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Ascertaining Erosion Potential of Watersheds using Morphometric and Fuzzy-Analytical Hierarchy Processes: A Case Study of Agrani River Watershed, India

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ABSTRACT

The dryland watersheds are particularly vulnerable to degradation, especially by soil erosion. The morphometric indices of such river watersheds quantitatively describe the process of soil-erosion and development. Prioritizing such watersheds for the conservation of existing natural resources by identifying erosion risk areas is crucial for sustainable development. The present study proposes an effective multicriteria decision support model (MCDSM) known as the fuzzy analytical hierarchical process to identify and prioritize the erosion-prone sub-watersheds of the Agrani river. The methodology is developed by integrating the Fuzzy-AHP method, basin morphometric analysis and Geographic Information System (GIS). The ranks assigned to all sub-watershed using final score derived from the Fuzzy-AHP process. These sub-watersheds categorized into five levels of prioritization based on Fuzzy-AHP scores as very low, low, medium, high, and very high for the management and conservation of soil. The result illustrates that eleven sub-watersheds covering approximately 68.62% of the Agrani River watershed falls in the medium, high, and very high, erosion risk areas. The current research shows that the fuzzy-AHP model, drainage morphometry, and GIS approach can be effectively used in identifying and prioritizing crucial sub-watersheds for better management practices and conservation of natural resources.

INTRODUCTION

Soil erosion is a prevalent issue that impacts agricultural productivity as well as creates several environmental challenges. In India, this scenario is very prevalent, where the spatial extension of the semi-arid land is the largest, covering about 34% of the total area of the land surface (Ramarao et al. 2019), which is continuously expanding by anthropogenic activities and climatic change. Millions of Indian farmers in semi-arid regions depend on a traditionally organized rainfed agricultural system that further intensifies the soil erosion process. Measures of erosion control must be taken into consideration while conserving the natural resources of the semi-arid area to improve land production (Huibers 1985). A river watershed is examined as an essential planning unit for the management of water and land resources because of the integrated relationship between soil, vegetation, and the water cycle, and therefore prioritizing sub-watersheds (SWs) for sustainable development is critical.

In the process of prioritizing SWs, the morphometric analysis of the watershed can play a significant role. This analysis quantitatively explains drainage systems to understand soil erosion properties (Arabameri et al. 2020). The quantitative definition of the structure and network of the drainage basin is also instrumental in studies such as hydrological modelling, watershed management, and natural resources management (Choudhari et al. 2018). Applications of morphometric analysis have shown to be of significant benefit in flood risk assessment (Prasad and Pani 2017; Karmokar and De 2020; Pathare and Pathare 2020), identifying potential groundwater zones (Choudhari et al. 2018), watershed management (Kudnar 2020), and plant growth potential (Kadam et al. 2017).

In this study, the analysis of basin morphometry was carried out to identify SWs that are vulnerable to soil erosion. Some of the earlier studies have been carried out where river morphometric indices were utilised to determine potential soil erosion areas at sub-watershed levels using various models and methods (Biswas et al. 1999; Chopra et al. 2005; Javed et al. 2009; Magesh et al. 2013; Nitheshnirmal et al. 2019b; Kudnar 2020; Radwan et al. 2020).

Numerous researchers dealt with the issue of identifying areas susceptible to soil erosion that has priority for conservation using various decision models. Recently, methods of decision making have enhanced remarkably. The multicriteria decision-making (MCDM) methods are extensively tested and proved to be beneficial in solving spatial problems (Javanbarg et al. 2012) Some of the recent studies have implemented various MCDM methods to identify erosion-prone SWs and prioritize them for conservation (Aher et al. 2013; Jaiswal et al. 2014, 2015; Vuleviæ et al. 2015; Rahaman et al. 2015; Ahmed et al. 2018; Nitheshnirmal et al. 2019a; Andualem et al. 2020; Arabameri et al. 2020; Hembram and Saha 2020).

The Analytical Hierarchical Process (Saaty 1988) is extensively adopted MCDSM and effectively used to resolve difficult spatial decision-making problems. (Vuleviæ et al. 2015; Elmahmoudi et al. 2019; Halefom and Teshome 2019). However, this method is usually criticized because of its uneven scale of decisions and its inefficiency in handling the vagueness and inherent uncertainty of the pairwise comparison process (Deng 1999). Buckley, in 1985 expanded Saaty's AHP to handle the subjectivity and vagueness in the pairwise comparison process. Buckley's fuzzy hierarchical analysis allows users to utilize fuzzy ratios in place of crisp ratios. Some of the researchers have incorporated Fuzzy-AHP model to resolve the difficulty of determining areas vulnerable to various natural risks that have priority for conservation (Li et al. 2009; Aher et al. 2013; Rahaman et al. 2015; Jaiswal et al. 2015; Ahmed et al. 2018; Uvaraj and Neelakantan 2018; Hembram and Saha 2020; Jothimani et al. 2020).

