Event-based Flood Susceptibility Mapping Using Modified Frequency Ratio

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1. INTRODUCTION

Floods are among the most devastating of natural catastrophes, and 1.47 billion people worldwide are at danger of severe floods[1]. Therefore, the destructive impacts of these flood risks must be mitigated by implementing suitable mitigation measures in flood-prone regions identified by susceptibility mapping, assuring efficient and effective disaster risk management. Flood susceptibility is a measurement of the occurrence probability of floods under certain geo-environmental conditions. A variety of innovative flood susceptibility mapping approaches have been developed and applied in recent years[2]. Frequency ratio (FR) method is one of the widely used bivariate statistical analysis (BSA) technique in hazard mapping. In general, BSA methods only consider the correlations between the flood occurrence and classes of each conditioning variable and overlooks the relationships between the various conditioning variables with flood occurrence, which is perceived as a drawback. The goal of this study is to overcome aforementioned issue by modifying the conventional FR method and map future flood-prone locations using this modified method in a GIS environment.

2. MATERIALS AND METHODS

2.1 Study area

Rathnapura city, Sri Lanka is selected as the study area. In Rathnapura district, the most devastating floods were occurred during the years 2003, 2010, 2014, and 2017 resulting hundreds of fatalities and economic losses. Climatic condition of Rathnapura city is hot, humid, and cloudy. The temperature normally ranges from 71°F to 93°F throughout the year and average annual rainfall is about 3100mm.

2.2 Spatial data layers

Flood occurrence data (445 flood points) were collected using historical flood data, satellite images and field surveys conducted by Disaster Management Center, Sri Lanka. The points were then divided into two sets as training set (70%) and validating set(30%) respectively. In addition, twelve flood conditioning variables were considered such as altitude, slope, normalized difference vegetation index (NDVI), ,topographic wetness index (TWI), distance from road, land cover, soil, and rainfall with 30m spatial resolution.

2.3 Modified Frequency Ratio (MFR) method

FR is the expression of the ratio of the probability of an occurrence to that of a non-occurrence for any attribute[3]. Let F and C stand for flood and a certain flood-related factor, respectively. Given that the factor C is categorized into n classes, the conventional FR for the i^{th} class of factor C (C_i) can be written as in the equation 1;

$$FR_i = \frac{(Flood\ points\ in\ C_i)/(total\ flood\ points)}{(C_i\ area)/(total\ area)} \tag{1}$$

FR values greater than 1 indicate higher correlation while values less than 1 indicate poor correlation. Then the above conventional FR method was modified as follows.

$$RF_i = \frac{FR_i}{\sum_{i=1}^{n} FR_i} \tag{2}$$

$$PR = \frac{(RF_{max} - RF_{min})}{(RF_{max} - RF_{min})_{min}} \tag{3}$$

Where: RF_i= Relative frequency (Normalized FR_i),
RF_{max}, RF_{min}= Absolute maximum and minimum RF values of the classes within a factor.
$(RF_{max} - RF_{min})_{min}$ = Lowest absolute difference of RF related to all factors and PR = Predictor rate.

Finally, all the conditioning factors were reclassified according to calculated RF values. Given that there are m factors, the final Flood susceptibility index (FSI) is calculated as follows.

$$FSI = \sum_{j=1}^{m} \sum_{i=1}^{n} PR_j * RF_i \tag{4}$$

3. RESULTS AND DISCUSSION

The FR for each flood conditioning factor classes was calculated based on the aforementioned equations and correlation between classes of each conditioning factor and flooding was represented in Fig.1. The findings of the altitude analysis show that the lowest classes of 4–22m, 22-47m, and 47-88 m were the most significant on floods, while the higher elevation classes were the least effective on flooding. This reflects the basic characteristics of floods, which happens predominantly in low-altitude locations rather than on mountain tops. the FR was greater than 1 for slope ranging from 0º–8.6º associated with flat region, representing a high susceptibility of flood occurrence. Meanwhile, high slope areas also have secondary effects that cannot be overlooked since they accelerate water flow and reduce the time it takes for water to infiltrate into the ground. According to the findings, distances up to 150 m from the road have a major effect on flooding(FR=3.06), while distances between 150 - 750 m indicated a ratio higher than 1, reflecting the fact that flood levels are significantly influenced by adjacent urban surfaces, impervious roadways, and other surfaces as they cause runoff and reduce the terrain's penetration capacity.

