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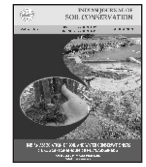

Multi-criteria analytical hierarchical process based decision support system for critical watershed prioritization of Andhiyarkhore catchment

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ABSTRACT

This study presents the application of analytical hierarchical process based multi-criteria decision support tool for prioritization of critical areas of Andhiyarkhore catchment for soil and water conservation (SWC) and management works. Fourteen different soil and water management parameters were calculated for each of the fifty-one delineated watersheds in Andhiyarkhore catchment. The normalized values of these parameters were arranged in a comparison matrix to assess corresponding weights to prioritize the watersheds. The average annual soil loss had highest weight of 0.23 and elongation ratio the minimum weight of 0.01 at 9.66% consistency ratio (within 10% limit). The highest priority for the SWC measures was obtained for SW-7 watershed and lowest for SW-47 watershed. The average annual groundwater recharge estimated in the Andhiyarkhore catchment was only 4.13% of average annual rainfall, which envisages need for SWC works in Andhiyarkhore catchment. Nine watersheds having 325.7 km^2 of the catchment have very high priority for undertaking SWC works.

1. INTRODUCTION

Land and water resource development programs are generally envisaged on watershed basis for sustainable development (Shrimali *et al.*, 2001). Soil and water conservation (SWC) works cannot be taken simultaneously for an entire catchment due to several resource constraints (Panda *et al.*, 2005). Watershed prioritization is, therefore, essential for identifying critical zones in catchment (Vittala *et al.*, 2004). Watershed prioritization using scientific criterions based on soil loss, sediment yield, morphological factors, and groundwater recharge have been applied individually by several researchers in the past (Mishra and Nagarajan, 2010).

The sediment yield index method, given by All India Soil and Land Use Survey (AIS&LUS, 1991), based watershed prioritization of Benisagar reservoir catchment by Yadav *et al.* (2015) showed that nearly 50% of the catchment needed immediate attention for implementing SWC measures. Kandpal *et al.* (2018) have used geomorphologic parameters for prioritization of hilly sub-watersheds in Chaukhutia watershed of Ramganga river basin in Uttarakhand state of India, and have observed that remote sensing (RS) based morphological parameters are convenient and cost effective for identifying areas highly vulnerable to soil erosion. Shivhare *et al.* (2018) compared results of prioritization based on morphological parameters, land use/land cover (LU/LC) and universal soil loss equation (USLE) to identify critical soil erosion prone areas of sub-watershed in lower middle part of Ganga basin. The future land use changes impact on watershed prioritization by analytical hierarchical process studied by Kundu *et al.* (2017) for a part of Narmada river basin in Central India showed most of the northern sub-watershed need high priority for efficient land use management. The integration of soil hydraulic parameters, microwave precipitation and morphometric analysis for watershed prioritization in Pahuj river basin in Bundelkhand region of India was carried out by Maurya *et al.* (2016) for SWC works. Fuzzy analytical hierarchical process based multi-criteria decision support system was applied for watershed prioritization by Jaiswal *et al.* (2015) in Benisagar reservoir catchment in Madhya Pradesh state of India, and observed that wide rectangular function is the most effective one in determining weights of erosion hazard parameters, with soil loss as the most sensitive, and circulatory ratio as the least sensitive parameter. The soil erosion estimation and prioritization of Khoslaya-Jhajhara watershed in North India using revised USLE by Chaudhary and Kumar (2018) showed that 6.5% area of the watershed is highly prone to soil erosion. Mishra *et al*. (2019) applied fuzzy analytical hierarchical process decision support system in environment of RS and GIS for Nagwan watershed of Hazribagh district, Jharkhand, India and found 19% area of watershed of very high priority for undertaking SWC works. Jain and Ramsankaran (2019) developed a GIS based integrated multi-criteria modelling framework for watershed prioritization in India following existing watershed guidelines as well as the hydrological aspects in a holistic way.