The integration of Fuzzy-AHP with the geospatial technology can increase the precision of the study and can also handle complex issues efficiently (Ali et al. 2019). The main objective of this study is to exhibits how the GIS and Fuzzy-AHP integrated approach can effectively be used to solve the spatial problems.

STUDY AREA

The Agrani river is a tributary of the Krishna river, located across

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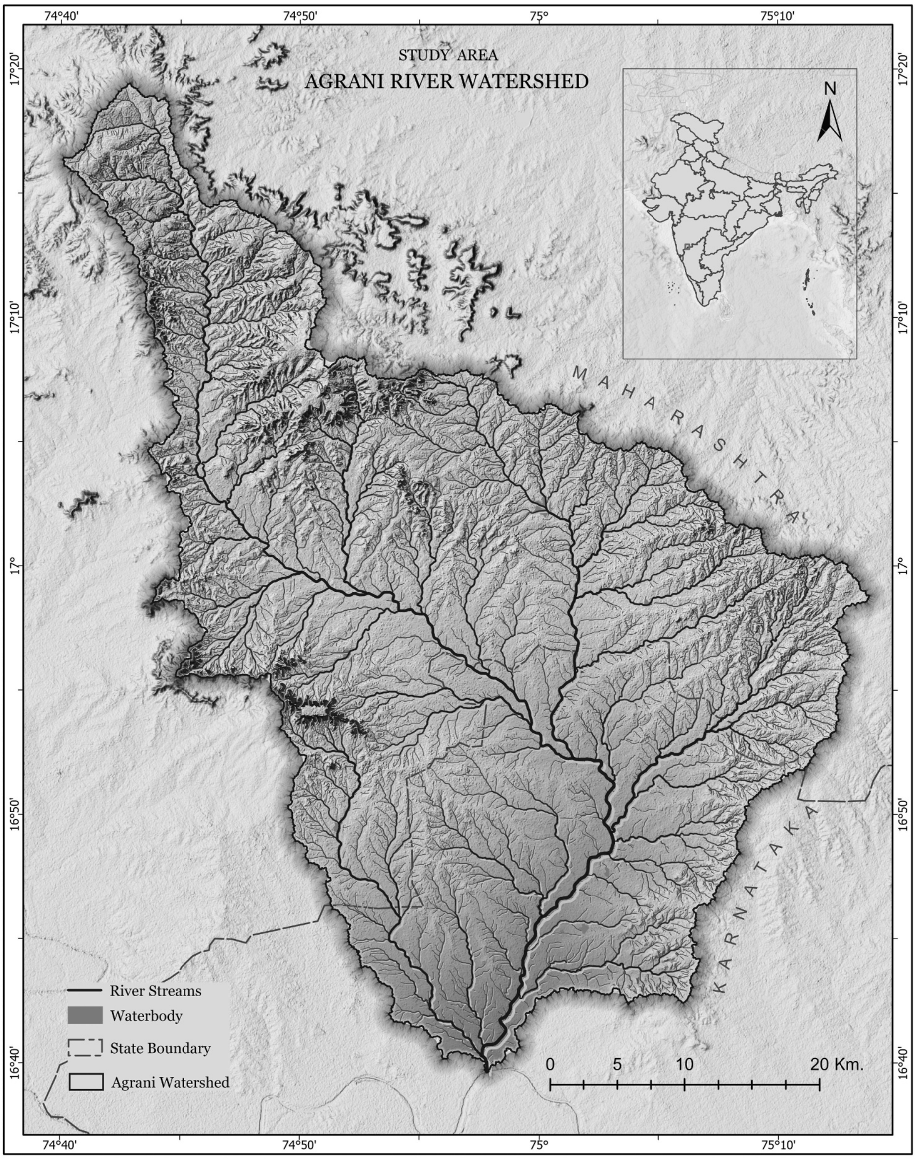

Fig.1. Location and drainage map of the Agrani River.

the border of the Maharashtra and the Karnataka states of India, with an area of 1929.38 km^2. The extent of the watershed is between 74.66º to 75.23º E and 16.66º to 17.32º N (Fig.1). The highest and lowest elevation in the watershed is 923m and 522m above the MSL, respectively, representing a gentle slope from north to south. Climatically, this area comes in the semi-arid region that receives an average rainfall of 400 to 800 mm per annum. Due to inadequate water availability, agriculture is mainly rainfed. Farmers in this region generally cultivate kharif and rabi crops from June to October and November to March, respectively. The Agrani river is a lifeline of this drought-prone area, which extends across the Maharashtra and the Karnataka border. The prevalent issue in this region is soil erosion induced by surface runoff and intensified by scanty vegetation cover.

