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Assessment of Flood hazard prone areas in parts of Thanjavur District, South India using FIGUSED Method

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Abstract: Thanjavur district is primarily an agricultural area enclosed with irrigation system of the Cauvery in Tamil Nadu. But during the monsoon period flooding has been disrupted the areas and directely effected the soil erosion in those areas. The flood hazard assessment is one of the important task to understand the soil erosion of the area due to natural hazards. In this context, the present study to assess flood hazard prone areas using FIGUSED method adopted with remote sensing data and GIS technology. In FIGUSED method, seven parameters has been used such as flow accumulation, distance from the drainage network, elevation, land use, rainfall intensity and geology. The relative importance of each parameter for the occurrence and severity of flood has been connected to weight values. These values are calculated following a normalized weight parameter rating method. According to their weight values, information of the different parameters is superimposed, resulting to flood hazard mapping. The Flood Hazard Index (FHI) has been defined and a spatial analysis in a GIS environment has been applied for the estimation of its value. The historical flood events, accuracy and sensitivity analysis not examined in this study and it is only understand the flood hazard area. The study revealed that about 12% of the area falls under very high flood hazard and 26% high to moderate flood hazard zones and indicates that immediate attention have to be taken and protect the agricultural lands for the sustainable development of those areas.

***Index Terms* – Normalized weight, flood prone area, GIS analysis, flood hazard area, South India**

1. INTRODUCTION

Flood is a major natural hazard with often immeasurable impact, affecting annually 170 million people (Kowalzig, 2008). Therefore, flood risk management needs to overcome national borders, geographic location and socio-economic limitations (Degiorgis et al., 2012). Flood risk management is usually divided into flood risk assessment and flood risk mitigation (Schanze et al., 2006). From sustainable development point of view, the flood hazard management is very essential for future (Schober et al., 2015). Tehrany et al., 2013 have studied 10 parameters with the relative importance of each parameter defined following a statistical analysis. During the JAL cyclone event (November to December 2010), severe floods, occurred in Thanjavur district and Thanjavur taluk which spreads at the margin of Cauvery River was one of the affected places. Cyclones ravage the district once in 3-5 years, during north east monsoon, resulting in flood and crop damage. During 1982-83, 1990-91 and 1992-93 cyclones of high intensity have affected the district. Every year monsoon cyclone flood and drought situation may occur during Rabi season which may also considerably affect the paddy production in Thanjavur district.

The application of GIS-based multi-criteria analysis in the context of flood risk assessment was rare until 2000. Black and Burns (2002) have studied the changes in the estimation of flood risk on Scottish rivers with time by re-analyzing flood records. An early attempt to use GIS on water-related hazards has been presented in Meja-Navarro et al. (1994). The present article deals with the first element of flood risk management, i.e. the definition of flood hazard areas in a specific region. The present study methodology adopted based on the Kazakis et al (2015) FIGUSED methods to identify flood hazard zones in parts of Thanjavur and the output of the results is very useful to the farmer and planners for the agricultural purposes in the study area.

2. STUDY AREA

Thanjavur district lies between 9º 50’ and 11º 25’ North latitude and 78º 45’ and 79º 25’ East longtitude (Fig.1). It is bounded on the North by Thiruchirapalli and Cuddalore districts, on the East by Tiruvarur and Nagapattinam districts, on the South by Palk Strait and Pudukottai district and on the west by Pudukkottai district and Tiruchirapalli districts. Total geographical of the study area is 1697 sq.km. The mean maximum temperature was 37.48ºC during May – July. Similarly, the mean minimum temperature was 20.82ºC during November-January. The north east monsoon provides much rainfall with 545.7 mm and 953.2 as normal and actual rainfall respectively, while southwest monsoon provides 342 and 303.1 mm as normal and actual rainfall respectively. The total population of Thanjavur district is 22,16,138. Thanjavur district stands unique from time immemorial for its agricultural activities and is rightly acclaimed as the granary of South India lying in the deltaic region of the famous river Cauvery and criss-crossed by lengthy network of irrigation canals. Therefore this coastal district abounds in green paddy fields, tall coconut groves, vast gardens of mango and plantain trees and other verdant vegetation.

The major crops cultivated in Thanjavur district are paddy, pulses, gingelly, groundnut and sugarcane. The minor crops like Maize, soyabeans, redgram are in rice fallows. In new delta area, the groundnut is the principal crop.