The watershed management needs for each agro-ecological region of India are different, which depends on a number of spatially distributed interdependent complex factors for any watershed (Chowdary *et al.*, 2013). In order to make a better judgment for prioritizing the critical watershed, it becomes important to include a set of spatially distributed parameters. Recent developments have improved decision making tools significantly, which are used in resolving conflicts related to decision making process (Javanbarg *et al.*, 2012). The Saaty's analytical hierarchical process (SAHP) is a multi-criteria decision analysis (MCDA) tool to decide priorities based on alternatives and judgement of the users (Saaty, 1980). This method involves defining an unstructured problem, developing hierarchy, pairwise comparison matrix, computation of relative weights, and consistency check to get a final priority (Lee *et al.*, 2008). The SAHP in combination with geographical information system (GIS) is used in watershed planning (De Steiguer *et al.*, 2003; Oyatoye *et al.*, 2010), forest management (Babaie-Kafaky *et al.*, 2009), and identification of erosion prone areas (Jaiswal *et al.*, 2014). In this study, an attempt was made to develop a Saaty's analytical hierarchical process based MCDA tool by integrating the morphological, hydrological and groundwater recharge parameters in the environment of GIS for prioritizing the delineated watersheds of Andhiyarkhore catchment in Chhattisgarh state of India. The developed MCDA tool can be used for identification of critical areas, and development of region specific catchment area treatment plan for Andhiyarkhore catchment.

2. MATERIALS AND METHODS

The description of study area, data sources used for this study, and different methods used for estimation of morphological, hydrological and groundwater recharge parameters for watershed prioritization in Andhiyarkhore catchment are given below in detail.

Study Area and Data Sources

The study was conducted for the Andhiyarkhore catchment, which is one of the catchments of Seonath river basin of the Mahanadi river basin in Chhattisgarh state of India. The basin extends between 21º45'33"to 22º30'16"N latitudes and 81°01'57" to 81°37'39"E longitudes. The Seonath river is east flowing with two major tributaries - Hamp and Sakari - which traverse through this intermediate catchment and join before Andhiyarkhore. The study area has two gauging sites, namely, Hamp-Pandariya and Sakari-Goreghat located upstream on the river Hamp and Sakari, respectively, and monitored by Water Resource Department, Chhattisgarh. These two streams join before Andhiyarkhore gauging site located downstream which is monitored by the Central Water Commission. The Andhiyarkhore catchment has an area of 2181 km^2 with the boundary length of 322.73 km. The basin has a mean annual rainfall of 1292 mm (1980-2009). The index map showing location of Andhiyarkhore catchment is shown in Fig. 1. The study area falls in three districts namely, Kawardha, Durg and Bilaspur. Basin area of 1877.02 km^2, 302.69 $km^2$and 1.09 km^2 falls in Kawardha, Durg and Bilaspur districts, respectively. Rainfall data of 30 years (1980-2010) from eight rain-gauge stations (Chirapani, Pandariya, Kawardha, Nawagarh, Bodla, Rajnandgaon, Bemtara and Saroda) was used for this study. ASTER-DEM of spatial resolution 30 m downloaded from Earth Explorer website of United States Geological Survey was used for delineation and extraction of drainage network. LANDSAT-8 satellite images (Row-33 Path-56 dated 23 February, 2014) and (Row-33 Path-56 dated 15 November, 2014) of spatial resolution 30 m were used to develop LU/LC for the Andhiyarkhore catchment. Data on soil properties was obtained from National Bureau of Soil Survey and Land Use Planning, New Delhi for estimation of soil erodibility in the catchment.

