



Priority Assessment of Sub-watershed Based on Optimum Number of Parameters Using Fuzzy-AHP Decision Support System in the Environment of RS and GIS

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Abstract

Identification for planning of land and water resource management based on efficient decision-making tool is very important for providing appropriate weightage in stressed site. In the present study, fuzzy analytical hierarchy process (FAHP) with different erosion hazards parameters (EHPs) have been used as a pronouncement for identification of naturally stressed sub-watershed in Nagwan watershed of Hazaribagh district in Jharkhand, India. In fuzzy-AHP, analytical hierarchy process (AHP) builds a hierarchy (ranking) of decision items using comparisons between each pair of items expressed as a matrix with fuzziness. Paired comparisons produce weighting scores that measure how much importance items and criteria have with each other and checking the consistency of the decision. In this study, the Nagwan watershed was divided in 21 sub-watershed which varies from 2.34 to 7 km² and all EHPs of sub-watersheds have been computed using remote sensing and GIS. From the study, it has been observed that best consistency ratio has been found when using 13 parameters that is 9.44 with narrow trapezoidal shape. Each morphometric parameter was ranked with respect to the value and weightage obtained by deriving the relationships between the morphometric parameters obtained through classification of the SW by associating the strength of fuzzy analytical hierarchy processes (FAHP). By this weight, the results revealed that the priorities in five categories, out of 21 sub-watershed 19 and 24% sub-watersheds qualify for very high and high priority, whereas 57% sub-watersheds fall under medium, low and very low priority.

Keywords Erosion hazard parameter (EHP) · Saaty's analytical hierarchical process (SAHP) · Soil loss · Sediment yield · Sediment production rate (SPR) · Watershed prioritization

Introduction

Land and water are vital resources towards ensuring food security, economic and social progress and ultimately for sustenance of life. These resources are hampered day by day by various environmental hazards. Besides environmental hazards, soil erosion plays a vital role in

deteriorating the natural resources. Soil erosion also threatens the global food security by reducing the productivity of soil, reducing the reservoir capacity etc. The dynamics of soil erosion and sediment yield are affected by spatial and temporal characteristics of the catchment like climate, soil type, land use pattern, topography and anthropology activities. Since these factors bear temporal and spatial variability, they can be isolated by discretizing the catchment into smaller homogeneous units and eventually adopting feasible soil erosion models for sub-watersheds. However, the major problem with execution of these models is the input data which are too spatial and rare. GIS tool along with different soil erosion models is very useful for estimation of soil erosion from un-gauged watershed. For this purpose, watershed is treated as unit for sustainable development of natural resources (Patel et al. 2012). Watershed management is defined as judicious use

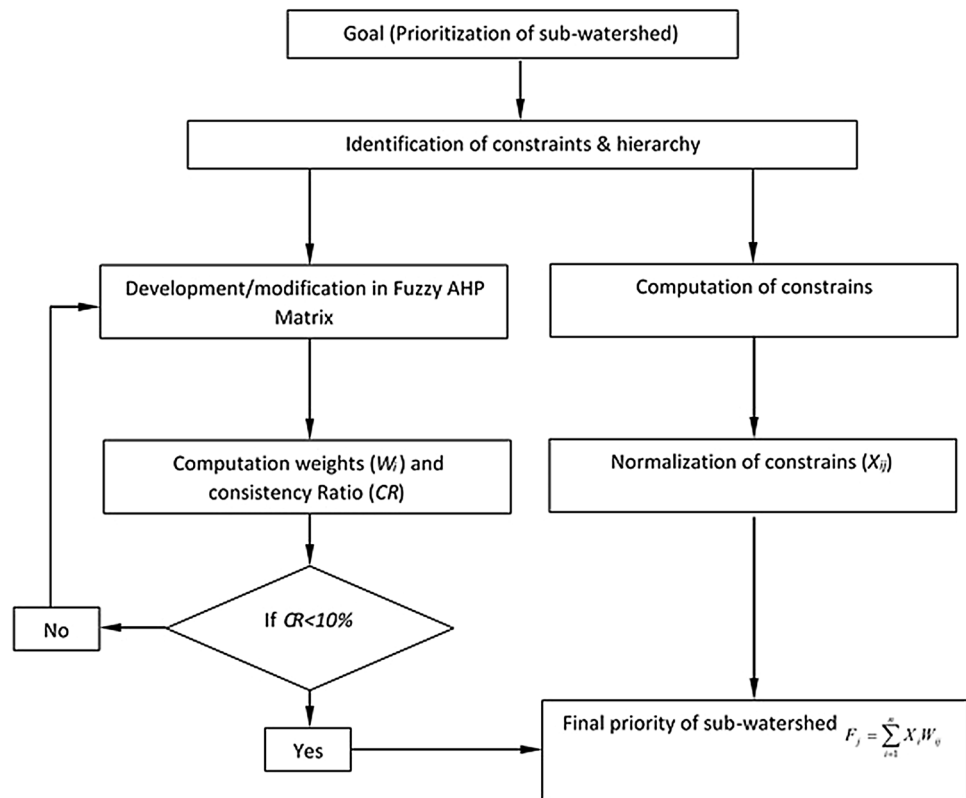
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Fig. 1 Flow chart of FAHP-based decision support model for prioritization of sub-watershed

