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Flood Conditioning Factors Identification And Evaluation Of The Baghain River Basin Using SWARA Technique

Swati Sharma[1, *] and Vineet Sharma[1]

[1] KIET Group of Institutions, Delhi NCR, Meerut Road (NH-58), Ghaziabad – 201206

Abstract

Remote Sensing and GIS which are considered as powerful ways for generating and use of thematic information, has been considered to appraise the geomorphologic prospective of Baghain river basin lying in parts of the Bundelkhand region, India. The Baghain is said to have its origination from a hill in Panna district. It then enters in Banda district in UP. A total of around 2643.76 km2 area is covered by the basin, with an elevation varying from 300 meters to 50.6 meters. The satellite data was collected from the community of USGS Earth Explorer. Subsequently, Shuttle Radar Topographic Mission (SRTM) data was used to identify the topographic characteristics and Digital Elevation Model (DEM). In this study, supervised classification method based on maximum likelihood algorithm was used to delineate the land use / land cover characteristics. The Normalized Difference Vegetation Index (NDVI) was used for the determination of the vegetation characteristics in the study area. A detailed Geomorphologic analysis is done using identified factors and corresponding SWARA weights are calculated.

Keywords: Geomorphologic, GIS, Remote Sensing, SWARA

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1. Introduction

Floods are considered as one of the most frequently occurring and most devastating disasters throughout the world. Per year there are millions of people that are affected by floods all over the world [1]. Infrastructure of cities and rural area were as crop production also best badly affected. There are many factors that influence the floods genesis some of which include topography, extreme rainfall, and other geomorphologic features of the area. River basins are unique as their different parts have different vulnerability towards occurrence of floods because of its varying geomorphologic features [2]. A Geomorphologic analysis of the area can help in flood hazard assessment. This in turn will be useful in designing protection measures by policy makers and local authorities in river basins.

The following flood risk mitigation strategies can be adopted: before flood occurrence flood mitigation strategies can be planned, during flood occurrence flood response measures need to be done and after floods certain recovery mechanisms needs to be planned. For any of the above-mentioned strategies remote sensing and GIS is considered as a very powerful method to collect and integrate data from different sources.

In past many years, the use of data accessed by remote sensing and applying of geographic information system (GIS) over the acquired data has been largely used in stocking of resources, data mapping, analysis and monitoring of various environmental related issues. Remote sensing has proved to be a powerful tool for conducting various surveys, problem identification, data classification, and monitoring enormous activities happening on earth. It also helps in acquiring the data of different remote locations at different intervals. Flood occurrence is a multi-dimensional phenomenon which has various spatial and temporal aspects that define the causes.

Geographic information systems (GIS) is used as a tool for producing flood susceptibility maps by applying logical and mathematical relations over synthesized input data of varied dimensions [3]. Different methods have been developed for identification and assessment of flood susceptible areas.

2. Related work

The structural measures used for controlling floods requires extensive ground data and field surveys which is often time consuming and not always feasible. The interpretation of data collected through satellites makes it possible to identify and outline various factors causing different activities on the earth such as occurrence of floods [4]. Remote sensing and geographic information system often prove to be a suitable way to gather, analyze and manipulate the required and relevant information so that various hazard zones can be demarcated. Remote sensing and GIS techniques are also suitable to identify flood conditioning factors and demarcate the damages occurred due to excessive rains in a river basin or in coastal regions [5]. The flood susceptibility analysis using RS, GIS along with frequency ration analysis model proved to be very useful and efficient technique for planning various flood mitigation strategies by the concerned authorities [6].

For performing susceptibility analysis over floods and assessment of flood risk various different factors are identified by different researchers worldwide [7]. Some of the flood conditioning factors is common that play a vital role in mapping of floods. [8] have computed very accurate results by using some of these factors. Most of the factors used were independent of each other. Although there are certain factors that are dependent on each other and thus a hierarchical relationship among them can be established. This can help in finding the interrelationship among the flood causing factors. This interrelationship can help us to focus on most driving factors among the various flood conditioning factors.