MATERIALS AND METHODOLOGY

In this study prioritization of the erosion prone SWs of Agrani river was performed based on the integrated use of the drainage morphometric analysis, Fuzzy-AHP, and GIS techniques.

A multi-tiered methodology has been implemented to attain aims and objectives of the research that comprises five steps: (1) delineation of river watershed, sub-watersheds, and drainage network, (2) selection and computation of different morphometric parameters, (3) application of the Fuzzy-AHP method and 4) identification & prioritization of the SWs using Fuzzy-AHP score. The materials and methods utilized in this research study have explained below and illustrated in Fig.2.

Delineation of River Watershed, Sub-watersheds, and Stream Network

The Survey of India toposheets (SOI) and SRTM DEM was utilized for extraction of the watershed, sub-watersheds, and the stream network. The UTM projection and WGS-84 datum was assigned to the toposheets and DEM. The stream network was first digitized from SOI toposheets (Scale: 1:50,000) and subsequently used for reconditioning the SRTM DEM in the Arc Hydro tool. This procedure trained the DEM to generate accurate result. The reconditioned DEM was used for the delineation of streams and sub-watersheds in ArcGIS software. The Agrani River watershed was divided into twenty-two SWs named as SW1 to SW22. The smallest (SW7) and the largest (SW3) sub-watersheds have an area of 15.52 km^2 and 346.33 km^{2,} respectively.

Calculation of Different Morphometric Parameters

The resultant database of drainage network and sub-watersheds was utilized in morphometric analysis using standard formulae (Table 1). The length of the basin, and stream, stream order, perimeter,

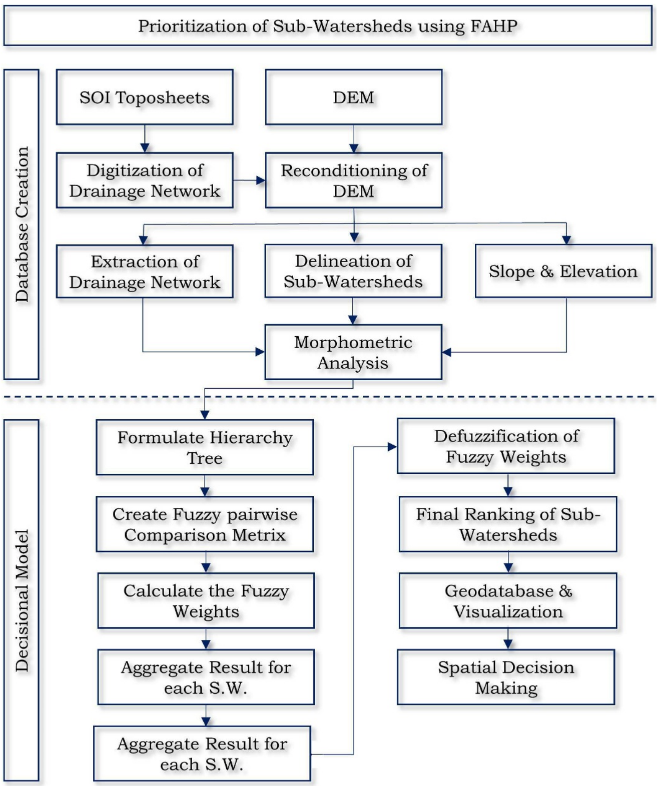

Fig. 2. Research methodology flowchart.

area, elevation data were computed using ArcGIS software. This data further employed in the morphometric analysis, for instance, drainage density (Dt), drainage texture (Dt), stream frequency (F_S), bifurcation ratio (R_b), the average length of overland flow (Lg), elongation ratio (R_c), shape factor (S_f), circularity ratio (R_c), form factor (F_f) and compactness coefficient (C_C) (Biswas et al. 1999). These ten parameters were examined as parameters for the assessment of erosion risk.