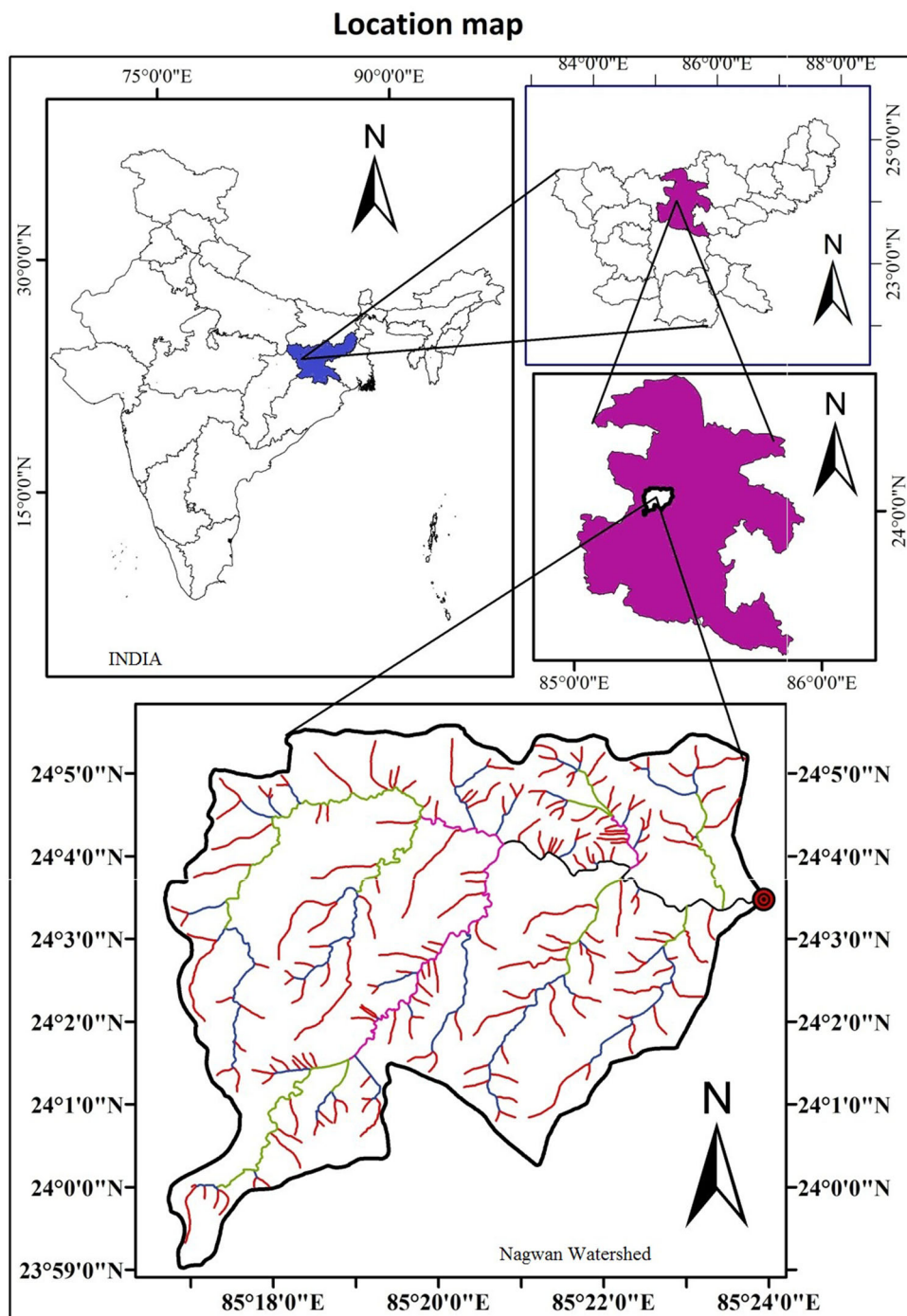


of the natural resources in a watershed to ensure optimum and sustained productivity (Yadav et al. 2014). Watershed is a natural hydrological entity which allows surface runoff to a defined channel, drain, stream or river at a particular point. It is the basic unit of water supply which evolves over time. Also it is describes as an area of land that contains common set of streams and rivers that all drain into a single large body of water (Black 2005). However, Chow (1964) defined watershed as the separating boundary of a drainage basin and termed it as a catchment. For sustainable management of watersheds, soil erosion is a major factor, which accelerates the rate of land degradation and hence influences agricultural productivity, runoff movement and sometimes leads to flood in the lower basin (Essiet 1990). Scientific planning of soil conservation requires knowledge of the relations among those factors that cause loss of soil and those that help to reduce such losses. Recent studies (Jaiswal et al. 2012; Pandey et al. 2007; Yoshino and Ishioka 2005; Sharma et al. 2001; Khan et al. 2001; Sidhu et al. 1998 and several others) discovered that Geographic Information System and remote sensing are great use in characterization and prioritization of watershed areas because of spatial computation of soil loss and other affecting parameters in erosion. Shrimali et al. (2001) presented mapping, monitoring and prioritizing the areas based on their susceptibility to degradation using remote sensing and GIS. Geomorphology parameters such

as stream length, stream order, drainage density, stream frequency, farm factor, texture ratio, circulatory ratio, bifurcation ratio, compactness ratio and elongation ratio have been extensively used across the world for prioritization of sub-watersheds (Mishra and Nagarajan 2010; Sharma et al. 2010; Javed et al. 2009; Hlaing et al. 2008; Chopra et al. 2005 and Vittala et al. 2004).

Analytical hierarchy process (AHP) approach is a multi-criteria decision method that uses hierarchical structures to represent a problem and then to develop priorities for the alternatives based on the judgment of the user (Saaty 1980). It involves building a hierarchy (ranking) of decision elements and then making comparisons between each possible pair in each cluster (as a matrix) to compute weight for each element within a cluster (or level of the hierarchy) with a consistency ratio (useful for checking the consistency of the data) of decision. Yahaya et al. (2010) has studied the causative factors for flooding in watershed using AHP and found the weightage for the different factors as 33.9% for rainfall, 25.5% for drainage network, 19.7% for slope, 15.2% for soil type and 5.7% for land cover. Oyatoye et al. (2010) used AHP method in decision-making on investment portfolio selection in the banking sector of the Nigerian capital market. Chowdary et al. (2013) has conducted a study for prioritization of micro-watersheds using multi-criteria decision approach of AHP

Fig. 2 Location map of the study area



and sediment yield index model (AHPSYI) under GIS environment.

In spite of popularity of AHP, this method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision-maker's perception to exact numbers (Deng 1999). Since fuzziness and vagueness are common characteristics in many decision-making problems, a fuzzy-AHP (FAHP) method should be able to tolerate vagueness

or ambiguity (Mikhailov and Tsvetinov 2004). In other words, the conventional AHP approach may not fully reflect a style of human thinking because the decision makers usually feel more confident to give interval judgments rather than expressing their judgments in the form of single numeric values and so FAHP is capable of capturing a human's appraisal of ambiguity when complex multi-attribute decision-making problems are considered (Erensal et al. 2006). This ability comes to exist when the crisp

Fig. 3 Contour map of the study area (Nagwan watershed)