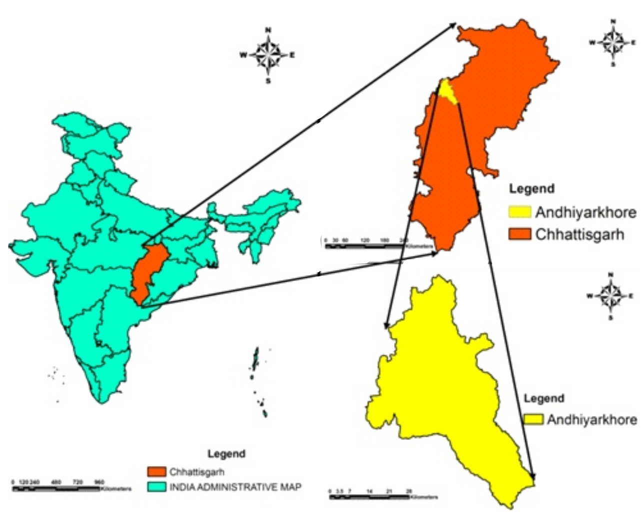

Fig. 1. Location of Andhiyarkhore catchment in Chhattisgarh state of India

Morphological Parameters

The watersheds were manually delineated based on second or third order stream using contour map of 10 m interval prepared from ASTER-DEM by data interpolation using Spatial Analyst Krigging tool in Arc-GIS 10.2. General features such as area, average slope, and total number of streams and total length of streams in each of the delineated watershed are presented in Table 1. The standard procedure used for computation of morphometric parameters as drainage intensity, drainage density, length of overland flow, stream frequency, drainage texture, circulatory ratio, form factor, compactness constant, elongation ratio, and mean bifurcation ratio for each watershed of the Andhiyarkhore catchment are given in Table 2.

Hydrological Parameters

The average annual soil loss (*SL*) was estimated using revised universal soil loss equation (RUSLE) given by Renard *et al.* (1991).

$$SL = R \times K \times L \times S \times C \times P \qquad ...(1)$$

Where, *SL* is the computed average annual soil loss caused by sheet and rill erosion by water (t $ha^{-1}yr^{-1}$), *R* is rainfall erosivity factor (MJ mm $h^{-1}ha^{-1}yr^{-1}$), *K* is soil erodibility factor (t ha h $ha^{-1}MJ^{-1}mm^{-1}$), *L* is slope length factor (dimensionless), *S* is slope steepness factor (dimensionless), *C* is cover and management factor, and *P* is support practice factor (last two are dimensionless, and vary from 0 to 1).

Sediment production rate (*SPR*), which is the volume of sediment produced per unit drainage area per unit time, was estimated using the empirical relationship based on geomorphology suggested by Jose and Das (1982) as given below:

$$log(SPR) = 4919.80 + 48.64\, log(100 + R_f) - 1337.77\, log(100 + R_c) - 1165.65\, log(100 + C_c) \qquad ...(2)$$

Where, *SPR* is the sediment production rate (ha-m 100 $km^{-2}yr^{-1}$), R_f is the form factor, R_c is the circulatory ratio, and C_c is the compactness coefficient.

Sediment yield (S_y) model developed for Indian condition (Kumar, 1985; Rao and Mahabaleswara, 1990) was used for estimation of sediment yield for each watershed as given below:

$$S_y = 1.067 \times 10^6 \times P^{1.384} \times A^{1.292} \times D_d^{0.392} \times S^{0.129} \times F^{2.51} \qquad ...(3)$$

$$F = \frac{(0.21F_1 + 0.2F_2 + 0.6F_3 + 0.8F_4 + F_5)}{\sum_{i=1}^{5} F_i} \qquad ...(4)$$

Where, S_y is sediment yield (M $m^3 \times 10^3 yr^{-1}$), *P* is annual precipitation (cm), *A* is watershed area (km^2), D_d is drainage density (km km^{-2}), *S* is average slope, *F* is the vegetative cover factor, F_1 is area under reserved and protected forest, F_2 is unclassified forest area, F_3 is cultivated area, F_4 is grass and / or pasture land area, and F_5 is wasteland area.