Application of the Fuzzy-AHP

Saaty in 1988 introduced the Analytical Hierarchy Process (AHP) concept for solving complex decision making problems (Huynh et al. 2018). The basic AHP carries ambiguity for individual perception, which has been improved by adding the concept of a fuzzy set. Fuzzy-AHP has become a popular method that assists in making decisions on complex multicriteria problems. The fuzzy matrix weights were computed using the Buckley's (1985) Geometric Mean Method. Subsequently, the resulted fuzzy weights of all fuzzy matrix were combined to evaluate the final fuzzy weights for SWs. The SWs were allocated to the highest to lowest ranks using the final fuzzy weights. The calculation steps are interpreted as follows:

Table 1. Morphometric parameters and formula applied for computation

Sl. No.	Morphometric parameters	Formula	Reference
1	Drainage Texture (*Dt*)	$Dt = N_u / P$	(Horton, 1945)
2	Bifurcation Ratio (R_b)	$R_b = N_u / N_u+1$	(Schumm & Schumm, 1956)
3	Stream frequency (F_S)	$F_S = \Sigma^k_{i=1} N_u / A$	(Horton, 1932)
4	Drainage density (*Dd*)	$Dd = \Sigma^k_{i=1} \Sigma^N_{i=0} L_u/A$	(Strahler, 1964)
5	Shape Factor (S_f)	$S_f = Lb^2/A = 1/F_f$	(Strahler, 1964)
6	Circularity ratio (R_c)	$R_c = 4\pi A / P^2$	(Miller, 1953)
7	Elongation ratio (*Re*)	$Re = Dc/L_b = 1.129\times\sqrt{(A/L_b)}$	(Schumm et al., 1956)
8	Form factor (F_f)	$F_f = A / Lb^2$	(Horton, 1932)
9	Compactness Coefficient (C_C)	$C_C = 0.282 \times P/\sqrt{A}$	(Horton, 1945)
10	Avg. Length of Overland Flow (*Lg*)	$Lg = 1/2 \times Dd$	(Horton, 1945)

Constructing Fuzzy Pairwise Comparison Matrices

AHP pairwise comparison matrices of each criterion were constructed using the fuzzification method. The following steps were performed while constructing the pairwise comparison matrices.

1. The triangular membership function (TFN) was used in the calculation (Fig. 3) to determine the preferences since decision-makers find it easy to use and calculate (Elmahmoudi et al. 2019).

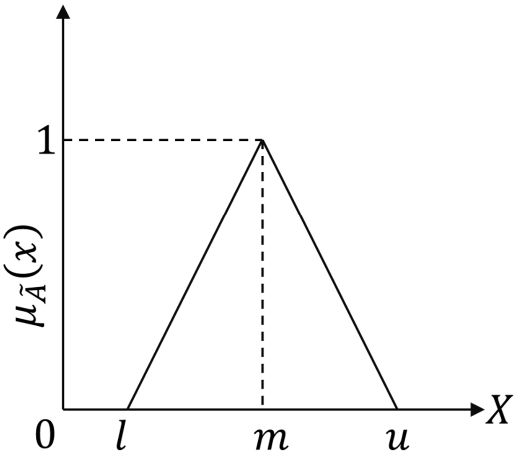

Fig.3. The membership of a Fuzzy Triangular Number (FTN)

A TFN is expressed as $\tilde{A} = (l, m, u)$ where $l \le m \le u$. The criteria l,m, and u represent the lowest possible value, the best-assuring value, and the possible upper value, respectively (Kannan et al. 2013).

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l), & 1 \le x \le \text{m}, \\ (u-x)/(u-m), & \text{m} \le x \le \text{u}, \\ 0, & < l\, x > l, \end{cases} \quad (1)$$

where l = lower valuer, m = middle value and u is the upper value of a fuzzy number.

2 Operational laws were executed as follows:
Let $\tilde{A}_1 = (l_1, m_1, U_1)$ and $\tilde{A}_2 = (l_2, m_2, U_2)$ the 2 fuzzy triangular numbers. Then, operational laws were translated using equations 2, 3, 4, and 5:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (3)$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1\, l_2, m_1\, m_2, u_1\, u_2) \quad (4)$$

$$\tilde{A}_1^{-1} = (l_1, m_1, u_1) = (1/u_1, 1/m_1, 1/,l_1) \quad (5)$$

3 The corresponding values from the AHP scale were transformed into the Fuzzy-AHP scale value (Table 2).

Calculation of the Weights

The following steps of Buckley's Fuzzy-AHP method were performed to calculate the criteria weights.

Table 2. Triangular scale for fuzzy number conversion

Intensity of Importance	Triangular Fuzzy Numbers	Definition
1	(1,1,1)	Equally influenced
3	(2,3,4)	Moderately influenced
5	(4,5,6)	Strongly influenced
7	(6,7,8)	Very Stronglyinfluenced
9	(9,9,9)	Extreme influenced

I. A fuzzy geometric mean calculated through the geometric mean method as follows:

$$\tilde{r}_i = (\tilde{a}_{i1}, \tilde{a}_{i2}, \dots, \tilde{a}_{in})^{\frac{1}{n}} \tag{6}$$

Consequently, the fuzzy geometric mean value $\tilde{r}_i$ is formulated as follows.

$$\tilde{r}_i = (lr_i, mr_i, ur_i) = \left(\left(\prod_{j=1}^{n} l_{ij} \right)^{\frac{I}{n}}, \left(\prod_{j=1}^{n} m_{iJ'} \right)^{\frac{1}{n}}, \left(\prod_{j=1}^{n} u_{ij} \right)^{\frac{1}{n}} \right) \tag{7}$$

The lr_i, mr_i and ur_i represents lower, middle, and a upper value of the fuzzy geometric mean value ($\tilde{r}_i$) of the criterion.