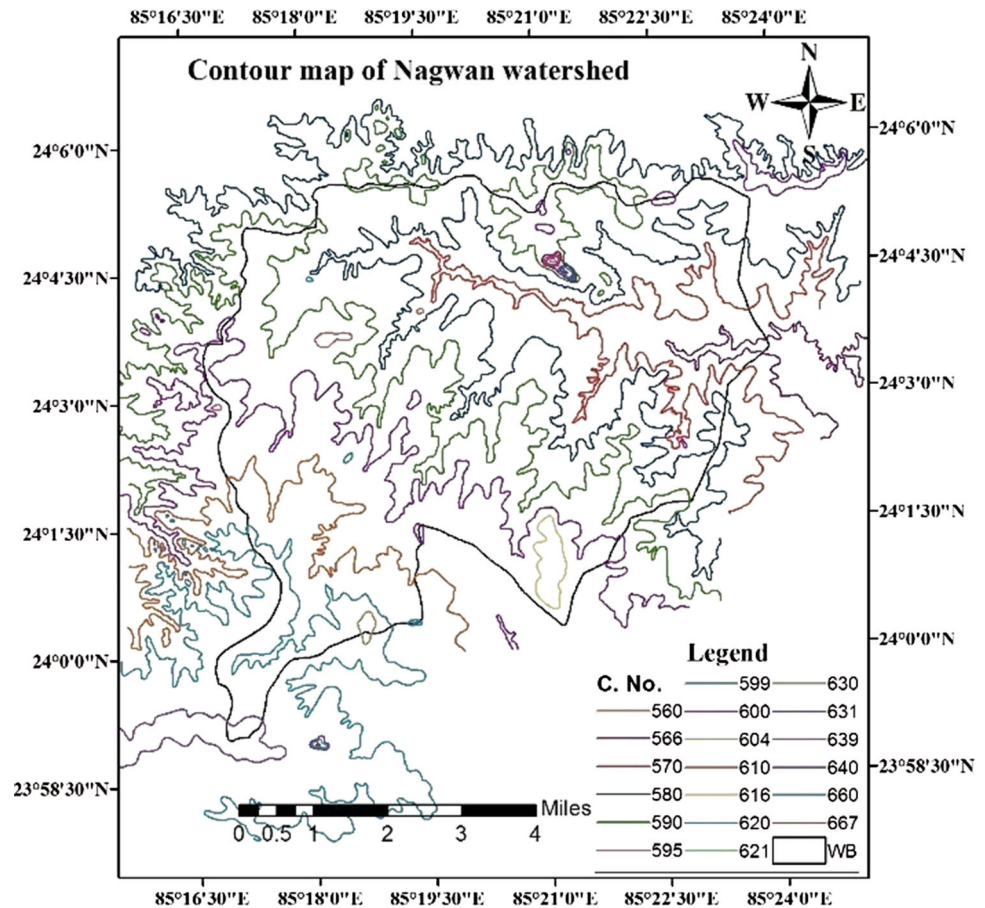


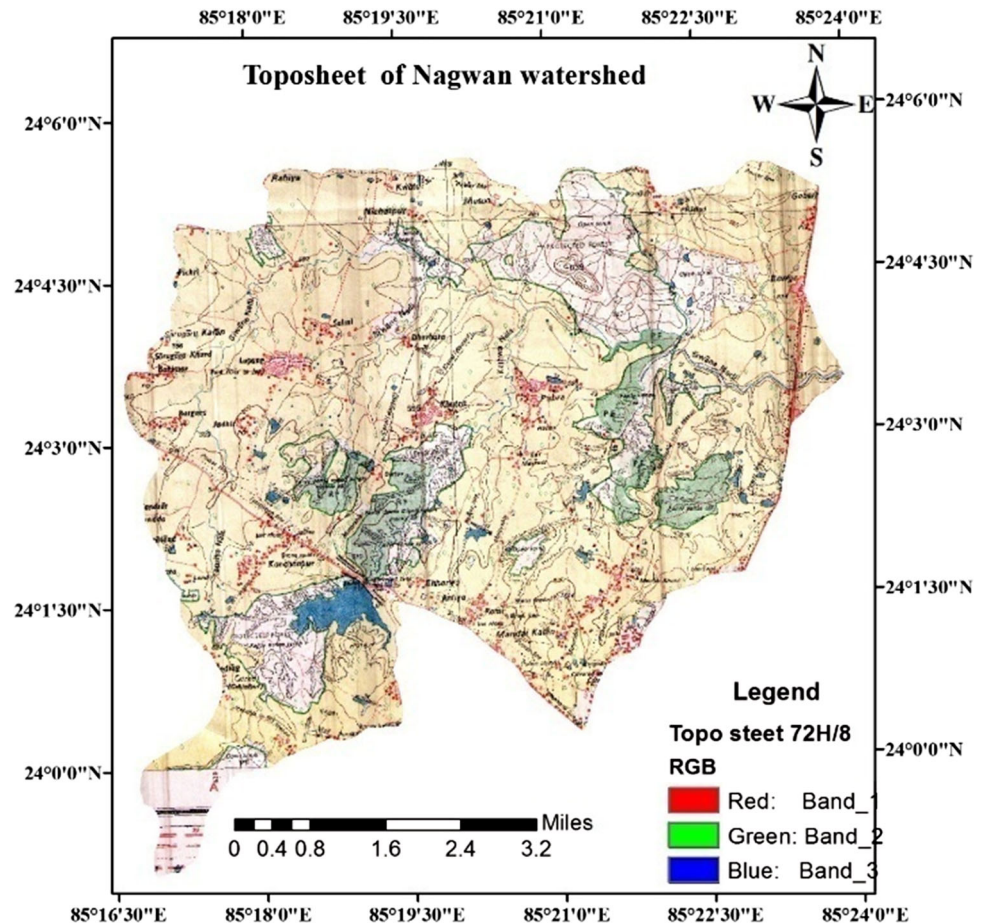
Table 1 Acquired data and their source used for study

S. no.	Name of data	Source	Objective
1.	Rainfall (period 1994–2014)	CRURRS District, Hazaribagh, Jharkhand	Determination <i>R-factor</i> of USLE model
2.	Topo-sheet (Fig. 4) 72 H/8 and 73 E/5	Survey of India, Kolkata	Preparation of drainage network, contour, sub-catchment boundaries
3.	IRS-P6 (LISS IV) image (Path-105 and Row-55) Date of pass: 22.12.2012 (Fig. 5)	N.R.S.C. Hyderabad (A.P.) India	Preparation of LULC map for estimation of C&P-factor of USLE model
4.	Soil texture map (Fig. 6)	DVC, Hazaribagh, Jharkhand	Determination of <i>K-factor</i> of USLE model

judgments are transformed into fuzzy judgments. Zadeh (1965) published his work fuzzy sets, which described the mathematics of fuzzy set theory. The main characteristic of fuzziness is the grouping of individuals into classes that do not have sharply defined boundaries (Hansen 2005). The uncertain comparison judgment can be represented by the fuzzy number. Jaiswal et al. (2015) gives the flow chart for proposed FAHP-based decision support, as shown in Fig. 1.

The present study aims at for prioritization of sub-watershed using different erosion hazard parameters by fuzzy analytical hierarchical process (FAHP) decision support system. This study is mainly helpful for planning and management of natural resource on sustainable basis. Tam et al. (2002) proposed a nonstructural fuzzy decision support system (NSFDSS) to integrate both expert's judgment and computer decision model for selecting site layout plan, and advocated the superiority of non NSFDSS over simple

Fig. 4 Topographic map of the study area (Nagwan watershed)



AHP because of its automatic consistency checking and correction, simplified scale of comparison and elimination of consistency deviation.

Methodology for Prioritization

Description of the Study Area

Study area, i.e. Nagwan watershed (92.33 km²) situated in upper part of Damodar Valley, district Hazaribagh, Jharkhand, India, is characterized as seriously eroded area (ranked second) in the world (El-Swaify et al. 1982). The latitudes of Nagwan watershed vary from 23°59'33"N to 24°5'37"N and longitudes vary from 85°16'41"E to 85°23'50"E as shown in Fig. 2. The soils of the study area are clay loam and silty loam type. The topography of the watershed is undulating, and maximum and the minimum elevations of the area are 667 m and 560 m (Fig. 3), respectively. The area experiences sub-humid subtropical monsoon type of climate, characterized by hot summers (40 °C) and mild winters (4 °C). The annual rainfall of the study area is about 1272.5 mm, out of which 80% received

in monsoon season. The distribution of rainfall is uneven and most of the storms are intense storms of 10 cm/h while considering the duration of rainfall is 30 min. The most of the agriculture of the Nagwan watershed is rain fed (only 20% area under irrigation) and mono-cropped. Farmers grow paddy and maize in kharif or wheat, gram and mustard in rabi season (Source: Directorate of Census, DVC, Hazaribagh).

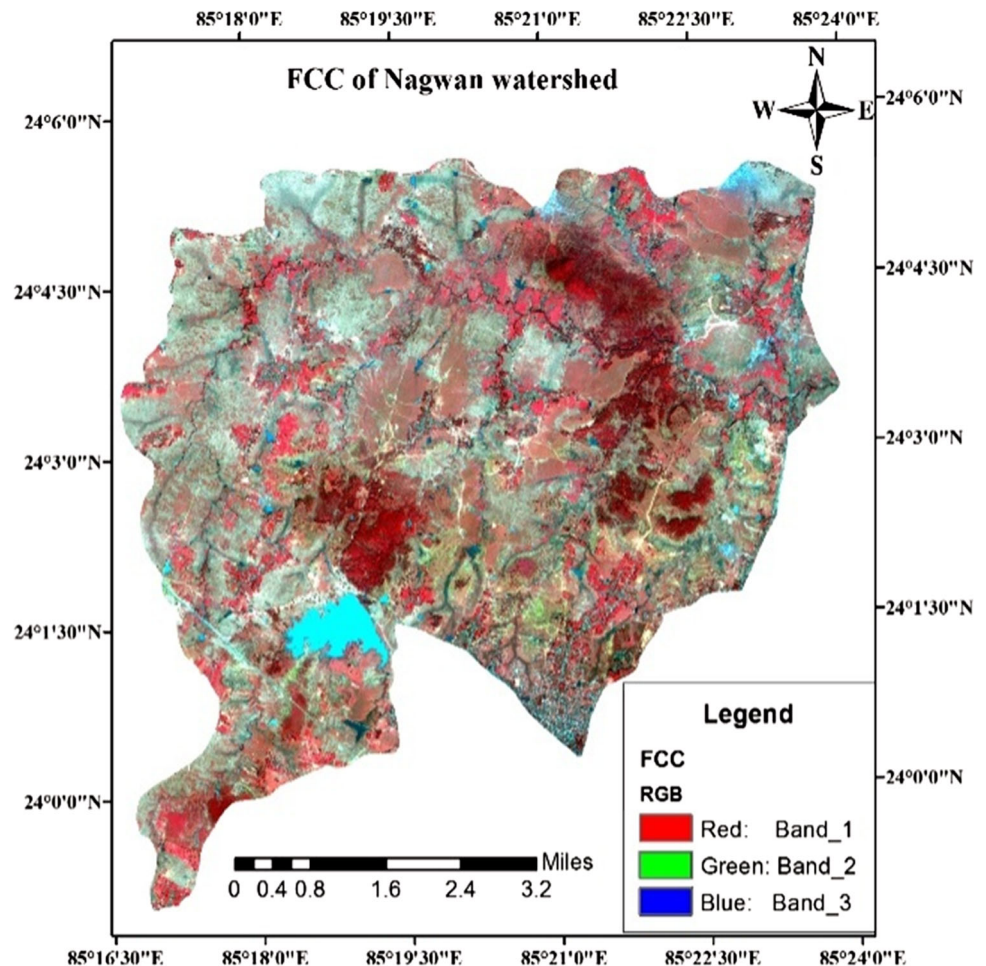
Data acquisition

The acquired data used in the present study, their source and purpose of acquisition are presented in summarized form in Table 1.

