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Flood risk microzonation using IWPCA mathematical model, case stady: firoozabad Basin in Fars province, Iran

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Abstract

Flooding is a serious global problem, so as its intensity and frequency increase, global concerns in terms of loss of fatalities and economic losses associated with this phenomenon also increase. In this research, were used Landsat ٨ image satellite, DEM٣٠ SRTM, annual precipitation statistics of Rain gauge stations and geological layer ١:١٠٠٠٠٠. Then, in order to analyze the effective parameters in flood risk, two methods, IWPCA,respectively were used in MATLAB, and ARCGIS software. In the next step, in order to validate the two methods, the OLS method was used to validate the mentioned model. The final flood hazard is modeled (at the last stage, the least-square method was used to test the mentioned models.The weighted linear combination (WLC) method was used for spatial modeling and layer combination to prepare potential flood maps. The results of Flood Risk Zoning with IWPCA was presented. The flood rates by IWPCA model was about ١٤٧ km^{٢} of the watershed, respectively. The value of this parameter in the central and northern parts was higher than in other regions. Finally,the validation of the model showed that IWPCA with $R^{٢}$ and P-value of ٠,٧٦ and ٠,٠٠٠١ had the highest degree of agreement between the dependent and independent variables.

Keywords: Flood zoning, IWPCA, OLS, Firouzabad watershed

Introduction

Flood hazards are among the most important and frequent natural hazards in Iran and claim many lives and cause vast financial losses, annually (Chang, ٢٠٠٨). The extent and intensity of these hazards vary greatly. In this research the flood potential and the corresponding hazards due to Firouzabad watershed which is the Sub-basin of Mand River are studied. Due to violating the proper riparian zone rights, and as in Firouzabad watershed annually large amounts of water are lost due to floods caused by recent droughts, loss of vegetation, erosion and human made factors such is over-cultivation in the agricultural lands etc., thus attempt is made that by studying this topic a step is taken forward to solve the issue. Furthermore, by investigating the effective hydrological factors and recent climatic changes, the intensifying factors are identified. Considering the current shortage of water, it is possible that agricultural activity encounter water shortage and lack of efficiency. Therefore, through implementing proper solutions to prevent loss of water in the area such as control of surface waters and artificial recharge of groundwater tables etc. we could witness rich vegetation and cultivable agricultural lands in the watershed area in addition to increased water resources. Many research works have been done in terms of flood hazards among them the following could be mentioned: Loczy et al., (٢٠٠٩); Veijalainen et al., (٢٠١٠); El-Magd et al., (٢٠١٠); Kim et al., (٢٠١١); Tarekegn et al., (٢٠١٠); Wang et al., (٢٠١١)., Camarasa & Soriano (٢٠١٢); Taylor et al., (٢٠١٣); Balica et al., (٢٠١٣); Mouri et al., (٢٠١٣); Volpi et al., (٢٠١٣); Altin (٢٠١٤); yenan et al., (٢٠١٥), Cherqui et al., (٢٠١٥), Portugués-Mollá et al., (٢٠١٦); R De Risi et al., (٢٠١٩) investigated the flood hazard maps and studied the ways to reduce vulnerability of Addis Ababa City., Mahmoodzadeh & Bakuei (٢٠١٨), Rahmati et al., (٢٠١٦). Rezaei Moghaddam et al., (٢٠٢١), Heydari, (٢٠٢١).Among the goals of this research one could refer to preparing the flood hazard map and identifying the hazardous areas in the sub-basins using the IWPCA mathematical model using MCI matrix in software environment from MATLAB wad applied. Among the other goals one could state; to alarm the authorities and planners for right and accurate management of these areas, emphasizing upon presenting appropriate patterns, guidelines and instructions for road making, bridge making and other facilities for minimizing the probable damages due to floods, presenting proper solutions to minimize the damages due to flood hazards and corresponding secondary damages and emphasizing upon proper planning for rural and urban development and road making.