Many researchers have been using various Geographic Information Systems software and Remote sensing methods to evaluate the flood conditioning factors of a remote area. Earth observation satellite (SPOT), United States Geological Survey Earth satellite along with a digital elevation model (DEM) has been used for the analysis of flood vulnerability of a coastal area. Recurrent flash flood cause in Jeddah city of Saudi Arabia has been analyzed by using multi-sensor Remote Sensing data [9]. GIS environment such as Quantum is used for visualization and production of geo hazard map [10] assessing flood hazard areas with a GIS environment along with AHP.

In other similar studies different remote sensing tools such as Landsat Thematic Mapper band 7 is used to delineate flooded areas [11], advanced very-high-resolution radiometer (AVHRR) for regional flood studies [12], also amplitude change detection method using multi-pass synthetic aperture radar (SAR) data for identification of flooded area have been used.

In this paper, an attempt has been made to utilize the potential of remote sensing and Geographic Information System techniques to identify the flood conditioning factors of Baghain river basin. A total of 11 flood conditioning factors are considered for analysis including Elevation, slope, Rainfall, Land cover land use (LCLU), Geomorphology, Soil type, Distance to river, Density of river, Curvature, topo graphic wetness index (TWI), Stream power index (SPI). Further the factors are subdivided into subcategories to analyze the available information.

3. Study Area

Madhya Pradesh is a state located in northern central part of India. It is in subtropical zone with substantial monsoon rains that provides water to large number of streams and rivers. In all there are twelve small and large rivers that originate in Madhya Pradesh. These rivers are Narmada, Chambal, Mahi, Tapti, Betwa, Son, Tons, ken, Dhasan, Paisuni, Kunwari, Sindh, and Baghain. Approximately the total length of these rivers in M.P is approximately 3966 km and 554 km share boundaries with the other neighboring states.

The Baghain is said to have its origination from a hill in Panna district. It then enters in Banda district in UP. While flowing in a north-east direction it seperates the district from Chitrakoot district, and consequently meets the river, Yamuna. A little of alluvial soil is deposited by baghain but often a large amount of sand is deposited near its junction with the river Yamuna. The river in total has six tributaries two of which are the Ranj and Barua. Having length of 125.24 km Baghain river basin is of seventh order system. A total of around 2643.76 km2 area is covered by the basin, with an elevation varying from 300 meters to 50.6 meters. It is located between latitude of 24°39′ 3″ N and 25°34′52” N, and longitude 80°11′ 47″ E and 81°2′ 42″ E. (Figure 1)

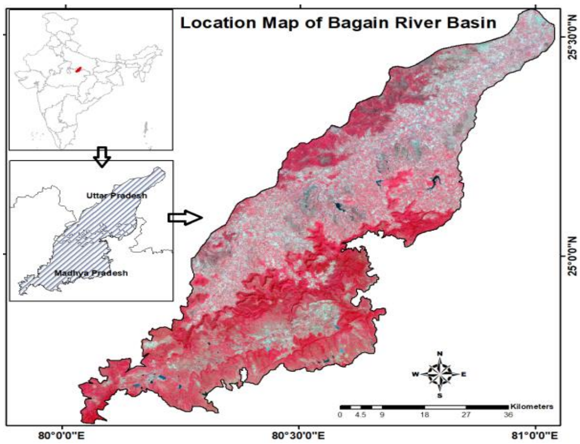

Figure 1 Study Area.

4. Methodology and Database

The study involves two major steps one is the generation of geomorphologic information, and the other is its analysis for flood susceptibility. For the purpose Landsat 8- Operational Land Imager (OLI) sensor was used with 30m spatial resolution and eleven spectral bands. The satellite data was collected from the USGS Earth Explorer Community. The satellite data was rectified based on Universal Transverse Mercator (UTM) projection system with World Geodetic Survey (WGS) 84 datum and North 44 zone. Subsequently, Shuttle Radar Topographic Mission (SRTM) data was used to identify the topographic characteristics and Digital Elevation Model (DEM)(Figure 2). The SRTM-DEM data was also used to identify the stream network using Spatial Analyst tool of QGIS software. In this study, supervised classification method based on maximum likelihood algorithm was used to delineate the land use / land cover characteristics. The Normalized Difference Vegetation Index (NDVI) was used to determine the vegetation characteristics in the study area. Flood conditioning factors identified are Elevation, slope, Rainfall, Land use land cover (LULC), Geomorphology, Soil type, Distance from river, Density of river, Curvature, Topological Wetness Index (TWI), Stream Power Index(SPI).