Methodology

The methodology used includes selection and computation of EHPs for sub-watersheds, calculation of weights of EHPs using FAHP-based decision support and finally prioritization of sub-watersheds for identification of environmentally stressed areas.

Fig. 5 False colour composite image of the Nagwan watershed



Erosion Hazard Parameters (EHPs)

EHPs analysis is carried out through measurement of spatial, linear, aerial and relief aspects of the basin and slope contribution (Nag and Chakraborty 2003) to understand the run-off characteristics of the area and potentiality of watershed deterioration. The linear morphometric parameters are mean bifurcation ratio (R_b), length of overland flow (L_o), and aerial or shape morphometric parameters are drainage density (D_d), drainage texture (D_t), stream frequency (F_s), drainage intensity (D_i), drainage factor (D_f), circularity ratio (R_c), elongated ratio (R_e), shape factor (B_s), compactness coefficient (C_c); relief aspects are relative relief, and other three parameters are soil loss, sediment yield and sediment production rate calculated as suggested by Jaiswal et al. (2014) and Smith (1950).

Computation of Weights

The principle of AHP theory lies on uncertainty in decision that creates basis of applying fuzziness in AHP. The AHP for MCDS constructs a matrix of pair-wise comparisons

(ratios) between the factors affecting the decision. A numerical value between 0 and 9 has been suggested by Saaty to indicate how one criterion is important than other as stated in Jaiswal et al. (2014). The degree of importance between two factors in the matrix is filled on the basis of field experience, survey results, judgment of decision makers and result reported by researchers (Jaiswal et al. 2014). The size of comparison matrix in AHP may be a square matrix with size equal to number of parameters (n) considered for decision. In FAHP method, the comparison matrix can be fuzzified by triangular or trapezoidal membership functions (Kordi 2008) and that can be expressed as $\bar{A} = [\bar{a}_{i,j}]$ in the following matrices form:

$$[\bar{a}_{i,j}] = |\sigma_{i,j}, \varepsilon_{i,j}, \tau_{i,j}, \mu_{i,j}| \quad (1)$$

where i and j may vary from 1 to n

The members of fuzzy matrix can be described by σ , ε , τ and μ which are four parts of the fuzzy membership function in such a way that $0 < \sigma \leq \varepsilon \leq \mu$. Buckley (1985) proved, if \bar{A} is consistent then fuzzy matrix = $[\bar{a}_{i,j}]$ will also be consistent. The weights from fuzzy matrix can be computed either by geometric mean method or λ_{\max}

Fig. 6 Soil texture map of the study area (Nagwan watershed)

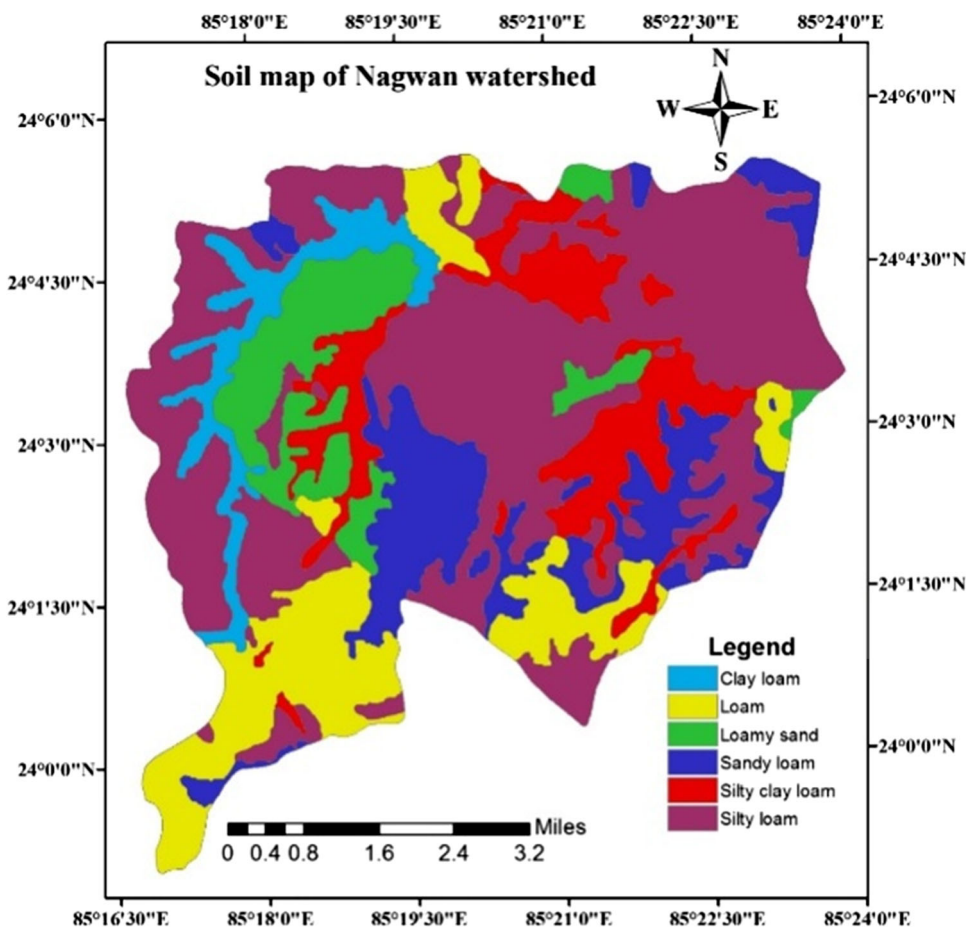


Table 2 Random consistency index for different matrix size

Size of matrix	8	9	10	11	12	13	14	15
Random consistency ratio (RI)	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

methods, in which both provide nearly same results for small consistency ratio. The normalized principal eigenvector, which is called priority vector, is used in λ_{\max} to assign the weights for different parameters. In the present case, geometric mean method is used to compute fuzzy membership function for the weights using following equations:

$$\sigma_i = \left[\prod_{j=1}^n \sigma_{ij} \right]^{1/n} \quad \text{and} \quad \sigma = \left[\sum_{i=1}^n \sigma_i \right] \tag{2}$$

$$\varepsilon_i = \left[\prod_{j=1}^n \varepsilon_{ij} \right]^{1/n} \quad \text{and} \quad \varepsilon = \left[\sum_{i=1}^n \varepsilon_i \right] \tag{3}$$

$$\tau_i = \left[\prod_{j=1}^n \tau_{ij} \right]^{1/n} \quad \text{and} \quad \tau = \left[\sum_{i=1}^n \tau_i \right] \tag{4}$$

$$\mu_i = \left[\prod_{j=1}^n \mu_{ij} \mu_{ij} \right]^{1/n} \quad \text{and} \quad \mu = \left[\sum_{i=1}^n \mu_i \right] \tag{5}$$