Table: 1
General features of delineated watersheds in Andhiyarkhore catchment

Watershed code	Area of watershed (ha)	Average slope (%)	Total number of streams	Total length of streams (km)
SW-1	5637	8.23	19	43.93
SW-2	4951	9.24	15	32.72
SW-3	4518	7.17	18	34.55
SW-4	2426	4.07	10	24.30
SW-5	1216	5.58	9	10.41
SW-6	2038	7.78	10	15.46
SW-7	2239	7.59	12	16.88
SW-8	6689	7.28	24	49.34
SW-9	4482	4.17	19	35.38
SW-10	1390	4.25	6	13.41
SW-11	3725	2.42	19	35.01
SW-12	5298	3.98	22	50.15
SW-13	4434	4.37	19	35.19
SW-14	6545	5.07	26	54.07
SW-15	4200	8.69	22	34.08
SW-16	5767	7.60	26	45.67
SW-17	5214	6.55	25	45.63
SW-18	2991	8.72	15	22.32
SW-19	4849	8.17	22	35.69
SW-20	2410	7.93	9	17.58
SW-21	1954	4.50	9	20.52
SW-22	6801	6.58	30	60.74
SW-23	4471	1.97	20	44.31
SW-24	8674	2.32	29	86.85
SW-25	2888	1.38	12	25.69
SW-26	1628	1.68	10	17.36
SW-27	3463	3.61	15	31.31
SW-28	7186	0.91	24	64.48
SW-29	5103	0.79	17	51.92
SW-30	2268	0.56	7	19.93
SW-31	4700	0.95	19	47.18
SW-32	2751	0.52	9	25.51
SW-33	3751	0.88	9	32.02
SW-34	2447	0.56	9	23.43
SW-35	2084	0.51	6	18.29
SW-36	4473	0.57	13	41.15
SW-37	5910	0.66	24	51.28
SW-38	8703	0.73	24	79.84
SW-39	5301	0.80	16	52.92
SW-40	4400	0.58	20	42.98
SW-41	5554	0.62	26	56.92
SW-42	4996	0.62	19	41.13
SW-43	4507	0.71	16	35.32
SW-44	2761	0.61	9	22.14
SW-45	4599	0.58	16	39.41
SW-46	3729	0.61	10	33.82
SW-47	4224	0.61	11	37.67
SW-48	4308	0.56	13	30.66
SW-49	5023	0.56	14	45.72
SW-50	4908	0.66	23	42.68
SW-51	3529	0.70	10	27.64
Minimum	1216.00	0.51	6.00	10.41
Maximum	8703.00	9.24	30.00	86.85
Mean	4276.73	3.27	16.39	37.31
SD	1721.94	3.04	6.52	16.10
Skewness	0.41	0.67	0.22	0.80
CV	0.40	0.93	0.40	0.43

Table: 2
Estimation of morphological parameters of watersheds in Andhiyarkhore catchment

Morphological parameters	Expressions	Variables	Reference
Drainage density	$D_d = \frac{\sum_{i=1}^{k}\sum_{i=1}^{n} L_u}{A_u}$	D_d is drainage density (km/sq km), L_u is length of i^{th} segment of drainage stream, n is number of segments, A_u is catchment area of corresponding stream order	Horton, 1932
Drainage intensity	$D_i = \frac{F_s}{D_d}$	D_i is drainage intensity, F_s is stream frequency (km^{-2}), D_d is drainage density (km^{-1})	Horton, 1945
Drainage texture	$D_t = \frac{\sum_{i=1}^{k}\sum_{i=1}^{n} N_u}{P_u}$	D_t is drainage texture, N_u is number of stream segment of order u, P_u is perimeter of basin of order u (km)	Horton, 1945
Stream frequency	$F_s = 0.694 \times D_d^2$	F_s is stream frequency (km^{-2}), D_d is drainage density (km^{-1})	Melton, 1958
Circulatory ratio	$R_c = \frac{A_u}{A_c}$	R_c is circulatory ratio, A_u is area of basin having stream of order u (km^2), A_c is area of circle having perimeter equal to perimeter of drainage basin of stream order u (km^2)	Miller, 1953
Form factor	$R_f = \frac{A_u}{L_b^2}$	R_f is shape factor, A_u is area of basin (sq km), L_b is maximum basin length (km)	Horton, 1932
Compactness constant	$C_c = \frac{P_b}{P_c}$	C_c is compactness constant, P_b is perimeter of basin (km), P_c is perimeter of circle having area equal to basin (km)	Gravelius, 1914
Elongation ratio	$R_e = \frac{D_e}{L_{bm}}$	R_e is elongation ratio, D_e is diameter of circle having same area as of given drainage basin (km), L_{bm} is maximum basin length (km)	Schumn, 1956
Bifurcation ratio	$R_b = \frac{N_u}{N_{u+1}}$	R_b is bifurcation ratio, N_u is number of stream segments of order u, N_{u+1} is number of stream segments of next higher order	Horton, 1945
Length of overland flow	$L_g = \frac{1}{2D_d}$	L_g is length of overland flow, D_d is drainage density (km^{-1})	Horton, 1945