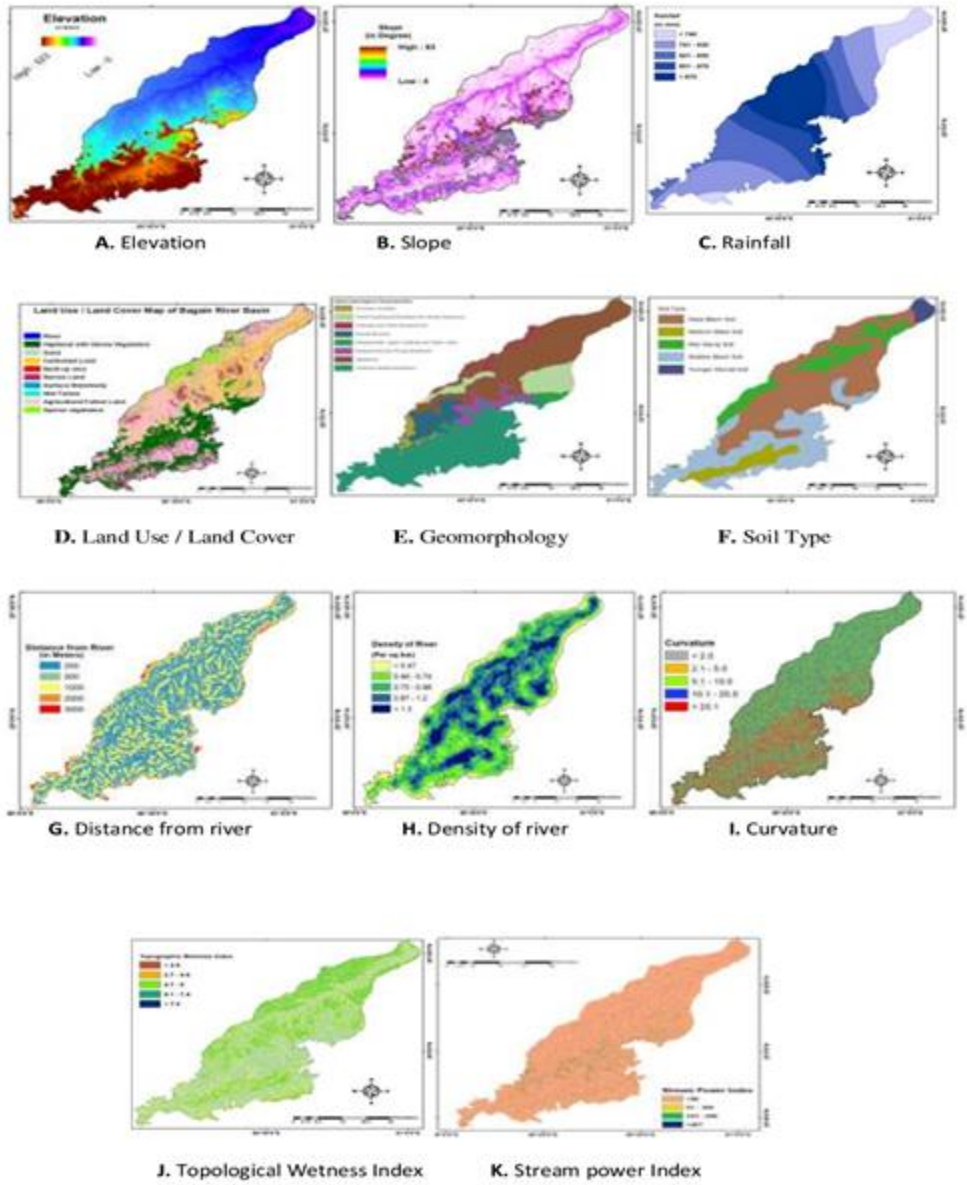

Figure 2 Digital Elevation Model.

4.1 Elevation

Conceptual relationship between various flood causing factors have been explored [13]. Elevation is considered as one of the important factors. The results of the analysis showed that areas with lower altitude are more prone to flooding. Nedkov [14] in his research shows that altitude of a place also has a considerable impact on regulation functions of floods. With increasing altitude there is a proven trend of increase in rainfall thereby increasing river discharge. In the current work, elevation is distinguished into 5 different categories (in meters): (1) <75 (2) 76-100; (3) 101-155; (4)156-264; and (5) >265.