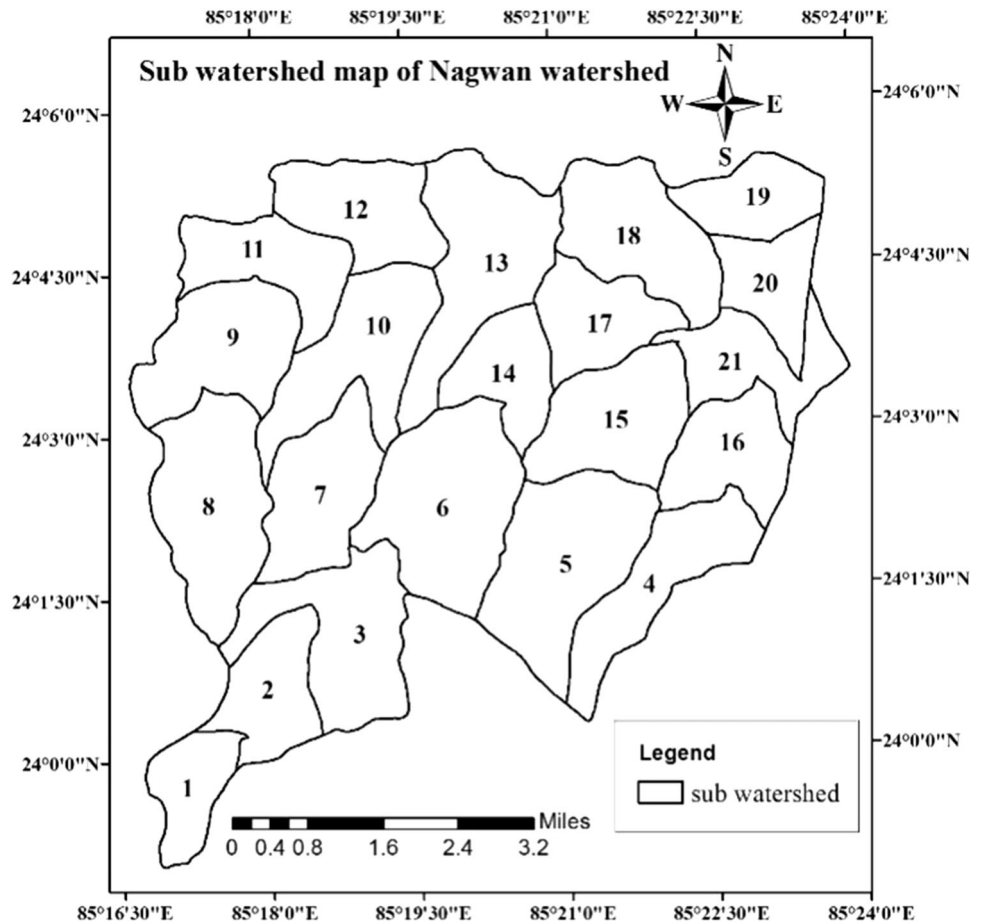
The fuzzy membership function describing the weights of different parameters is defined by the following equation:

$$\bar{x}_i = \varphi(x_i) = \left[\frac{\sigma_i}{\mu}, \frac{\varepsilon_i}{\tau}, \frac{\tau_i}{\varepsilon}, \frac{\mu_i}{\sigma} \right] \tag{6}$$

The centroid method is employed to de-fuzzify the membership function, which gives crisp weights for all the parameters used in the analysis. The formula used to compute crisp weights x_i of membership function $\varphi(x_i)$ between the limits σ and μ (Zimmermann 1934) is

$$x_i = \frac{\int_{x_i=\sigma}^{\mu} \varphi(x_i) x_i dx}{\int_{x_i=\sigma}^{\mu} \varphi(x_i) dx} \tag{7}$$

Fig. 7 Sub-watersheds of Nagwan watershed



Consistency Check

The comparative importance between the members in fuzzy-AHP is subjective that depends on personal ability or understanding about the subjects and feedback from different sources. Therefore, a consistency check is employed to judge the consistency of decisions in FAHP analysis. The consistency of judgment is checked by estimating consistency ratio (CR) computed using the following equation:

$$CR = \frac{CI}{RI} \times 100 \tag{8}$$

where CI is the consistency index and RI is the random consistency index. The consistency index depends on size of matrix (number of parameters), and the consistency in decisions is estimated using the following equation:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{9}$$

where λ_{max} is the principal eigen value (Han and Tsay 1998; Malczewski 1999) that can be computed approximately by calculating the product of the pair-wise comparison matrix and the weight vectors, de-fuzzifying this

matrix and adding all elements of the resulting vector. A unitless random consistency index (RI) depends on matrix size (n), after generating reciprocal matrix of various sizes (Saaty 1980). The average RI for different sizes of matrix is given in Table 2.

If CR is less than 10%, the subjective evaluation about decision is considered as consistent.

Priority assessment

The EHPs considered may vary in the diverse ranges, and therefore, there is a need to bring down those on same scale. Normalization approach to restrict the variation in the range from 0 to 1 is applied using Eq. (10) as follows:

$$W_{ij} = \frac{EHP_{ij} - OLB_i}{OUB_i - OLB_i} \tag{10}$$

where W_{ij} is the normalized value of i th EHP of j th watershed; OUB_i and OLB_i are the original upper and lower bound for i th EHP. EHP_{ij} is the original value of i th EHP for j th sub-watershed. The final priority (F_j) of a watershed in the present FAHP-based MCDS is computed by summing the product of normalized value of EHP and

its corresponding weights obtained from FAHP analysis, as follows:

$$F_j = \sum_{i=1}^n x_i * W_{ij} \tag{11}$$

After getting the final priorities of all sub-watersheds in the study area, they are grouped in different priority classes for deciding the intensity and urgency of soil conservation measures.

Results

Nagwan watershed was divided into 21 sub-watersheds named as SW-1 to SW-21 (Fig. 7). An analysis of the configuration of stream pattern revealed that the complex pattern is found in Fig. 8. The land uses and land cover were classified into eight classes, namely agriculture land (with crops—7.32 km² and without crops—45.99 km²), barren land—1.25 km², built-up land—2.43 km², dense

forest—1.64 km², grass land—24.34 km², open forest—5.50 km², shrubs—2.15 km² and water body—1.48 km² (Fig. 9). For evolution of FAHP-based MCDS, weights of each erosion hazard parameter (EHP) using FAHP method, priority calculation using weights of EHP and their corresponding normalized intensity and finally categorization of different sub-watersheds in different groups for soil conservation measures are determined.

EHPs computation

Thirteen EHPs, viz. USLE model (SL), Sy, SPR, R_{hp}, D_i, D_d, D_f, F_s, D_t, R_c, L_o, C_c and R_b, have been computed as suggested in Jaiswal et al. (2014) and Smith (1950), and result is shown in Table 3. For computation of soil loss from sub-watersheds, the R-factor, K-factor, LS-factor, C-factor and P-factor of the watershed were found as 540.92 MJ mm ha⁻¹ h⁻¹ year⁻¹, 0.19 to 0.34 Mg h MJ⁻¹ mm⁻¹, 0.03 to 19.54, 0.009 to 1.000 and 0.80 to 0.1, respectively. These factors are combined in a

Fig. 8 Drainage map of study area (Nagwan watershed)