II. The next step is to identify the fuzzy weights of each parameter by implementing the following formula:

$$\tilde{w}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \dots \oplus \tilde{r}_n)^{-1} \tag{8}$$

III The final step is to perform defuzzification of the fuzzy weights ($\tilde{w}_i$) to derive the crisp weight $w_{i.}$

To find out the crisp numerical weights of each parameter, we implemented the Centre of Area (COA) method by using equation (9):

$$w_i = \frac{lw_i + mw_i + uw_i}{3} \tag{9}$$

Finally, derived weights were normalized using the following equation (10):

$$w_{in} = \frac{w_i}{\sum_{j=1}^{n} w_i} \tag{10}$$

where w_{in} is the normalized weight

RESULTS AND DISCUSSION

Morphometric Analysis of the Agrani River

Morphometric analysis is the most scientific and logical approach to study watershed characteristics and thus for soil erosion risk assessment of the watershed. In this study, morphometric parameters which are known as parameters for evaluation of erosion risk were computed (Table 3). The morphometric parameters were computed from the watershed and drainage properties. The drainage network was extracted from the Survey of India (SOI) toposheets (Scale 1:50,000) which later used in reconditioning the SRTM DEM. A common datum and projected coordinate system i.g. The World Geodetic System 1984 (WGS-84) and Universal Transverse Mercator (UTM) have assigned to the SOI toposheets and SRTM DEM to carryout comparative analysis and accuracy assessment. This procedure has helped to extract accurate drainage network and watershed boundary and consequently, to compute morphometric parameters. The Agrani river watershed was divided into twenty-two SWs, namely SW1, to SW22 for priority purposes.

Prioritization of SWs using Fuzzy-AHP

In the process of prioritizing the SWs of the Agrani River, the Fuzzy-AHP method was employed with ten morphometric parameters for the assessment of erosion risk. These morphometric parameters are also considered as parameters for assessing erosion risk. Uncertainty in prioritizing morphometric parameters based on their influence on erosion has overcome by assigning Triangular Fuzzy Numbers (TFN). The TFN conversion scale (Table 2) was utilised to assign scores to the morphometric parameters. The linkage of morphometric parameters with the intensity of soil-erosion can help to identify the erosion-prone SWs. The linear morphometric parameters are positively related

Table 3. Matrix of morphometric parameters

	Linear Parameters					Shape Parameters				
SWS	Dt	Rb	F	Di	Lg	S_f	Rc	Re	Ff	Cc
SW1	5.333	4.568	3.446	2.709	0.185	2.973	0.215	0.654	0.336	2.173
SW2	3.867	3.848	3.928	2.871	0.174	2.528	0.225	0.710	0.396	2.125
SW3	6.537	5.451	3.094	2.584	0.194	4.293	0.163	0.545	0.233	2.494
SW4	2.328	3.285	2.520	2.285	0.219	2.795	0.202	0.675	0.358	2.242
SW5	3.616	3.745	2.842	2.413	0.207	3.463	0.226	0.606	0.289	2.119
SW6	0.872	3.411	1.530	1.773	0.282	2.654	0.118	0.693	0.377	2.933
SW7	0.669	4.833	1.600	1.628	0.307	2.459	0.146	0.720	0.407	2.634
SW8	3.291	3.711	3.307	2.494	0.200	3.944	0.226	0.568	0.254	2.118
SW9	2.081	3.731	1.742	1.892	0.264	2.236	0.150	0.755	0.447	2.599
SW10	1.698	3.018	1.498	1.855	0.269	3.377	0.230	0.614	0.296	2.098
SW11	1.452	4.589	1.512	1.661	0.301	4.439	0.165	0.536	0.225	2.478
SW12	1.655	5.310	1.973	1.902	0.263	5.724	0.102	0.472	0.175	3.152
SW13	0.628	3.900	1.094	1.421	0.352	2.805	0.226	0.674	0.356	2.117
SW14	1.563	4.722	1.745	1.743	0.287	5.106	0.137	0.499	0.196	2.717
SW15	4.119	3.441	2.475	2.323	0.215	3.886	0.192	0.572	0.257	2.297
SW16	0.790	4.233	0.952	1.379	0.362	3.617	0.168	0.593	0.276	2.456
SW17	1.759	4.355	2.047	1.996	0.251	4.405	0.179	0.538	0.227	2.380
SW18	2.327	3.611	2.073	1.869	0.267	3.546	0.191	0.599	0.282	2.305
SW19	0.882	3.681	1.376	1.715	0.291	3.076	0.129	0.643	0.325	2.802
SW20	2.246	4.967	2.530	2.351	0.213	3.775	0.167	0.581	0.265	2.464
SW21	2.373	3.928	1.784	1.942	0.257	5.802	0.140	0.468	0.172	2.690
SW22	1.437	4.444	1.798	2.059	0.243	4.706	0.144	0.520	0.213	2.652