Groundwater Recharge

The average annual groundwater recharge for various watersheds in Andhiyarkhore catchment was estimated using groundwater water table fluctuation and specific yield method given by Groundwater Estimation Committee (1984).

$$G = (S + DW - R_s - R_{igw} - R_{is}) \times \frac{R_{nf}}{R_{af}} + R_s + R_{is} \quad ...(5)$$

$$S = WT \times S_y \quad ...(6)$$

Where, G is annual ground water recharge (mm), S is change in ground water storage depth during pre and post monsoon period (mm), WT is change in water table depth during pre and post-monsoon period (mm), S_y is specific yield of the underlying aquifer in the area (dimensionless), DW is annual gross ground water draft during monsoon (mm), R_s is recharge from canal seepage during monsoon (mm), R_{igw} is recharge from recycled water from ground water irrigation during monsoon (mm), R_{is} is recharge from recycled water from surface water irrigation during monsoon (mm), and R_f is rainfall (mm).

Saaty's Analytical Hierarchical Process (SAHP)

The SAHP is a multi-criteria decision analysis tool in which a matrix is prepared of pair-wise comparisons between parameters affecting any decision. The morphological parameters (drainage intensity, drainage density, length of overland flow, stream frequency, drainage texture, circulatory ratio, form factor, compactness constant, elongation ratio, and mean bifurcation ratio), hydrological parameters (average annual soil loss, sediment production rate and sediment yield) and average annual groundwater recharge parameter were rated on 1 to 9 scale, where 1 indicated that two factors are equally important and 9 indicated that one factor is more important than other. The reciprocal of 1 to 9 (*i.e.* 1/1 and 1/9) showed that one is less important than the other. Saaty's rating scale was used to allocate weights for different morphological, hydrological and ground water recharge parameters depending on their relative importance in SWC work (Table 3). Comparison matrix was filled for each of these parameters using Table 3 with total judgement values to be $^nC_2$, which was equal to 98 values. The diagonal elements of the comparison matrix were reserved as 1. If the judgment value was to the left side of 1, then for filling the upper triangular matrix, actual judgment value was used. If the judgment value was to the right side of 1, then reciprocals of same were used. The lower triangular matrix was completed by taking reciprocal of upper triangular matrix. In this way, comparison matrix was calculated for SAHP. The comparison matrix priority vector was calculated as the normalized eigen vector of matrix, and was used to assign weights for different morphological, hydrological and ground water recharge parameters.

Table: 3
Saaty's rating scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat more important	Experience and judgment slightly favour one over the other
5	Much more important	Experience and judgment strongly favour one over the other
7	Very much more important	Experience and judgment very strongly favour one over the other
9	Absolutely more important	The evidence favouring one over the other is one of the highest possible validity
2, 4, 6, 8	Intermediate values	When compromise is needed

Consistency Check

The consistency of subjective judgment was checked by estimating consistency ratio, which is the comparison between consistency index and random consistency index. The consistency ratio (CR) was computed using relationship given by Saaty (1980).

