45′ E longitudes (Fig. 1), with the maximum and minimum elevations of 766 m and 3166 m a.s.l., respectively. The natural landscape of this township is quite mountainous. Approximately one fifth of the township comprises plain areas and the rest is highlands. The average elevation of this township is about 1050 m and the highest point corresponds to Safidar Summit located between Khafr and Simakan with a 3170 m height. The lowest point with a nearly 766 m height is located in Simakan. The coldest month is in January with an average temperature of about 10 °C and the hottest month is in July with an average temperature of about 33 °C. The rainiest months are in February and March in which devastating floods occur (CONRWMJT, 2015). The main cause of flooding in the study area is heavy rainfall in a short period of time, changes in land use, especially in pastures and also lack of basic measures to prevent flood. The most devastating floods in the region in the last ten years happened in 2010 and 2017. In 2017, the flood caused financial losses and casualties due to long and intense rainfall for seven days. Among these damages, 3 people were dead, several bridges were destroyed and a village went thoroughly under water in the path of flood. From geological viewpoint, various lithological formations outcrop in the study area perpendicular to the Zagros belt. They correspond to different geological ages such as Cenozoic (93.56%), Mesozoic (6.36%), and Paleozoic (0.08%). Qft2 as the most prevailing lithological formation (28.9%) is composed of loose low level piedmont fan, valley terrace deposits.

2. Material and methods

The methodological approach applied in the current study is an ensemble of ANFIS and metaheuristic algorithms including eight main steps (Fig. 2). The procedural details of the study are given as follows.

[1] Central Office of Natural Resources and Watershed Management in the Jahrom Township.