٢. Materials and Methods

٢,١. Study area location

The study area is located within the geographical area of southern Iran on the south west folded skirts of Zagros mountain ranges. Firouzabad area is limited to Mok and Mahkoyey Basin from north, Dehram Plain from south, Farashband from west and Meimand Plain from east. Firouzabad watershed is one of the appropriate areas for agricultural activity in Fars Province which is located within ١٠٠km distance from south east of Shiraz city. It is located within ٥٢º ١٠' to ٥٢º ٣٨' E longitudes and ٢٦º ٣٦' to ٣٦º ٤٨' N latitudes. The watershed area is equal to ٧٢٣ $Km^٢$ of which ٢٤٠ $Km^٢$ is plain and ٤٨٣ $km^٢$ is mountainous (Fig. ١).

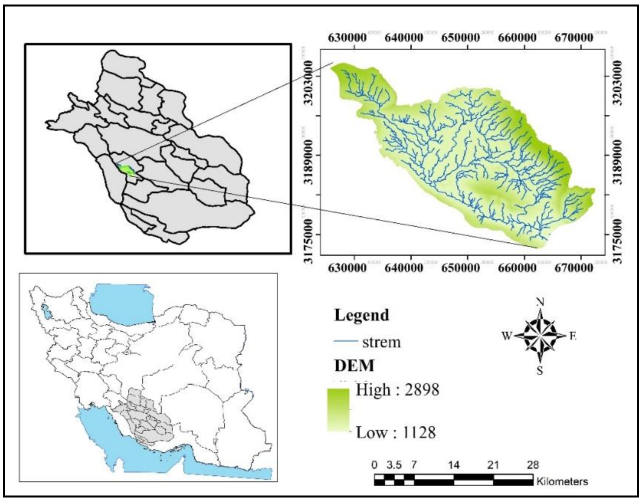

Fig. ١. Location of the study area

In this research use was made of ten effective parameters in order to investigate and create the flood hazard zones for Firouzabad watershed. For preparing the slope layer and its direction and topographic situation of the drainage density and distance from river use was made of DEM٣٠ layer. Also for preparing the lithology layer use was made of geology layer with ١:١٠٠٠٠٠٠ scale. Also Landsat٨ satellite images were used to create the land use and vegetation layer. Furthermore, the synoptic and rain-gage data corresponding to the existing station were utilized (Tab. ١).

Table ١: Parameter specifications

Row	Criterion	IWPCA	Score	Class
١	Elevation	٠,٢٦٩٧	١	١١٢٨-١٤٤٤
			٢	١٤٤٤-١٦٩٩
			٣	١٦٩٩-٢٠٠٠
			٤	٢٠٠٠-٢٣٦٠
			٥	٢٣٦٠-٢٨٩٠
٢	Slope	٠,٢٨٢٩	٥	٠-٧
			٤	٧-١٥
			٣	١٥-٢٤
			٢	٢٤-٣٧
			١	٣٧-٧٢
٣	Distance-river	٠,٢٨٢٤	٥	٠-٢٧٨
			٤	٢٧٨-٥٧٥
			٣	٥٧٥-٨٦٢
			٢	٨٦٢-١١٥٠
			١	١١٥٠-١٤٣٨
٤	Leitology	٠,٢٤٢٩	١	Alluvial sediments
			٢	Conglomra FM
			٣	Limstone FM
			٤	Mishan.FM
			٥	Gachsaaran-FM
٥	Acpect	٠,٢٣١٣	٥	South, Southwest and
			٤	West East
			٣	North Northeast. North West
			٢	Flat
٦	Landuse	٠,٢٣٦٧	٤	Barren lands
			١	Rangelands
			٥	Constructed area
			٣	Gardens and
٧	Preceptation	٠,٢٦٦٣	٥	٣٧٩-٣٨٣
			٤	٣٨٣-٣٨٥
			٣	٣٨٥-٣٨٧
			٢	٣٨٧-٣٨٨
			١	٣٨٨-٣٩١
٨	TPI	٠,١٩٣٧	١	Gentle slope
			٣	Steep slope
			٤	Upper slope
			٥	Valleys
			[illegible]	Ridg[illegible]
٩	NDVI	٠,٢٧٤٥	٢	>٠
			١	<١
١٠	Density-Drainge	٠,٢٨٢٤	١	٠-٠,١٢
			٢	٠,١٢-٠,٢٩
			٣	٠,٢٩-٠,٤٥
			٤	٠,٤٥-٠,٦٣
			٥	٠,٦٣-٠,٨٨