4.1 **Slope:**

Slope angle is considered as an important flood conditioning factor as the velocity of water is determined by the slope gradient [15]. Flow of water from higher to lower elevations influences the amount of surface runoff and penetration. Areas with lower slope angle i.e., areas with lower elevations gets flooded more frequently than areas at higher elevations. Stream power models and the longitudinal distribution of river floods have shown that slope is also important for tracking the changes in downstream of a river. Celik et. al. [16] in his research has concluded that transforming the precipitation into runoff is often accelerated by high slopes. In the current work, 5 categories (in degrees) were used to distinguish the slope: (1) <2; (2) 2.1 - 5.0; (3) 5.1 - 8.0; (4) 8.1 – 11.0; and (5) >11.0.

4.2 **Rainfall**

There is a large amount of work done in different research papers illustrating the correlation between rainfall and floods [17]. Rainfall is one of the major driving factors of flood generation [18], and the amount of rainfall act as an important factor in flooding of an area. Although not much of evident exist to prove as to what level an increase in rainfall will impact the occurrence of floods. Thus, research done for various regions consider rainfall as a persuading factor for the susceptibility analysis of floods [19]. In the current work, annual rainfall was divided into 5 categories (in mm): (1) <740; (2) 741 - 820; (3) 821 - 850; (4) 851 - 870; and (5) >870.

4.3 **Land use Land Cover**

Land use and land cover plays a substantial role in influencing flood frequency as it affects the surface runoff and there by affecting transport of sediment. García-Ruiz et al. [20] in their research showed that land uses are of at most significance when hydrologic ally generated responses are compared with different scales that are temporal. Similarly, Beckers et al. [21] showed that the way land is being used plays a major factor for flood risk analysis.

In the current work, land use was distinguished into 10 categories: (1) Wet fallow; (2) Surface water body; (3) Spars Vegetation / Agricultural Plantation; (4) Sand; (5) River; (6) Highland with dense vegetation; (7) Cultivated land; (8) Built-up area; (9) Barren Land; (10) Agricultural fallow Land.

4.4 **Geomorphology**

Impact of Floods greatly depends upon the geomorphology of a location [22]. The Geomorphology of the Baghain river basin is very wide and can be divided into eight categories: (1) Vindhyan Shales / Sandstone; (2) Sandstone; (3) Residual Soil and Fluvial Sediments; (4) Residual Hills, Upper Vindhyan and Table Lands; (5) Recent Alluvium; (6) Pediment and Other Residual Soil; (7) Fluvial Sediment & Residual Soil, Mostly Ravineous; (8) Archaean Granites.

4.5 **Soil Type**

The study area under consideration has a variety of soil type. It has been shown from a study that type of soil has an impact over the floods. Different soils have different water holding capacities thus greatly affect the water runoff. Getahun and Gebre [23] said that Soils have a high capacity of generating floods. The soil is distinguished into 5 categories; (1) Deep Black Soil; (2) Medium Black Soil; (3) Red Sandy Soil; (4) Shallow Black Soil; (5) Younger Alluvial Soil.

4.6 **Distance to a river:**

Post rainfalls sediments starts accumulating when discharge from rivers increases which ultimately results in flooding of the nearby locations. In their research Predick and Turner [24] concluded that network of rivers also plays a significant role in expansion of floods. Previous researches also showed that tellurian accumulation of water is having a major association with local flooding [25]. In the current work, the distance to a categorization was done into 5 categories (in meters): (1) <250; (2) 251 - 500; (3)501 - 1000; (4) 1001 - 2000; and (5) >2000.

4.7 **Drainage Density**

River density and river distance have a significant impact on the magnitude of flood occurrence [26]. Network of various rivers was used in the preparation of density and distance of river maps. Dividing the river length in meters by the area of the river basin in sq km gives the river density. This parameter can be grouped into 5 different categories (per sq km): (1) < 0.47; (2) 0.48 – 0.74; (3) 0.75 – 0.96; (4) 0.97 – 1.2; (5) >1.3.