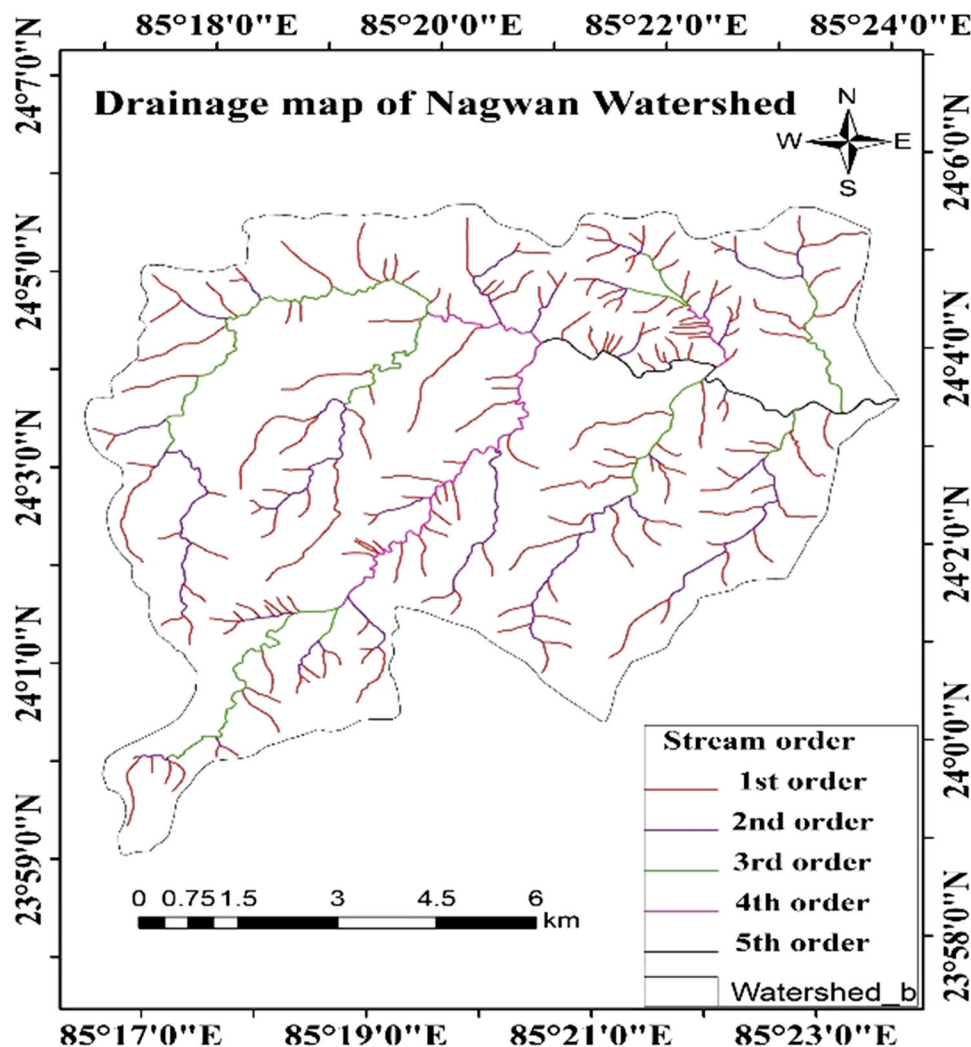


Fig. 9 Land use/land cover map of the study area (Nagwan watershed)

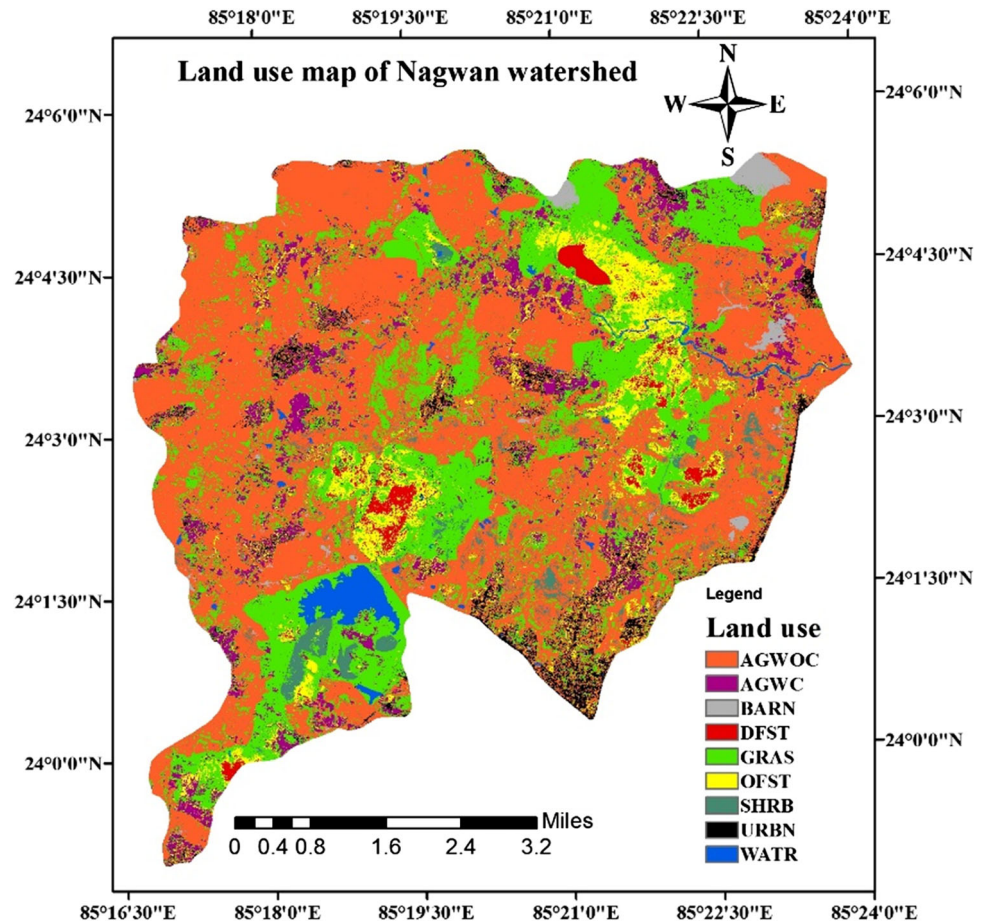


Table 3 Variation of different EHPs in sub-watersheds of Nagwan watershed

EHP with unit	Range	Maximum		Minimum	
		Value	Watershed	Value	Watershed
Soil loss (SL) (t/ha/year)	33.67–6.52	33.67	SW-21	6.52	SW-2
Sediment yield (Sy) (mm ³ /year/km ²)	0.80–0.34	0.80	SW-3	0.34	SW-17
SPR (ha-m/100 km ² /year)	2.41–0.07	2.41	SW-14	0.07	SW-21
Relative relief	1.27–0.39	1.27	SW-17	0.39	SW-21
Drainage intensity (D_i)	2.06–0.64	2.06	SW-18	0.64	SW-10
Drainage density (D_d) (km/km ²)	3.77–1.44	3.77	SW-18	1.44	SW-9
Drainage factor (D_f)	0.94–0.31	0.94	SW-1	0.31	SW-10
Stream frequency (F_s) (km ⁻²)	7.79–1.04	7.79	SW-18	1.04	SW-9
Drainage texture (D_t) (km ⁻¹)	3.99–0.51	3.99	SW-18	0.51	SW-9
Circularity ratio (R_c)	0.71–0.25	0.71	SW-19	0.25	SW-21
Length of overland flow (L_o) (m)	348.42–132.59	348.42	SW-9	132.59	SW-18
Compactness constant (C_c)	1.99–1.18	1.99	SW-21	1.18	SW-19
Mean bifurcation ratio (R_b)	7–2.25	7	SW-7	2.25	SW-21

number of formulas in USLE, which returns a single number, the computed soil loss per unit area, equivalent to predicted erosion in $t\ ha^{-1}\ year^{-1}$ (Wischmeier and Smith 1978). Once all erosive factor maps were generated, these maps were included in a Raster operation of multiplication

in ArcGIS; therefore, a soil loss map was obtained (Fig. 10). The mean annual soil loss was predicted as 26.81 t/ha/year.