to the rate of erosion (Rahaman et al. 2015). Therefore, the higher value of the linear indices received the highest rank.

On the contrary, the shape is inversely related to the intensity of the soil-erosion. Hence, the shape parameter values were inversed in the matrix of morphometric parameters. Consequently, the ranks were assigned to each parameter of the twenty-two SWs following their influence on soil erosion. The morphometric values were normalized (Table 5) before the construction of a pairwise comparison matrix. This matrix was constructed while considering the relative significance of each morphometric parameter with others parameters (Table 4).

Table 4. Pair-Wise Comparison matrix of morphometric parameters based on erosion risk.

	Dt	Rb	Fs	Di	S_f	Rc	Re	Ff	Cc	Lg	Weight
Dt	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	(3, 4, 5)	(4, 5, 6)	(4, 5, 6)	(6, 7, 8)	(5, 6, 7)	0.237
Rb	(0.33, 0.5, 1)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)	(2, 3, 4)	(3, 4, 5)	(4, 5, 6)	(5, 6, 7)	(5, 6, 7)	0.185
Fs	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 2, 3)	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(3, 4, 5)	(5, 6, 7)	(4, 5, 6)	0.162
Di	(0.25, 0.33, 0.5)	(0.33, 0.5, 1)	(0.33, 0.5, 1)	(1, 1, 1)	(3, 4, 5)	(3, 4, 5)	(5, 6, 7)	(5, 6, 7)	(6, 7, 8)	(6, 7, 8)	0.159
S_f	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(0.2, 0.25, 0.33)	(0.2, 0.25, 0.33)	(1, 1, 1)	(1, 2, 3)	(1, 2, 3)	(2, 3, 4)	(3, 4, 5)	(3, 4, 5)	0.072
Rc	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(0.2, 0.25, 0.33)	(0.2, 0.25, 0.33)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(4, 4, 4)	(2, 3, 4)	0.057
Re	(0.17, 0.2, 0.25)	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(0.14, 0.17, 0.2)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 1, 1)	(2, 3, 4)	(3, 4, 5)	(2, 3, 4)	0.054
Ff	(0.17, 0.2, 0.25)	(0.17, 0.2, 0.25)	(0.2, 0.25, 0.33)	(0.14, 0.17, 0.2)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(1, 1, 1)	(1, 2, 3)	(1, 1, 1)	0.029
Cc	(0.13, 0.14, 0.17)	(0.14, 0.17, 0.2)	(0.14, 0.17, 0.2)	(0.13, 0.14, 0.17)	(0.2, 0.25, 0.33)	(0.25, 0.25, 0.25)	(0.2, 0.25, 0.33)	(0.33, 0.5, 1)	(1, 1, 1)	(1, 0, 0)	0.018
Lg	(0.14, 0.17, 0.2)	(0.14, 0.17, 0.2)	(0.17, 0.2, 0.25)	(0.13, 0.14, 0.17)	(0.2, 0.25, 0.33)	(0.25, 0.33, 0.5)	(0.25, 0.33, 0.5)	(1, 1, 1)	(4, 3, 2)	(1, 1, 1)	0.027

Buckley's geometric mean method was adopted for the computation of the matrix of fuzzy weights. The Centre of Area (COA) approach was used in the process of de-fuzzifying the membership function and providing crisp numerical weights of all the parameters utilized in the analysis. Following the calculation of the weights of every input morphometric parameter using the Fuzzy-AHP model, all parameters and their respective weights were normalized, and subsequently, the final priority was assessed to each SW (Jaiswal et al. 2015). The prioritization of the SWs was conducted using the final Fuzzy-AHP score, which ranged from 0.020 to 0.106 (Table 6). The first rank was assigned to SW3, which has the highest Fuzzy-AHP score (0.106) in terms of soil erosion sensitivity. Likewise, all sub-watersheds were ranked based on their Fuzzy-AHP score. Thus, the SWs that received the highest rank assigned the highest priority in soil conservation planning and management.