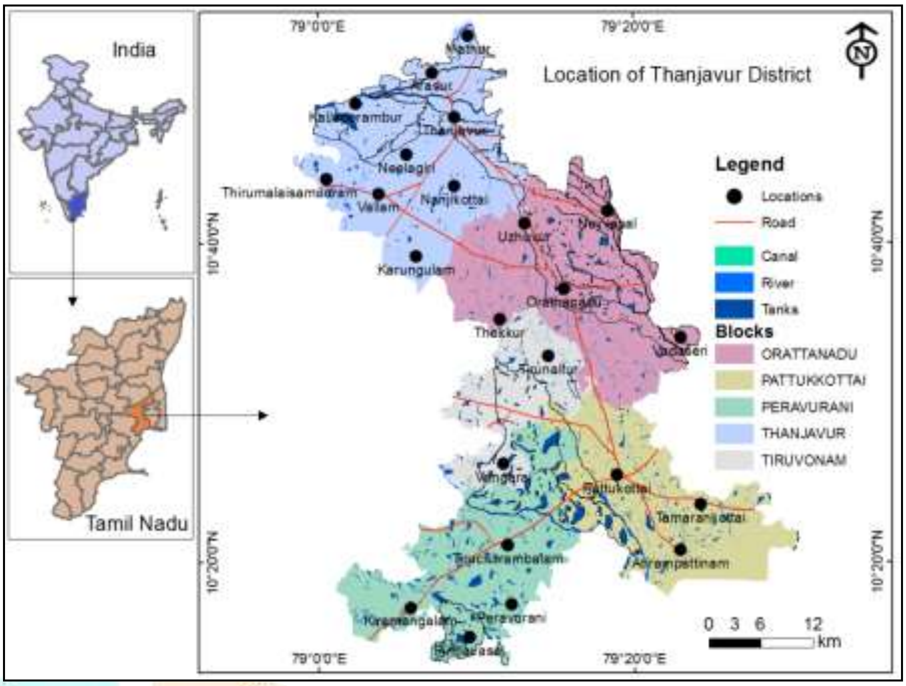

Figure 1 Location of the study area Thanjavur district

3. METHODOLOGY

FIGUSED methods, the parameters were selected such as flow accumulation (F), rainfall intensity (I), geology (G), land use (U), slope (S), elevation (E) and distance from the drainage network (D). These parameters chosen based on their relevance to flood hazards as documented in the literature (Haan et al., 1994 and Kazakis et al 2015). Input data for each parameter is processed in a GIS environment and the seven parameters are visualized in independent thematic maps. The elevation, slope and flow accumulation are products of the digital elevation model (DEM). Moreover, geological information offers insight on the geological units, while land use information1 results to the relevant thematic map. Distance from the rivers can be calculated by imposing buffer zones around the drainage network information. Finally, rainfall intensity is estimated from rainfall measurements, using a modified Fournier index. The flowchart has been prepared and shown in Fig.2.

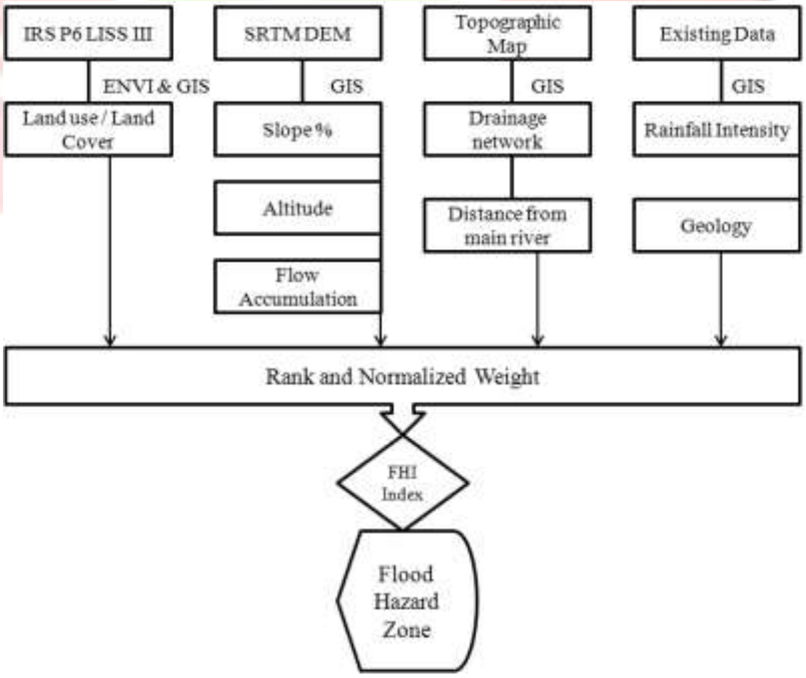

Figure 2 Flowchart

3.1 FIGUSED parameters

3.1.1 Flow Accumulation

Flow accumulation is the most important parameter in defining flood hazard. Accumulated flow sums the water flowing down-slope into cells of the output raster. High values of accumulated flow indicate areas of concentrated flow and consequently higher flood hazard. The flow accumulation values have been prepared using satellite data spatially and its vary in a range between 0–37 shown in Fig.3.