4.8 **Curvature**

In a study of the lower Mississippi River, a relationship between the curvature of the place and occurrence of floods in the area was identified. It was observed that the area with curvature value between 1- 2 is highly flood prone [27]. The heterogeneity and hypothetic flow are affected by the curvature values. For more precise representation of flow, it becomes important to include curvature as it supports water depths projections. In the current work, curvature was distributed in 5 main categories: (1) < 2.0; (2) 2.1 – 5.0; (3) 5.1 – 10.0; (4) 10.1 – 20.0; (5) > 20.1

4.9 Topographic wetness index (TWI)

The Topographical wetness index i.e. TWI can be defined by the following Eq.

$$\mathrm{TWI} = \log\frac{a}{\tan b} \qquad (1)$$

Moore et al. [28] in their research defined the above equation as follows: ‘a’ is defined as the aggregate upslope area which is draining via a particular point per unit of the length of contour and ‘tan b’ is the local slope angle of that point. Being a physical parameter of a flood prone area, TWI is considered as an essential attribute. It includes two essential parameters: flat land and the hydrographic position. The spatial soil moisture patterns are defined by the TWI of the area. Higher values of TWI are associated with the development of floodplains. In the current work, 5 categories of TWI are taken into consideration: (1) <2.6; (2) 2.7 – 4.6; (3) 4.7 – 6.0; (4) 6.1 – 7.4; (5) > 7.5.

4.10 Stream power index (SPI).

The SPI estimation can be performed with the following Equation.

$$SPI = As \tan \beta \qquad (2)$$

where 'As' is defined as the particular catchment area and 'β', taken in radians, represents the gradient of slope [28]. Knighton [29] found that several processes of the fluvial system are influenced by the SPI. An analysis on the geomorphic impact of a flood which took place in New Zealand depicted that sudden channel transformation is a result of high SPI which is generated in confined channels. The SPI can be defined as an impact of fluvial sediment transport, and erosion caused by river channel. In the current work, the SPI was categorized in 5 categories: (1) <50; (2) 51 – 100; (3) 101 – 150; (4) 151 – 200; (5) > 201.

5. Step Wise Weight Assessment Ratio Analysis (SWARA) Approach

In this paper a reliable model based on step-wise weight assessment ratio analysis (SWARA) method for ranking flood conditioning factors is proposed. The SWARA method is preferred over other MCDM approaches because the principal element of SWARA method is based on ratio of multiple criteria. For factors which use data in discrete form, the SWARA method calculates the final weight value of each category. For the factors which uses data in continuous form the SWARA method can also be used to obtain results in relation to the center of every class.

An expert of an area plays an important role in evaluating the criteria and factors of an event. Whenever a decision has to be taken for a process expert opinion is inescapable. In SWARA technique the priority of every criterion is specified exclusively by every expert, and then, by considering the aggregated outcome, critical factors are ranked from first to last. It is the knowledge, information, and experience of an expert that plays an important role in making a suitable decision. In the SWARA method the highest rank is allocated to the criteria that is of at most importance and the lowest rank is allocated to the lesser one. Ranking from N experts is sought and thereafter, an average rank is calculated. The vital feature of the SWARA method is that it is able to make assessment of the expert's opinion regarding the accuracy of the weighted criteria [30].

To further illustrate the detail methodology map is shown (figure 3):

The steps used are as follows:

Step 1: Preparation of base map of the study area using Landsat - 8 OLI and USGS Earth.

Step 2: Visual interpretation of satellite imagery, SRTM and DEM is used to identify flood conditioning factors.

Step 3: Crucial factors are identified, and thematic maps are digitized.

Step 4: Dividing each factor into subcategories through supervised classification method based on maximum likelihood classification algorithm.

Step 5: Experts are allowed to rank the sub criteria and provide weights based on their domain knowledge.

Step 6: In this step aggregated ranks and weights of the sub factors are calculated. Then the criteria are ordered according to their ranks.

Step 7: Each expert determines the comparative importance of each criterion with respect to other in order.

Step 8: SWARA is applied by calculating the geometric mean value of the comparative importance (Sj) Table 1.