In addition, to assess sub-watersheds which were comparable in risk of erodibility, all sub-watersheds were classified. Jenks natural breaks optimization method (Jenks, 1989) was used to determine the arrangement of Fuzzy-AHP score into five classes. The twenty-two sub-watersheds of the Agrani river were divided into five soil erosion risk groups based on the Fuzzy-AHP scores (Table 7) such as: very high (0.080 – 0.106), high (0.054 - 0.061), moderate (0.041 - 0.051), low (0.029 - 0.037), and very low (< 0.024).

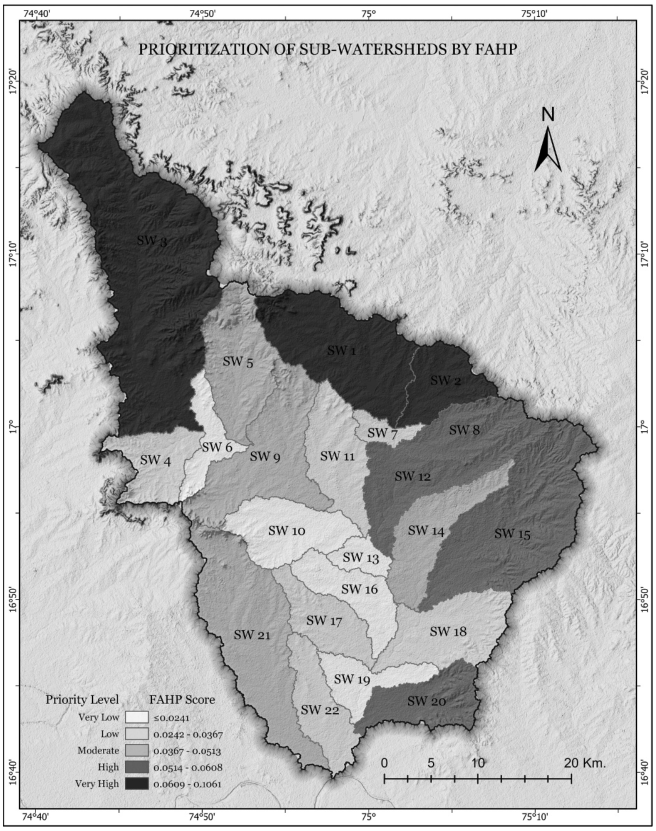

Fig.4. Prioritization of erosion-prone sub-watersheds in the Agrani watershed

Table 5. Normalized morphometric parameters matrix of the Agrani sub-watersheds

	Linear Parameters					Shape Parameters				
SWS	Dt	Rb	F	Di	Lg	S_f	Rc	Re	Ff	Cc
SW1	0.816	0.838	0.877	0.943	0.509	0.488	0.068	0.133	0.248	0.310
SW2	0.592	0.706	1.000	1.000	0.480	0.564	0.025	0.060	0.116	0.326
SW3	1.000	1.000	0.788	0.900	0.534	0.260	0.292	0.278	0.479	0.209
SW4	0.356	0.603	0.641	0.796	0.604	0.518	0.124	0.106	0.200	0.289
SW5	0.553	0.687	0.723	0.841	0.572	0.403	0.020	0.197	0.355	0.328
SW6	0.133	0.626	0.390	0.618	0.778	0.543	0.488	0.082	0.158	0.070
SW7	0.102	0.887	0.407	0.567	0.847	0.576	0.365	0.046	0.091	0.164
SW8	0.503	0.681	0.842	0.869	0.553	0.320	0.018	0.247	0.433	0.328
SW9	0.318	0.685	0.842	0.659	0.729	0.615	0.348	0.000	0.000	0.175
SW10	0.260	0.554	0.381	0.646	0.743	0.418	0.000	0.186	0.338	0.334
SW11	0.222	0.842	0.385	0.579	0.830	0.235	0.283	0.290	0.496	0.214
SW12	0.253	0.974	0.502	0.663	0.725	0.013	0.557	0.375	0.609	0.000
SW13	0.096	0.715	0.279	0.495	0.971	0.517	0.017	0.107	0.203	0.328
SW14	0.239	0.866	0.444	0.607	0.792	0.120	0.404	0.338	0.562	0.138
SW15	0.630	0.631	0.630	0.809	0.594	0.330	0.166	0.242	0.425	0.271
SW16	0.121	0.777	0.242	0.480	1.000	0.377	0.270	0.214	0.382	0.221
SW17	0.269	0.799	0.521	0.695	0.691	0.241	0.223	0.288	0.492	0.245
SW18	0.356	0.663	0.528	0.651	0.738	0.389	0.172	0.206	0.370	0.269
SW19	0.135	0.675	0.350	0.598	0.804	0.470	0.439	0.148	0.273	0.111
SW20	0.344	0.911	0.644	0.819	0.587	0.349	0.275	0.230	0.408	0.218
SW21	0.363	0.721	0.454	0.676	0.710	0.000	0.392	0.379	0.615	0.146
SW22	0.220	0.815	0.458	0.717	0.670	0.189	0.374	0.311	0.525	0.159