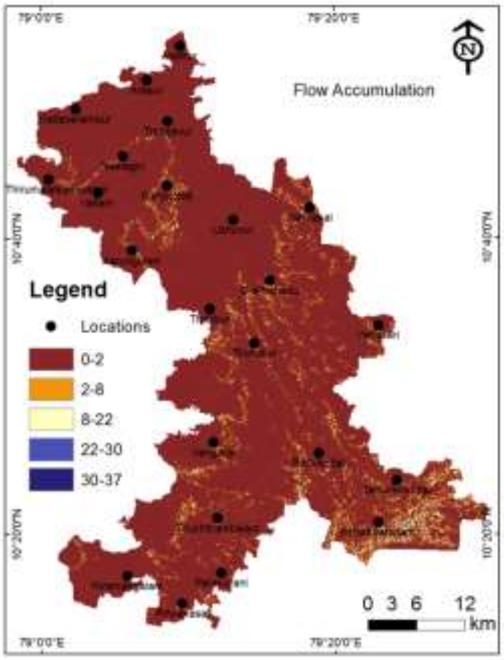

Figure 3 Flow Accumulation in the study area

3.1.2 Rainfall Intensity

Rainfall intensity is expressed using the modified Fournier index (MFI). MFI is the sum of the average monthly rainfall intensity at each rain gauge station. The spatial distribution of the rainfall intensity has been performed considering the allocation of stations in the studied area. Taking into account their relatively sparse set-up, and the spline interpolation method used, considering that a geo-statistical method would be more appropriate than ordinary kriging/co-kriging (Huang et al., 1998); (Hutchinson, 1998); (Lloyd, 2005). The MFI of the study area ranges from 59 to 193 (Table 1), with the higher values located in the north central part of the study area (Fig.4).

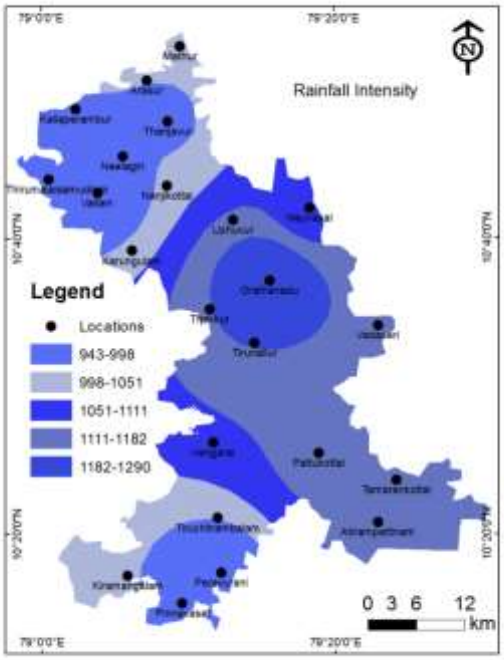

Figure 4 Rainfall intensity of the study area

3.2.3 Geology

The geology of flood hazard areas is an important criterion, due to it may amplify/extenuate the magnitude of flood events and permeable formations favor for water infiltration, through flow and groundwater flow. On the contrary impermeable rocks, such as crystalline rock, favor surface runoff. Karst formations can also significantly affect the generation of flash floods (Bonacci et al., 2006).

Therefore, karstic formations and lacustrine deposits (clays, marbles and loam) have been rated with 8 (Table 1). Lower rating has been assigned to alluvial and continental deposits due to their higher infiltration capacity (Fig.5).