٢,٢. Improved weighted PCA (IWPCA) Method

Here we use an improved weighted PCA (IWPCA) method of Heydari et al., (٢٠٢١) to rank the operative variables of our data. The classical renowned feature extraction method PCA has been improved to be used for feature selection aims. Since the classical PCA method didn't have interoperability capability of original dimensions because of transferring the original dimensions to a new space of variables, (Kim & Rattakorn, ٢٠١١) has tried to rank the operative variables with the aim of removing redundant variables by improving PCA algorithm as follows. Let $\{x_1 \ldots . x_m\}$ be the original dimensions of the data. Then new extracted variables of PCA algorithm are linear combination of original variables as follows.

Eq. (١)

$$Y_1 = v_{11}x_1 + v_{12}x_2 + \cdots + v_{1m}x_m$$

$$Y_2 = v_{21}x_1 + v_{22}x_2 + \cdots + v_{2m}x_m$$

$$.Y_m = v_{m1}x_1 + v_{m2}x_2 + \cdots + v_{mm}x_m$$

Where the coefficient values v_{ij} is the importance degree of original dimension x_j in the i^{th} $PC\ (Y_i)$ formation and computed by taking eigenvectors of covariance matrix of original data set by rearranging them according to the decreasing order of the eigenvalues $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_m$ of the covariance matrix. Then define the weight of importance of each original dimension as follows (Equation ٢):

Eq. (٢) $\omega_j = \sum_{i=1}^{K} |v_{ij}| \pi_i \quad j = 1.2. \ldots . m$

Where $K \leq m$ is selected so that $\sum_{j=1}^{K} \pi_j \approx 1$ and $\pi_i's$ are the proportion of total variance explained by principal dimension Y_j calculated by the relation $\pi_j = \frac{\lambda_j}{tr(\Sigma)}$.

Then (Heydari et al., ٢٠٢١), uses MIC matrix (Reshef et al., ٢٠١١) instead of covariance matrix of data set since its entries are sensitive to more general relationships among variables in contrast to classical covariance matrix that consider only linear correlation between dimensions.

However, in this context we firstly calculate MIC matrix for our data that comprises maximized mutual information between each pair of variables as its entries and play a classical correlation matrix role and of course sensitive to more general relationships among dimensions in spite of linear ones. Then the variables are ranked using IWPCA approach. The resulted ranks of variables and their weighs of importance are calculated using Matlab while MIC entries are computed by applying the library that could be found in (Tab. ٢) .

Table ٢: Pair Matrix of IWPCA Model

1	0.41	0.22	0.098	0.169	0.15	0.120	0.098	0.1022	0.233
0.417	1	0.198	0.069	0.112	0.12	0.056	0.070	0.082	0.272
0.223	0.198	1	0.123	0.2815	0.257	0.165	0.12	0.051	0.546
0.098	0.069	0.12	1	0.141	0.41	0.068	0.75	0.0370	0.17
0.16	0.112	0.28	0.141	1	0.211	0.495	0.140	0.080	0.43
0.15	0.127	0.257	0.416	0.211	0.974	0.149	0.37	0.033	0.315
0.120	0.056	0.165	0.068	0.495	0.149	1	0.068	0.033	0.258
0.098	0.07	0.123	0.751	0.140	0.37	0.068	1	0.0379	0.174
0.102	0.08	0.051	0.037	0.08	0.033	0.033	0.037	0.9872	0.114
0.23	0.272	0.546	0.173	0.435	0.315	0.258	0.174	0.114	0.99

٢,٣. Model of Ordinary Least Squares (OLS)

The ordinary least squares method is the simplest and most common among the prevalent regression models. The initial design of this method is usually indicated by OLS (Fig ٢). The rationale for the OLS method is assume values foe the model coefficients that the sample regression model is closest to the observations or shows the least deviation from the above observations. The coefficients or parameters of the statistical model are constant concerning the location (geographical coordinates) in spatial modeling with the OLS method. Thus, the value of dependent variable estimated by this model is for the whole study area, estimating the same values in different parts of the catchment. This is one of the drawbacks of this method in spatial modeling. The simple univariate linear regression model is as follows:

Eq. (٤) yi=β٠+β١xi+εi

In which,

γ = dependent (estimated) variable, x = independent (estimator) variable, εi = model error or deviation in estimation, and β٠ and β١= model parameters or coefficients, assumed constant for the overall surface of the aquifer. The statistical model of OLS and the model coefficient estimation matrix are expressed as follows:

Eq (٥) β ^ =(XTX)-١XTy

Eq (٦) y=Xβ+ε

in which,

T = Matrix Transpose, XTX (-١) = Inverse of variance-covariance matrix, and X = matrix of independent variables. The coefficients of the OLS multivariate regression model are constant across the location. It is impossible to map the spatial changes of the model parameters or coefficients using this model. Besides, this model is incompatible with ARC GIS software and does not consider spatial correlation (Erfanian et al., ٢٠١٣).

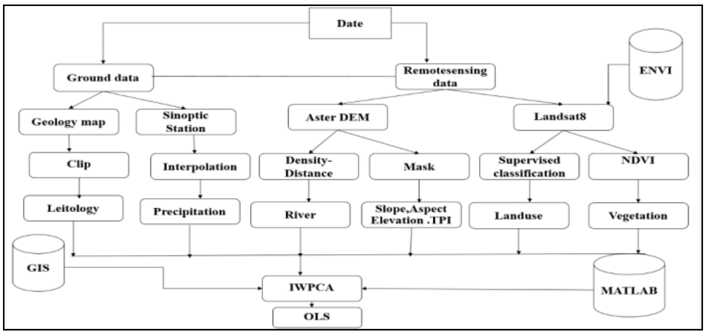

Fig. ٢. General flowchart of the research

٣. Results and discussion

In this section, the research results are presented in order. First the used layers and their corresponding weights which are calculated based on IWPCA is shown in Table ١. This table shows the weight of used criteria in determining the flood potential, percentage of the area and score of each class. According to the results of IWPCA method, the variables of slope, distance from river have the highest weights. The TPI variable also has the lowest weight among the investigated variables.

٣,١. Slope and aspect

Fig.٣ shows the slope of Firouzabad watershed and its direction. The minimum slope in the central portion of the plain area is about ٧٪ which belongs to the plain and without slope areas. The maximum slope belongs to the eastern and western portions of the watershed which is about ٧٢٪. The areas with maximum slope which cause extended floods in the area are those that are located in the south, south west and south east of the watershed (Fig. ٣).

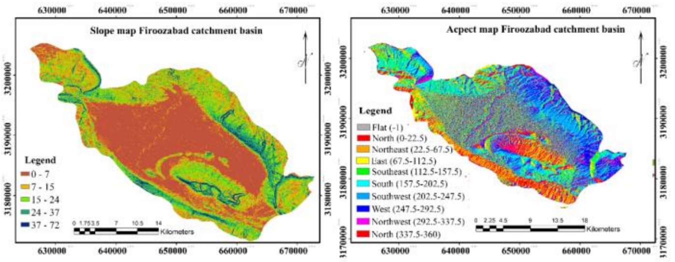

Fig. ٣. Slope and aspect layer for Firouzabad watershed

٣,٢. Vegetation and land use

The output obtained for vegetation in the watershed shows that the areas without vegetation in NDVI index are less than zero, which cause movement of runoff and reduced soil permeability. When the vegetation density approaches unity the runoff movement is reduced and due to vegetation density, permeability is increased and flood hazard is reduced. The output for land use layer in the watershed shows that two portions i.e. the barren areas and residential areas have the highest potential for flood occurrences. Lack of proper vegetation in these areas for control of inflow to the watershed causes frequent damages over the watershed area (Fig. ٤).