Step 9: Calculate coefficient K_j using the following equations.

$$K_j = \begin{cases} 1 & if \ = 1; \\ S_j + 1 & if \ j > 1; \end{cases} \quad (3)$$

Step 10: Recalculate weight Q_j

$$Q_j = \begin{cases} 1 & if \ j = 1; \\ Q_{(j-1)}/K_j & if \ j > 1; \end{cases} \quad (4)$$

Step 11: Calculate SWARA weight

$$W_j = Q_j / \textstyle\sum_{j=1}^{n} Q_j \quad (5)$$

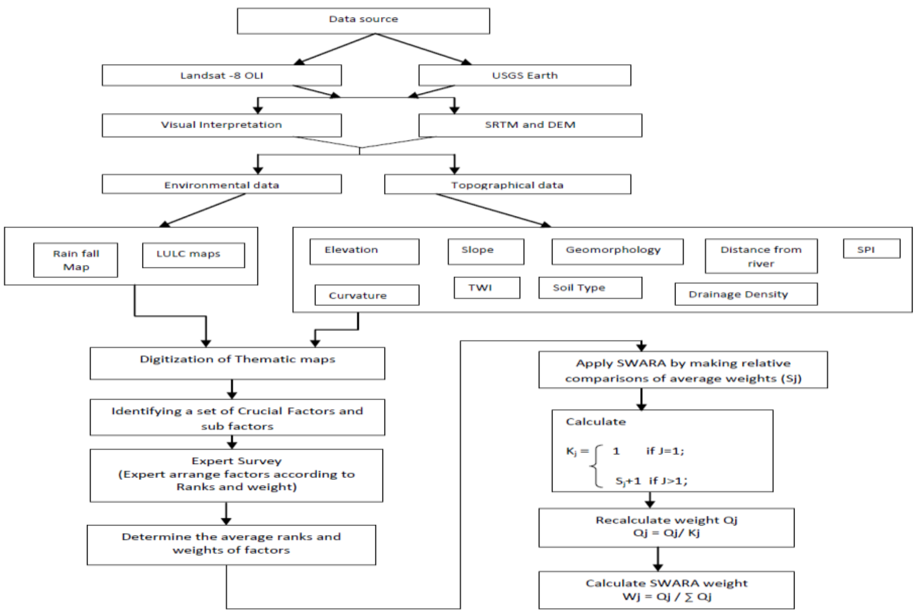

Figure 3 Methodology Flow chart.

6. Results

In the study, Baghain river basin having length of 125.24 km is considered. Based on the critical literature survey and expert opinions, 11 critical flood influencing factors were identified. These factors include elevation, slope, rainfall, land use, geomorphology, Soil type, Distance from river, Density of river, Curvature, TWI and SPI of the study area. The United States Geological survey i.e. USGS Earth Explorer Community was used for the collection of satellite data. Subsequently, Shuttle Radar Topographic Mission (SRTM) data was used to identify the topographic characteristics and Digital Elevation Model (DEM). The data obtained through remote sensing and GIS of the study area under consideration is analyzed through SWARA technique which is an expert-based weighing method. The calculations obtained through SWARA method are shown in table 1.

For each identified factor, sub classes are identified using supervised classification method based on maximum likelihood classification algorithm. Using SWARA method the spatial correlations between flood conditioning factors and flood occurrences is evaluated. On applying SWARA method normalized SWARA weights of each sub category is calculated. As per the results the area with the high SWARA weight values in different categories have high probability of flood and hence need to be monitored. The SWARA value increases as the elevation decreases. The lowest elevation categories (<75m) have a SWARA value of 0.282 which is highest among all the other categories thus showing the higher probability of flood occurrence. In case of slope lesser the slope more is the area prone to flood. Thus SWARA value is highest (i.e. 0.28) with slope less than 2 m. For Rainfall it is clear that the area that receives the highest rainfall (>870mm) has highest SWARA value of 0.278. Results depict that the land used by water bodies had the maximum effect on flooding (0.155), were as barren lands have minimum (0.072). As geomorphology and soil type of an area is concerned recent or young alluvium soil shows recent flood activities in the area thus SWARA weight is highest i.e 0.188 and 0.279 respectively. Distance of river plays a major role in floods thus lesser the distance more is the area prone to flood. For area less than 250 m SWARA value is highest 0.277. High drainage density per sq km indicates a greater flood risk (0.275). The TWI value directly influences the occurrence of floods, the more is the TWI value, the greater the flood occurrence probability. The value of TWI >7.5 has a SWARA value of 0.282. For SPI, the largest value is of the class which is greater than 201 (0.276) and values decreases as SPI reduces.

Table 1 Calculations using SWARA technique.