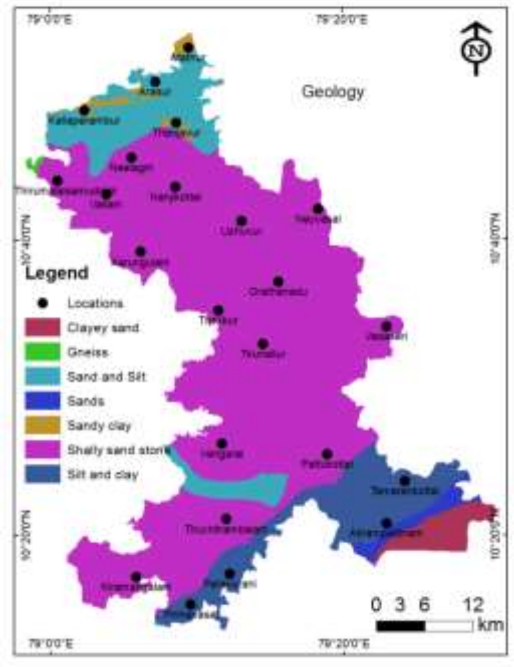

Figure 5 Geology of the study area

3.2.4 Land use

Land use influences the infiltration rate, the interrelationship between surface and groundwater as well as debris flow. Thus, while forest and lush vegetation favor infiltration, urban and pasture areas support the overland flow of water. A large proportion of the studied area is covered by mixed forests and vegetated areas which have been assigned rates equal to 2 and 4, respectively (Fig.6).

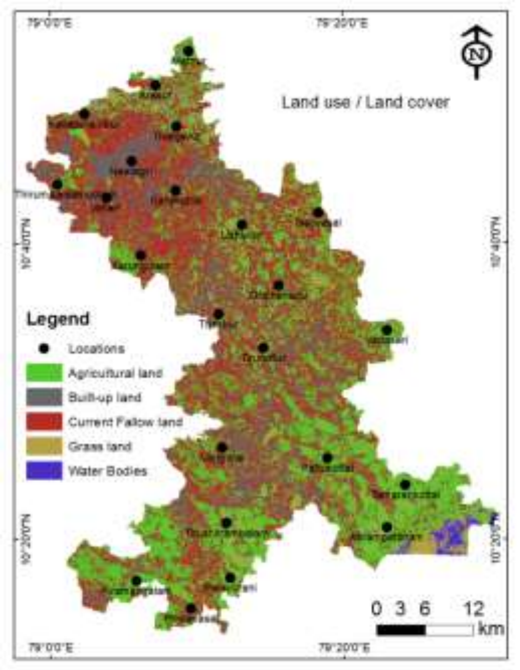

Figure 6 Land use / land cover of the study area

3.2.5 Slope

Water flows from higher to lower elevations and therefore slope influences the amount of surface runoff and infiltration. Flat areas in low elevation may flood quicker than areas in higher elevation with a steeper slope. In the study area high-elevation appears in the central and northern part, where the slope is also steeper. Naturally, low slope and low elevation have been assigned the highest rating, as prone areas (Fig.7).

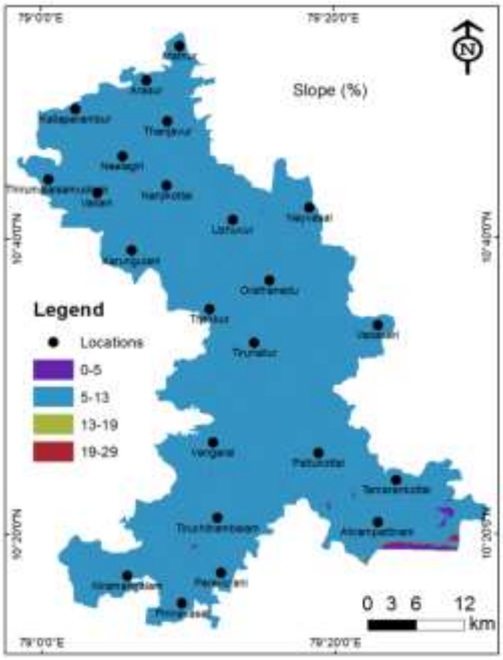

Figure 7 Slope (%) of the study area

3.2.6 Elevation

Water flows from higher to lower elevations and therefore slope influences the amount of surface runoff and infiltration. Flat areas in low elevation may flood quicker than areas in higher elevation with a steeper slope. In the studied area high-elevation appears in the central and northern part, where the slope is also steeper. Naturally, low slope and low elevation have been assigned the highest rating, as prone areas (Fig.8).