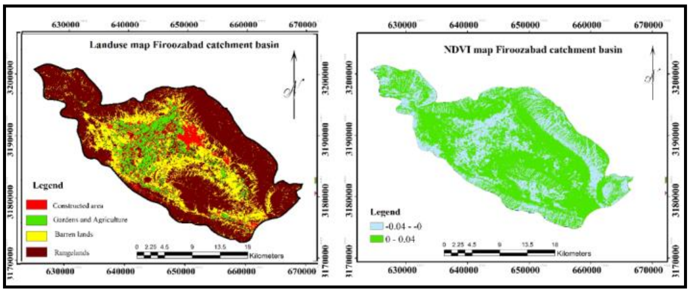

Fig. ٤. Vegetation and land use layer for Firouzabad watershed

٣,٣. Lithology and topography situation

Investigating the lithology situation of the watershed area shows that the central portion of the watershed is formed of permeable alluvial sediments. These sediments are comprised of clay, sand, and gravel which have a high permeability. On the other hand, Gachsaran and Mishan formations are among the salt domes and are impermeable formations in the watershed area which increase the flood hazard potential in the watershed area. Investigating the topography index situation in the watershed area reveals that the valley areas are among the areas with high potential of flood occurrence in Firouzabad watershed (Fig. ٥).

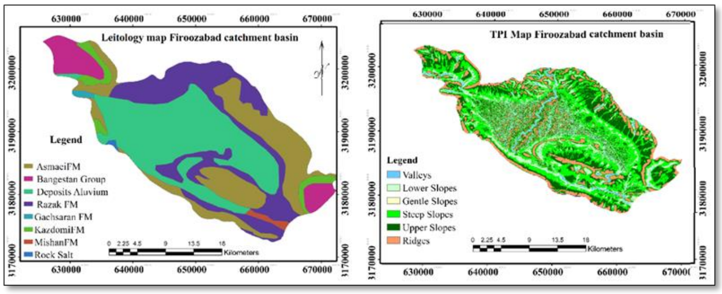

Fig. ٥. Lithology and topography situation of Firouzabad watershed

٣,٤. Precipitation and elevation layer

The study area due to being situated in the region where western and Mediterranean cyclones enter it, possess precipitation in most of the year. The maximum precipitation over the watershed area is about ٣٩١mm which is concentrated over the north eastern and southern portions of the watershed area and these regions are accounted as areas with high potential of flood hazards. As this watershed is located in a mountainous region, the precipitation pattern not only is affected by the atmosphere but also by local and environmental characteristics and precipitation in these areas is more severe and powerful. Therefore, precipitation could be an effective factor in flood occurrence in Firouzabad watershed. There are very small fluctuations in the amount of precipitation. Digital Elevation Model (DEM) is an important source for obtaining the effective topographic factors influencing flood activity in the region. By increase in the elevation, the precipitation amount also increases and by increase in precipitation the resulted runoff also intensifies. The output of elevation layer shows that the watershed elevation is in the range of ١١٢٨-٢٨٩٥m (Fig. ٦).

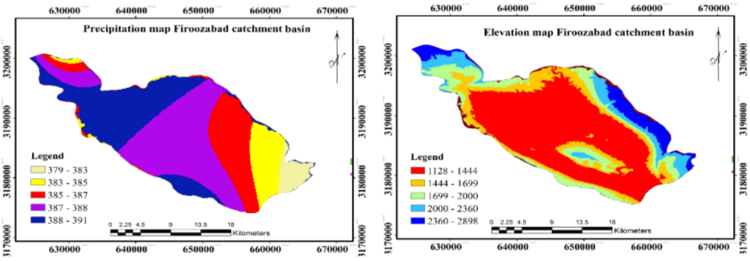

Fig. ٦. Elevation and precipitation layer for Firouzabad watershed.

٣,٥. Density and distance from river

Density of the waterways over the watershed area indicates their concentration in the watershed area. By increase in the density, the flood hazard potential increases over the watershed area. The main river is located within Firouzabad watershed area which is directed towards south by being accumulated and drained. By increase of distance the flood hazard is reduced (Fig. ٧).