Table 6. Fuzzy-AHP ranks of the sub-watersheds

SW Name	SW3	SW2	SW1	SW8	SW12	SW20	SW15	SW5	SW9	SW21	SW14
FAHP Score	0.106	0.088	0.080	0.061	0.060	0.060	0.054	0.051	0.046	0.044	0.041
Rank	1	2	3	4	5	6	7	8	9	10	11
Area (Km^2)	346.33	55.00	141.53	55.83	88.22	60.25	182.61	91.12	120.89	160.39	74.54

SW Name	SW7	SW4	SW22	SW17	SW11	SW18	SW6	SW16	SW19	SW13	SW10
FAHP Score	0.037	0.036	0.035	0.034	0.030	0.029	0.024	0.022	0.021	0.020	0.020
Rank	12	13	14	15	16	17	18	19	20	21	22
Area (Km^2)	15.52	54.06	56.64	52.66	71.18	84.04	35.54	52.40	40.89	18.75	70.97

Table 7. Prioritization of sub-watersheds based on erodibility through fuzzy AHP score

S. No.	Fuzzy AHP Score	Priority Class	Total SWs	Sub Watersheds	Area (km^2)	% Area
1	> 0.0609	Very High	3	SW3, SW2, SW1	542.86	28.14
2	0.0513 - 0.0608	High	4	SW8, SW12, SW20, SW15	334.11	17.32
3	0.0367 - 0.0513	Medium	4	SW5, SW9, SW21, SW14	446.95	23.17
4	0.0242 - 0.0367	Low	6	SW7, SW4, SW22, SW17, SW11, SW18	218.55	11.33
5	< 0.0242	Very Low	5	SW6, SW16, SW19, SW13, SW10	386.91	20.05

The final priority ranks of all SWs revealed that SW3, SW2, and SW1 have very high soil erosion risk with a Fuzzy-AHP score of 0.106, 0.088 and 0.080 respectively that requires intensive soil conservation measures. High relief ratios and scanty vegetation in these SWs have made it highly prone to soil erosion and hence comes under a very high priority zone. The next highly erosive sub-watersheds with the Fuzzy-AHP score range of 0.054 to 0.061 are SW8, SW12, SW20, and SW15 which also requires the attention of soil conservation planners. Moderate priority was given to the SW5, SW9, SW21, and SW14, with the Fuzzy-AHP score ranged from 0.041 to 0.051. The SWs with a gentle slope, dense vegetation cover received less Fuzzy-AHP score, consequently falling in low to very low priority zones for soil conservation practices. Approximately 45.45% of the watershed area (876.97 km^2) comes under high to very high prioritized SWs, and nearly 23.17 % area (446.95 km^2) of the watershed was moderately prioritized. A total of 11 SWs cover 31.38% of the Agrani watershed, with an area of 605.46 km^2 identified in the category of low to very low priority zones. Furthermore, GIS database and Fuzzy-AHP scores of all SWs were imported into the ArcGIS Pro software to map the erosion-prone SWs for spatial planning of measures to prevent and manage soil erosion (Fig.4).

CONCLUSION

In the semi-arid watershed of the Agrani river, soil erosion is a significant environmental problem, so this demands the effort to prioritise areas for sustainable resource managemen. In this study, an attempt was made to evaluate the erosion-prone SWs of the Agrani watershed for prioritisation through morphometric analysis and the Fuzzy-Analytical Hierarchy Process. The Fuzzy-AHP method can enable decision-makers to resolve their uncertainty in preferring crucial SWs that are prone to soil erosion by implementing a triangular fuzzy conversion scale. The result of this study reveals that 68.62% area of the Agrani watershed (eleven SWs) comes under the category of a very high to moderate soil erosion-prone zones. In the study of soil erosion assessment, the proposed approach is effective and helps decision-makers in conservation planning, demonstrating strong potential for a realistic application in resource management of the other areas. The method can be used in the planning of soil conservation measures and assist as guidance for the administrators and planners to take practical action to mitigate soil erosion in sub-watersheds to avoid further soil degradation. The present study demonstrates that using Fuzzy-Analytical Hierarchy Method and GIS techniques, drainage morphometric analysis can achieve better soil resource management at the sub-watershed level.

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