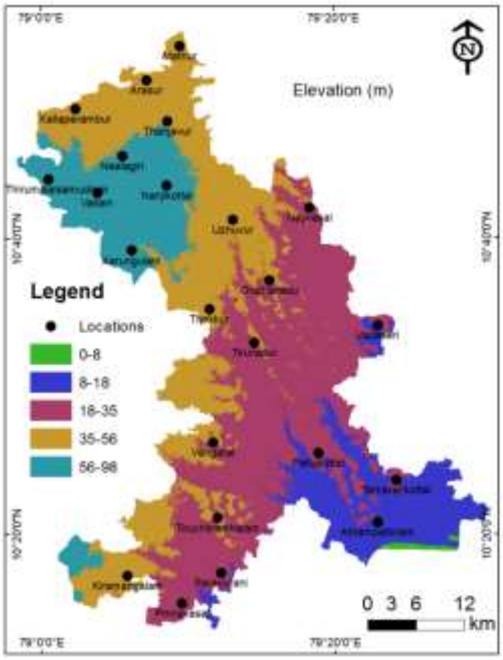

Figure 8 Elevation of the study area

3.2.7 Distance from drainage network

Apart from the areas of concentrated surface water, river-overflows are crucial for the initiation of a flood event. Often the inundation emanates from riverbeds and expands in the surroundings. The role of riverbed decreases as the distance increases. That explains why "distance from the drainage network" has been assigned a high weight in the methodology. The classes of this criterion have been defined by processing records of historical floods in the study area. It appears that areas near the river network (b200m) are highly flood hazard, whereas the effect of this parameter decreases in distances N2000 m (Fig.9).

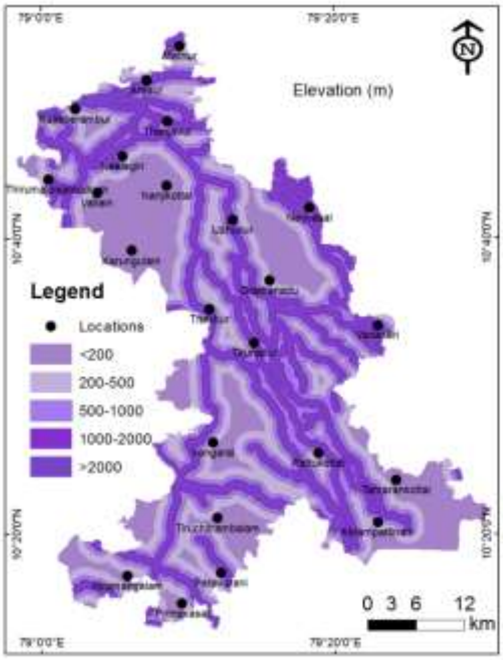

Figure 9 Distance from drainage network of the study area

3.2 Normalized Weights

The normalized weight is an indicator of multi-parameter analysis for groundwater potential. The normalized weight was derived from the assigned weight of a parameter feature class divided by the corresponding geometric mean. The formula is represented as:

$$\text{Normalized weight} = (\text{Assigned weight of a parameter}) / (\text{Geometric mean}) \qquad \ldots.1$$

The normalized weighted map is an indicator of potential groundwater zone. The class with maximum weight is considered as very high suitable zone and least weighted class is less or unsuitable zone for groundwater. Normalized weights of different features of thematic layers the map of each thematic layer was classified. Ranks assigned to different features of the individual themes and their normalized weights are presented in Table 1.

Table 1 Classes of the parameters and according to normalized weights

Parameters	Classes	Rating	Normalized weights
Flow Accumulation (values)	0-2	2	0.067
	2-8	4	0.133
	8-22	6	0.200
	22-30	8	0.267
	30-37	10	0.333
Rainfall intensity (mm)	943-998	2	0.067
	998-1051	4	0.133
	1051-1111	6	0.200
	1111-1182	8	0.267
	1182-1290	10	0.333
Geology	Sand and Silt	3	0.081
	Sandy clay	4	0.133
	Sands	2	0.067
	Gneiss	10	0.333
	Shally sand stone	5	0.135
	Silt an clay	6	0.162
	Clayey sand	7	0.189
Land use land cover	Grass land	8	0.195
	Current fallow land	7	0.171
	Agricultural land	6	0.146
	Built-up land	10	0.244
	Water bodies	10	0.244
Slope (%)	0-5	10	0.357
	5-13	8	0.286
	13-19	6	0.214
	19-29	4	0.143
Elevation	0-8	10	0.333
	8-18	8	0.267
	18-35	6	0.200
	35-56	4	0.133