Key Words: Flood susceptibility, Frequency ratio, Remote sensing(RS), Geographical information system(GIS), Area under curve(AUC)
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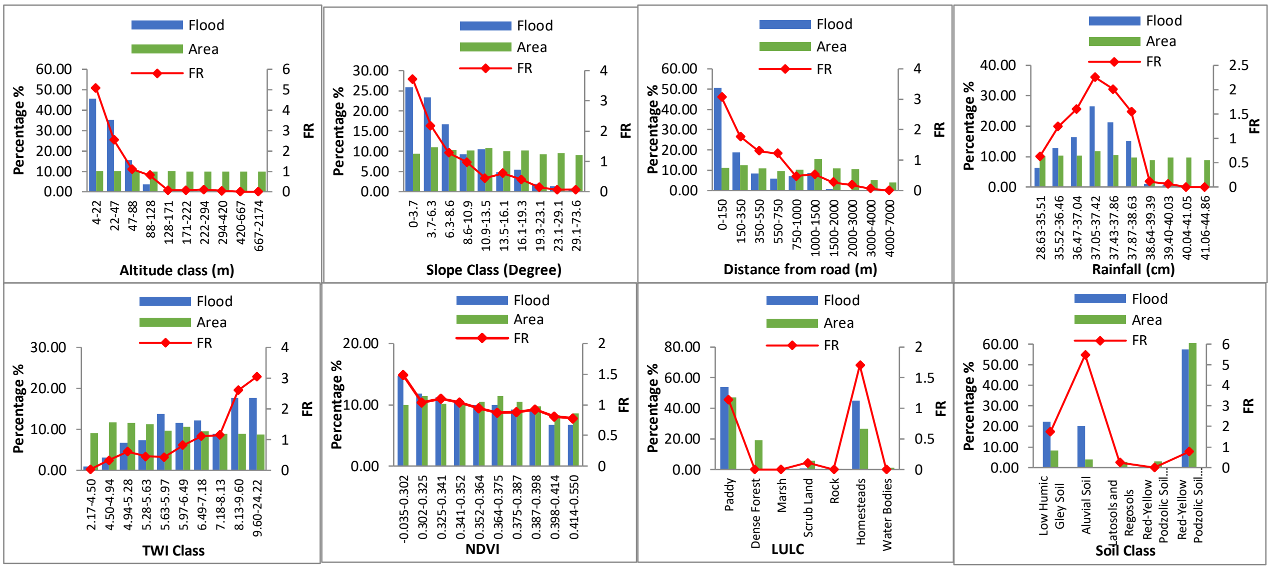

Fig. 1. FR calculation results

Since the type of soil has an apparent influence on drainage, water storage, permeability, this factor was used in this study. Alluvial soil type had the greatest FR(5.48) . According to the LULC results, residential areas(1.70) and paddy(1.14) fields had the greatest FR and dense forest regions had the lowest FR which reflect the fact that metropolitan regions, where there are more impermeable surfaces which increase the stormwater runoff and vegetated regions provide varying degrees of protection against flooding. Our findings showed that all NDVI classes greater than 0.352 had a FR less than 1, indicating minimal effect on flooding. This also reveals that increasing vegetation density can have positive effect on flood reduction. According to the results, as TWI increases, the FR also increases. TWI is a metric that helps identify areas of a landscape that are likely to have high soil moisture, and these areas are also more likely to experience flooding due to increased runoff. Rainfall is a major triggering factor for flooding, and without it, there won't be any flooding. The highest FR of rainfall was observed in the areas with 3552-3863 mm precipitation. PR rankings which can be considered as the degree of influence of each factor on flood occurrence from highest to lowest as follows : soil, LULC, altitude, rainfall, slope, distance from road, slope, TWI, and NDVI.

Table. 1. Predictor rate calculation results

Factor	Predictor Rate(PR)	Factor	Predictor Rate (PR)
Altitude	7.34	TWI	4.02
Slope	5.22	Soil	9.40
Rainfall	6.08	LULC	8.20
Distance from road	4.88	NDVI	1.10

Finally, the flood susceptibility map was created (Fig.2) using FSI, and classified into five groups as very low risk, low risk, moderate risk, high risk and very high risk using the natural break approach.

Table. 2. Model evaluation

Performance	AUC(%)
Success Rate	78.47
Prediction Rate	79.54

According to the map, the central region along with the river line was identified as a highly susceptible area. Validation was conducted by applying the AUC method with flood training and testing locations and obtained success rate and prediction rate values were 78.47% and 79.54% respectively (Table 2).

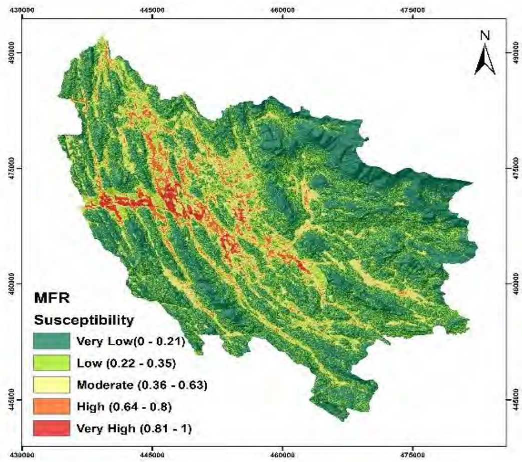

Fig. 2. Flood susceptibility map

4. CONCLUSION

This paper has proposed a modification of the conventional FR method for assessing flood susceptibility while evaluating the effect of both flood conditioning factors and its sub classes on flood occurrence. Both success and prediction rate values were closed to 80% can be considered as a fine indicator of the reliability of MFR method. Furthermore, this method can also be easily adapted by those who have limited experience in hydrology.

REFERENCE

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