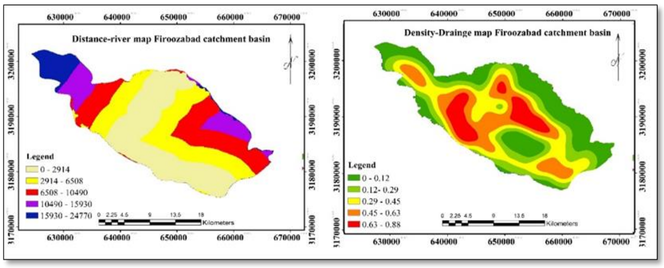

Fig. ٧. Density and distance from the river layer for Firouzabad watershed

٣,٦. Flood hazard zoning

After determining the effective variables on the flood, and preparing the corresponding maps of each variable in ArcGIS environment, a score is designated for each variable with respect to its importance. Next, using the AHP analysis, zoning of the flood potential for Firouzabad watershed was performed. At the next step, based on the importance and designated score, the combination of the mentioned ten variables layers was performed using the weighted linear combination (WLC) method, and the watershed was divided into five classes with flood occurrence probabilities ranging from high to low. Equation (١) shows the weight of each criterion for combining the layers and determining the flood potential of the watershed. Accordingly, the flood potential zoning map was obtained by overlapping of the effective criteria (Fig.٨).

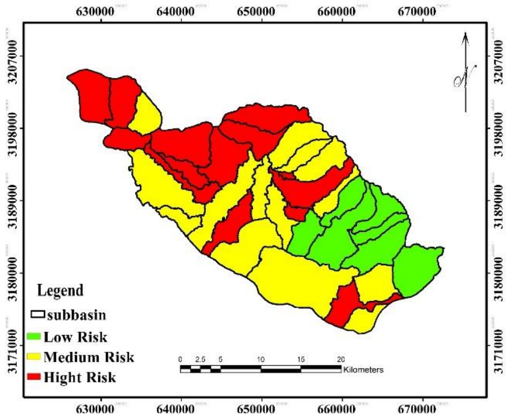

Fig. ٨. Flood hazard zoning IWPCA map for Firouzabad watershed

The results of weighting ١٠ effective parameters in flood occurrence of the Firouzabad watershed using IWPCA model showed that the slope and distance from river were the most significant parameters. In this case, the highest flood risk was in the central part of the basin. The results of zoning by IWPCA showed that the highest flood risk in the central part of the basin was about ٢٤٨ km^٢, respectively.Finally, the OLS method was used to evaluate the validity of the mentioned methods. The R^٢ coefficient in the IWPCA was about ٠,٧٦ and ٠,٤١. The most important parameter in this output is R^٢ values, which indicate the appropriateness and accuracy of the used model. In a case, in which R^٢ is close to ١, the independent variables can exactly explain the changes in the dependent variables. Also, a P-value of at least ٠,٠٠١ confirms the effectiveness of the IWPCA model in adapting to the dependent and independent variables (Tab. ٣).

Table ٣: Results of OLS validation

Parameters	**IWPCA**
significant p-value	٠,٠٠١
VIC	١,٥
R^٢	٠,٧٦

٤. Conclusion

Flood is a natural phenomenon which could occur with different return periods, based on the condition of the watersheds. In recent decades, by increase of population and overgrowth of cities and residential centers, humans by their aggressive behavior towards nature have exposed themselves to hazardous natural phenomena like floods. Considering the increased fatalities and financial outcomes in recent decades, the urban planners have sought new solutions and in locating new towns consider this issue. But concerning the old cities which are located near the rivers or where they overflow, other methods have been proposed. First there is need for further recognition of the situation and the flood potential and this has become possible by implementing new methods and tools developed by mankind. In this research, use has been made of ten effective criteria on flood potential. In this study and many similar research works both domestic and international studies performed in relation to the natural sciences, the geographic information system has been under focus of attention due to its various capabilities and tools and also tangible results. Also for enhancing the efficiency of these systems, use has been made of decision making techniques. Flood proneness in a watershed not only causes soil erosion but results in accumulation of runoffs in the main waterways, increased probability of formed gullies and flood occurrence downstream of watershed close to the exit point. The results of weighting ١٠ effective parameters in flood occurrence of the Firouzabad watershed using IWPCA model showed that the slope and distance from river were the most significant parameters.The results of zoning by IWPCA showed that the highest flood risk in the central part of the basin was about ٢٤٨ km٢, respectively.

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