Theme	**Sub-category**	S_j	K_j	Q_j	W_j
Elevation (m)	<75		1	1	0.282
	76 – 100	0.28	1.28	0.781	0.22
	101 – 155	0.23	1.23	0.635	0.179
	156 – 264	0.11	1.11	0.572	0.161
	>265	0.03	1.03	0.556	0.157
e (d eg	<2		1	1	0.28

	2.1 - 5.0	0.27	1.27	0.787	0.221
	5.1 - 8.0	0.2	1.2	0.656	0.184
	8.1 - 11.0	0.13	1.13	0.581	0.163
	>11.1	0.07	1.07	0.543	0.152
Rainfall (mm)	>870		1	1	0.278
	851 – 870	0.28	1.28	0.781	0.217
	821 – 850	0.18	1.18	0.662	0.184
	741 – 820	0.11	1.11	0.596	0.166
	<740	0.08	1.08	0.552	0.154
Land use	Surface Waterbody		1	1	0.155
	Cultivated land	0.15	1.15	0.87	0.134
	Wet fallow	0.14	1.14	0.763	0.118
	Sparse Vegetation/Agricultural Plantation	0.12	1.12	0.681	0.105
	Built-up area	0.11	1.11	0.614	0.095
	River	0.09	1.09	0.563	0.087
	Agricultural fallow Land	0.07	1.07	0.526	0.081
	Sand	0.05	1.05	0.501	0.077
	Highland with dense vegetation	0.04	1.04	0.482	0.075
	Barren Land	0.03	1.03	0.468	0.072
Geomorphology	Recent Alluvium		1	1	0.188
	Fluvial Sediment & Residual Soil, Mostly Ravenous	0.21	1.21	0.826	0.155
	Residual Hills, Upper Vindhyan and Table Lands	0.16	1.16	0.712	0.134
	Sandstone	0.12	1.12	0.636	0.12
	Archaean Granites	0.09	1.09	0.584	0.11
	Vindhyan Shales/Sandstone	0.07	1.07	0.545	0.102
	Residual Soil and Fluvial Sediments	0.05	1.05	0.519	0.098
	Pediment and Other Residual Soil	0.04	1.04	0.499	0.094
Soil	Younger Alluvial Soil		1	1	0.279
	Shallow Black Soil	0.25	1.25	0.8	0.224
	Deep Black Soil	0.21	1.21	0.661	0.185
	Medium Black Soil	0.16	1.16	0.57	0.159
	Red Sandy Soil	0.04	1.04	0.548	0.153
Distance from River (m)	<250		1	1	0.277
	251-500	0.26	1.26	0.794	0.22
	501-1000	0.22	1.22	0.651	0.18
	1001-2000	0.11	1.11	0.586	0.163
	>2001	0.02	1.02	0.575	0.159
Density	>1.3		1	1	0.275

	0.97 - 1.2	0.23	1.23	0.813	0.224
	0.75 - 0.96	0.22	1.22	0.666	0.184
	0.48 - 0.74	0.11	1.11	0.6	0.165
	<0.47	0.09	1.09	0.551	0.152
Curvature	< 2.0		1	1	0.275
	2.1 - 5.0	0.26	1.26	0.794	0.218
	5.1 - 10.0	0.2	1.2	0.661	0.182
	10.1 - 20.0	0.1	1.1	0.601	0.165
	>20.1	0.03	1.03	0.584	0.16
TWI	>7.5		1	1	0.282
	6.1 - 7.4	0.25	1.25	0.8	0.226
	4.7 - 6.0	0.22	1.22	0.656	0.185
	2.7 - 4.6	0.17	1.17	0.56	0.158
	<2.6	0.06	1.06	0.529	0.149
SPI	>201		1	1	0.276
	151-200	0.31	1.31	0.763	0.211
	101-150	0.16	1.16	0.658	0.182
	51-100	0.08	1.08	0.609	0.168
	<50	0.03	1.03	0.592	0.163

7. Conclusions

In this paper a detailed Geomorphologic analysis of Baghain River basin is done using identified flood conditioning factors and corresponding SWARA weights are calculated. The results obtained in this study shows that SWARA technique is useful in identifying important flood conditioning factors. Thus, it will help in building more effective mitigation strategies and improves preparedness towards floods.

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