For calculation of sediment production rates from different sub-watersheds, the empirical model proposed by

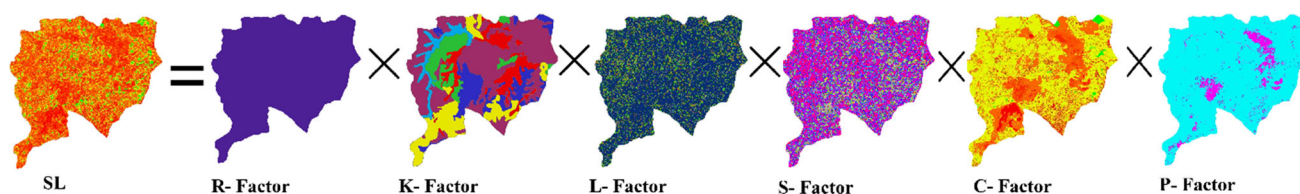


Fig. 10 Soil erosion map of the watershed

Table 4 Variation of consistency ratio with increasing parameters

No. of parameters	Triangular	Trapezoidal		
		Narrow	Medium	Wide
9	9.108	59.48	7.393	4.64
10	10.27	10.26	10.44	13.65
11	9.84	9.84	10.02	14.49
12	9.89	9.88	10.07	14.65
13	9.45	9.44	9.62	13.89
14	9.48	9.47	9.66	13.84
15	9.60	9.59	9.79	13.82

Jose and Das (1982) and further elaborated by Mishra et al. (1984) that uses geomorphological parameters was used. The sediment yield was estimated by a simple regression model (Rao and Mahabaleswara 1990) using rainfall, slope, land use and some other geomorphological parameters. The variation of EHPs for different sub-watersheds is given in Table 3.

FAHP-Based Prioritization

Considering the huge investment in the watershed development program, it is important to plan the activities on priority basis for achieving relevant fruitful results. Such an

Table 5 Fuzzy matrix for pair-wise comparison of 13 EHP's for narrow trapezoidal function

NT	SL	Sy	SPR	Rhb	D_i	D_d	D_f	F_s	D_t	R_c	L_o	C_c	R_b
SL	[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[6 6.5 7.5 8]	[8 8.5 9.5 10]	[8 8.5 9.5 10]	[8 8.5 9.5 10]	[8 8.5 9.5 10]
Sy		[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[6 6.5 7.5 8]	[8 8.5 9.5 10]	[8 8.5 9.5 10]	[8 8.5 9.5 10]
SPR			[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[6 6.5 7.5 8]	[8 8.5 9.5 10]
R_{hb}				[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[4 4.5 5.5 6]	[6 6.5 7.5 8]
D_i					[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]
D_d						[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]
D_f							[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[4 4.5 5.5 6]
F_s								[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]
D_t									[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]
R_c										[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]	[2 2.5 3.5 4]
L_o											[1 1 1 1]	[2 2.5 3.5 4]	[2 2.5 3.5 4]
C_c												[1 1 1 1]	[2 2.5 3.5 4]
R_b													[1 1 1 1]

Table 6 Fuzzy matrix of geometric mean and fuzzy matrix of the final weight for narrow trapezoidal fuzzy function

EHP	Fuzzy matrix of geometric mean				Fuzzy matrix of the final weight				Final weight (W_i)
	σ_i	ε_i	τ_i	μ_i	σ	ε	τ	μ	
SL	3.912	4.379	5.266	5.695	0.184	0.216	0.287	0.329	0.254
S _y	2.997	3.308	3.885	4.157	0.141	0.163	0.212	0.240	0.189
SPR	2.063	2.275	2.654	2.827	0.097	0.112	0.145	0.163	0.129
R _{hb}	1.758	1.881	2.098	2.196	0.083	0.093	0.114	0.127	0.104
D _i	1.238	1.326	1.470	1.532	0.058	0.065	0.080	0.088	0.073
D _d	1.173	1.205	1.255	1.277	0.055	0.059	0.068	0.074	0.064
D _f	0.948	0.956	0.966	0.969	0.045	0.047	0.053	0.056	0.050
F _s	0.808	0.793	0.769	0.759	0.038	0.039	0.042	0.044	0.041
D _t	0.667	0.640	0.598	0.581	0.031	0.032	0.033	0.034	0.032
R _c	0.569	0.530	0.473	0.452	0.027	0.026	0.026	0.026	0.026
L _o	0.474	0.431	0.370	0.348	0.022	0.021	0.020	0.020	0.021
C _c	0.413	0.364	0.298	0.275	0.019	0.018	0.016	0.016	0.017
R _b	0.300	0.263	0.212	0.194	0.014	0.013	0.012	0.011	0.012

Table 7 Weightage values for thirteen erosion hazard parameters

EHPs	SL	S _y	SPR	R _{hp}	D _i	D _d	D _f	F _s	D _t	R _c	L _o	C _c	R _b
Weight (X_i)	0.254	0.189	0.129	0.104	0.073	0.064	0.050	0.041	0.032	0.026	0.021	0.017	0.012

effort also facilitates the problematic areas to arrive at optimal solutions. The resource-based approach is found to be realistic for watershed prioritization, as it involves an integrated approach. For prioritization of sub-watersheds, fuzzy analytical hierarchy process (FAHP) along with different number of erosion hazard parameters (EHP's) from 9 to 15 was used to prioritize the watershed under reference. The fuzzy matrix representing triangular, narrow trapezoidal, medium trapezoidal and wide trapezoidal membership functions was used to assess the uncertainty in the decision-making. The geometric mean method (Eqs. 2–6) was used for computing and fuzzy assigning weightage to the matrix. The crisp weightage to all EHPs was determined by centroid method de-fuzzification of matrix weightage. The fuzzy matrix of geometric mean [$\sigma_i, \varepsilon_i, \tau_i, \mu_i$] and fuzzy membership function of the final weightage towards triangular and trapezoidal with narrow, medium and wide trapezoidal shape functions were computed in respect of from 9 to 15. The consistency ratios of fuzzy-AHP decision matrix for triangular, narrow rectangle and wide rectangle functions were computed for different sets of EHP's from 9 to 15 and are present in Table 4.

It has been observed that when the number of parameters exceeds 10, no significant difference is noticed in consistency ratio. The best weightage of the EHPs was found to be assorted with number 13 parameters having narrow trapezoidal shape with consistency ratio or as 9.44,

it has also the smallest consistency ratio. As such this was taken as base for determining the final priority scores for sub-watershed. The fuzzy matrixes for pair-wise comparison of narrow trapezoidal function of 13 EHP's are present in Table 5.

Fuzzy matrix of geometric mean and fuzzy matrix of the final weightage of 13 EHP's in respect of narrow trapezoidal fuzzy function are shown in Table 6. The computed weights for thirteen erosion hazard parameters are present in Table 7.

Having the weightage assigned to 13 erosion hazard parameters (EHPs) using FAHP with narrow trapezoidal shape, the final priority of each sub-watershed was computed using normalized values of EHPs and their respective weightage. The computed values of priority assessment for different sub-watersheds are given in Table 8, which varied from 0.278 to 0.627. Based on the cluster of the distribution, scatter graph in Fig. 11 was divided into five different ranges of prioritization, i.e. very high, high, medium, low and very low, as present in Table 9.