	56-98	2	0.067
Distance from main river (m)	<200	10	0.333
	200-500	8	0.267
	500-1000	6	0.200
	1000-2000	4	0.133
	>2000	2	0.067

FIGUSED methods consider the above hydro geological, morphological parameters and the weight of each factor determines its role in the final result. Thus, a spatial analysis of studied areas evaluates each grid-point on every parameter. Then, according to the local conditions, each grid point is assigned values in a scale between 2 and 10 (rating score). The classes of the flow accumulation, elevation and rainfall intensity were defined using the grading method of natural breaks which has been used in similar studies (Huan et al., 2012; Kazakis and Voudouris, 2015). The slope classes were defined according to the Demek (1972) classification,whereas the classes of the distance fromthe drainage network have been defined by processing records of historical floods in the study area. The qualitative parameters of land use and geological formation were classified similarly to previous studies with modifications accordingly the characteristics of the study site (Kourgialas and Karatzas, 2011; Tehrany et al., 2013; Ouma and Tateishi, 2014). The acquired values are processed in order to calculate the relative significance of each criterion and the corresponding weighting factor (w). Following the calculation of the weights, the FHI can be calculated using Eq. (2).

$$FHI = \sum_{i=1}^{n} \mathrm{r_i}.\mathrm{w_i} = \mathrm{F}.\mathrm{w_F} + \mathrm{I}.\mathrm{w_I} + \mathrm{G}.\mathrm{W_G} + \mathrm{U}.\mathrm{w_U} + \mathrm{S}.\mathrm{w_S} + \mathrm{E}.\mathrm{w_E} + \mathrm{D}.\mathrm{w_D} \quad \ldots 2$$

The acquired values are processed in order to calculate the relative significance of each criterion and the corresponding weighting factor (w). Following the calculation of the weights, the FHI can be calculated using Eq. (2).

4. RESULTS AND DISCUSSION

The methodology linearly combines the selected parameters, taking into account the relative weights. This involves superimposing the thematic maps with different weights in a GIS environment. Eventually, the flood hazard map is created (Fig. 10), defining 5 classes of flood vulnerability (very low, low, moderate, high, and very high). Classification is based on the inherent information of the derived, linearly combined data. Thus, the break-points in the datasets are spotted by minimizing the variability inside each class and maximizing the variability among them, in a way similar to Statistics “Cluster Analysis”. Accordingly, datasets are divided into clusters by setting boundaries where significant changes in data values appear.

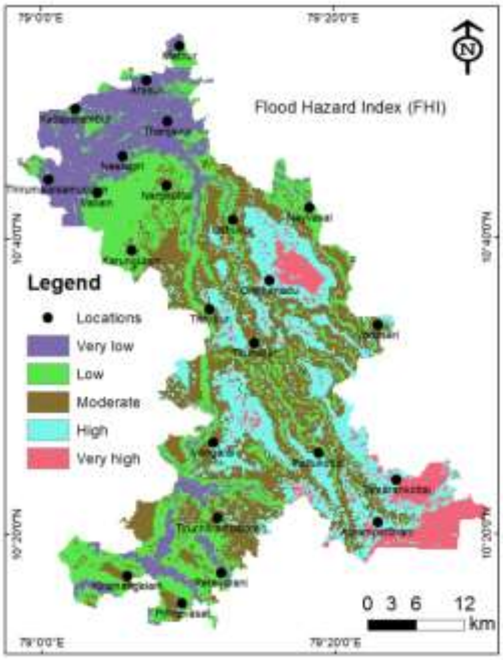

Figure 3 Flood hazard index in the study area

5. CONCLUSION

An index-based methodology has thus been developed, named “FIGUSED” and it is expressed with the corresponding FHI index. The method spatially analyzes seven parameters, combining the information in the Flood Hazard Index (FHI). The parameters are flow accumulation (F), rainfall intensity (I), geology (G), land use (U), slope (S), elevation (E) and distance from the drainage network (D). The relative importance of each parameter is calculated by a sophisticated statistical method, the Analytic Hierarchy Process. The higher weight was assigned to flow accumulation and the lower to geology. Following that, the effect of each criterion is combined in a linear manner and their numerical superimposition results to mapping that visualizes highly prone zones. Accordingly, the 68% and 22% of the very high flood hazard zones are agricultural areas and urban-wetland areas, respectively. Similarly, the majority of prone zones are agricultural areas, whereas mixed forest constitutes 20% of this zone. Very low to moderate prone areas appears mainly at mixed forests and sparsely vegetated areas.

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