The analysed results of sub-watersheds' prioritization using FAHP (Table 9 and Fig. 12) depicted that of 21 sub-watersheds, 5 sub-watersheds (SW-18, SW-3, SW-17, SW-19 and SW-20) covering a total area of 19.02 km² and 4 sub-watersheds (SW-21, SW-16, SW-6 and SW-14) of total area 16.89 km² could be put under very high and high prioritization category in immediate execution of

Table 8 Normalization of EHPs and priority assessment of sub-watersheds

SW	SL 0.254	Sy 0.189	SPR 0.129	R_{hp} 0.104	D_i 0.073	D_d 0.064	D_f 0.050	F_s 0.041	D_t 0.032	R_c 0.026	L_o 0.021	C_c 0.017	R_b 0.013	Final priority
SW-1	0.002	0.005	0.854	0.409	0.811	0.200	1.000	0.352	0.192	0.842	0.601	0.090	0.000	0.333
SW-2	0.000	0.350	0.901	0.163	0.164	0.282	0.168	0.117	0.049	0.610	0.490	0.239	0.579	0.282
SW-3	0.043	1.000	0.389	0.557	0.777	0.374	0.705	0.443	0.325	0.287	0.388	0.541	0.395	0.482
SW-4	0.236	0.252	0.441	0.285	0.203	0.009	0.516	0.047	0.001	0.339	0.971	0.481	0.579	0.282
SW-5	0.161	0.359	0.883	0.249	0.348	0.174	0.484	0.156	0.209	0.882	0.641	0.068	0.789	0.370
SW-6	0.135	0.445	0.822	0.240	0.513	0.502	0.340	0.375	0.489	0.953	0.273	0.031	0.474	0.404
SW-7	0.202	0.125	0.893	0.362	0.231	0.179	0.335	0.112	0.090	0.741	0.634	0.150	1.000	0.329
SW-8	0.287	0.244	0.905	0.130	0.306	0.088	0.544	0.108	0.128	0.744	0.794	0.148	0.158	0.354
SW-9	0.234	0.124	0.936	0.115	0.062	0.002	0.313	0.001	0.000	0.827	1.000	0.098	0.368	0.285
SW-10	0.341	0.317	0.286	0.010	0.001	0.259	0.000	0.040	0.002	0.253	0.519	0.584	0.789	0.240
SW-11	0.236	0.156	0.706	0.095	0.777	0.243	0.887	0.364	0.222	0.444	0.540	0.376	0.158	0.360
SW-12	0.062	0.143	0.879	0.212	0.348	0.042	0.679	0.104	0.081	0.859	0.892	0.080	0.789	0.300
SW-13	0.153	0.472	0.787	0.262	0.447	0.242	0.518	0.224	0.197	0.414	0.542	0.404	0.263	0.379
SW-14	0.506	0.149	0.999	0.216	0.219	0.160	0.340	0.101	0.035	0.716	0.663	0.166	0.368	0.397
SW-15	0.003	0.153	0.749	0.492	0.385	0.345	0.348	0.240	0.253	0.981	0.419	0.018	0.263	0.301
SW-16	0.266	0.324	0.962	0.337	0.328	0.709	0.076	0.352	0.248	0.713	0.135	0.168	0.211	0.410
SW-17	0.196	0.023	0.889	0.997	0.912	0.558	0.629	0.631	0.473	0.864	0.231	0.078	0.298	0.480
SW-18	0.034	0.481	0.847	0.568	1.003	1.000	0.377	0.999	0.999	0.888	0.000	0.065	0.203	0.524
SW-19	0.223	0.539	0.801	0.271	0.765	0.316	0.767	0.403	0.273	1.008	0.450	0.005	0.105	0.467
SW-20	0.485	0.310	0.780	0.523	0.494	0.336	0.467	0.288	0.129	0.507	0.428	0.319	0.000	0.461
SW-21	1.000	0.125	0.000	0.005	0.569	0.063	0.956	0.186	0.028	0.004	0.845	1.005	0.000	0.415

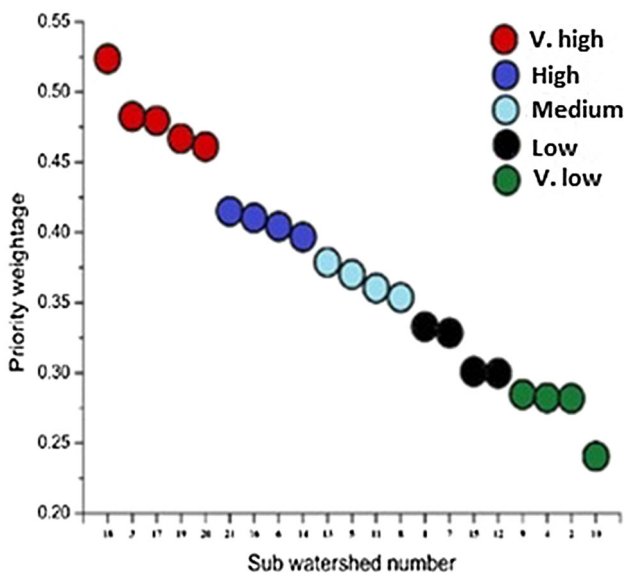


Fig. 11 Scattered graph for priority classes

catchment area treatment plan. The remaining 11 sub-watersheds categorized of medium, low and very low priorities can have implementation of soil conservation measures at later stage. However, the agronomical and/or biological treatment is recommended to pursue and continue for such prioritized sub-watersheds.

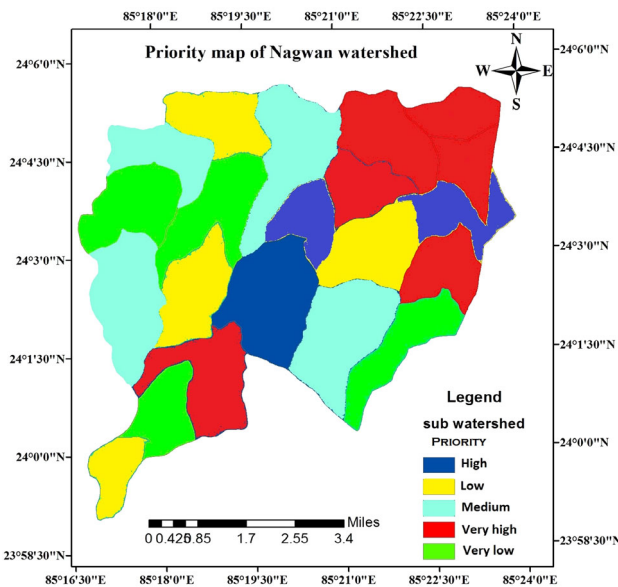
The analysis revealed that the combination of soil loss from USLE model (SL), sediment yield (SY), sediment production rate (SPR) and relative relief has contributed nearly 66% weight in decision-making and those can be considered as the super parameters in prioritization work.

Conclusions

Prioritization of sub-watersheds for planning and management of soil conservation measures can significantly economize the cost of catchment area treatment. A fuzzy analytical hierarchical process (FAHP)-based multi-criteria decision support model (MCDSM), as an extension of Saaty’s AHP by overcoming its uncertainty in selection of environmentally degraded sub-watersheds, has been developed for prioritizing the areas in a catchment/watershed for soil conservation measures. Instead of incorporating large number of parameters, it is advisable to go for selective and relevant parameter while applying MCDSM method for prioritizing watersheds. The model considered the weights of thirteen erosion hazards parameters (EHPs), namely soil loss by USLE, mean bifurcation ratio (R_b), drainage density (D_d), drainage texture (D_t), stream frequency (F_s), drainage intensity (D_i), sediment production rate (SPR), sediment yield (V_s), circularity ratio (R_c),

Table 9 Details of sub-watersheds as per priority classes derived using FAHP

S. no	Priority class	Range of the final priority	No. of sub-watershed	Series of sub-watersheds	Total represented area (sq.km)
1.	V. high	Exceeding 0.45	5	SW-18, SW-3, SW-17, SW-19, SW-20	19.02
2.	High	0.38 to 0.45	4	SW-21, SW-16, SW-6, SW-14	16.89
3.	Medium	0.34 to 0.38	4	SW-13, SW-5, SW-11 SW-8	22.89
4.	Low	0.29 to 0.34	4	SW-1, SW-7, SW-15, SW-12	15.69
5.	V. low	< 0.29	4	SW-9, SW-4, SW-2, SW-10	17.83
Total					92.32

**Fig. 12** Priority map of Nagwan watershed

compactness constant (C_c), elongation ratio (R_e), length of overland flow (L_o), drainage factor (D_f) and relative relief (R_{hp}) with triangular, narrow rectangular, medium rectangular and wide rectangular fuzzy membership functions. The geometric mean method for weight matrix and centroid method for crisping of weights have been considered for determining weights of EHPs. The model can successfully be used in prioritizing the areas in any watershed for soil conservation measures.

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