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad ...(7)$$

$$CR = \frac{CI}{RI} \quad ...(8)$$

Where, CI is the consistency index (dimensionless), λ_{max} is the principal eigen value obtained from priority matrix (dimensionless), n is the size of the comparison matrix (dimensionless), RI is the random consistency index (dimensionless), and CR is the consistency ratio (dimensionless).

Saaty (1980) has determined average random consistency index (RI) on the basis of various sample sizes n as given in Table 4. If the value of CR is smaller or equal to 10%, the consistency is acceptable. If CR is greater than 10%, the subjective judgment needs to be revised. The RI in combination with λ_{max} is used for computation of CR, and if computed value is less than 10%, it establishes that decisions considered are consistent.

Normalization of Morphological, Hydrological and Groundwater Recharge Parameters

The morphological, hydrological and groundwater recharge parameters identified for watershed prioritization may vary in diverse range, and hence require normalization to restrict the variation in a defined range of 0 to 1 for comparison amongst them. The standard methodology for normalization of different parameters used by Jaiswal *et al.* (2014) is given below:

$$N_i = \frac{(U_{nor} - L_{nor})}{(U_{act} - L_{act})}(X_i - L_{act}) \quad ...(9)$$

Where, N_i is the normalized value of a parameter for i^{th} watershed, U_{nor} is the upper value in the standard scale (*i.e.* 1), L_{nor} is the lower value in the standard scale (*i.e.* 0), U_{act} and L_{act} are the maximum and minimum values of parameters, respectively, and X_i is the observed value of parameters for i^{th} watershed.

Computation of Weights

The pairwise comparison matrix prepared for different morphological, hydrological and ground water recharge parameters is given in Table 5 and estimation of final weights for each parameter is given in Table 6.The final weight obtained of each morphological, hydrological and groundwater recharge was multiplied with the normalised values of the different parameters estimated for each watershed. The clustering technique used by (Jaiswal *et al.*, 2014) is used for grouping the delineated watershed into different classes (*i.e.* very high, high, moderate, low and very low priority). The scatter plot of the normalised values of the different morphological, hydrological and groundwater recharge parameters for different watershed leads to formation of clusters. These clusters are then formed into five classes with values ranging from 0 to 1. The values from 0.8 to 1.0 are assigned very high priority, 0.6 to 0.8 as high priority, 0.4 to 0.6 as moderate priority, 0.2 to 0.4 as low priority and 0-0.2 as very low priority.

3. RESULTS AND DISCUSSION

The area of delineated watersheds in Adhiyarkhore catchment varies from minimum of 1216 ha for SW-5 to maximum of 8703 ha for SW-38, with mean watershed area of 4277 ha in Andhiyrakhore catchment (Table 1). The small watersheds are present near the north-western part of Ahdiyarkhore catchment, which may be due to higher slope and drainage density. The average slope of watersheds varies from minimum of 0.5% for SW-35, in the middle of the catchment, to maximum of 9.2% for SW-2, in the

Table: 4
Random consistency index for different sample sizes

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56	1.57

N = Sample size, RI = Random consistency index

Table: 5
Comparison matrix for morphological, hydrological and groundwater recharge parameters in Adhiyarkhore catchment

	SL	S_y	SPR	G	D_i	D_d	L_g	F_s	D_t	R_c	R_f	C_c	R_e	R_b
SL	1	3	3	3	5	5	5	5	7	9	9	9	9	9
S_y	0.33	1	3	3	3	3	5	5	5	7	9	9	9	9
SPR	0.33	0.33	1	3	3	3	3	5	5	5	7	9	9	7
G	0.33	0.33	0.33	1.00	3	3	3	3	3	3	5	7	7	5
D_i	0.20	0.33	0.33	0.33	1	3	3	3	3	3	5	5	7	3
D_d	0.20	0.33	0.33	0.33	0.33	1	3	3	3	3	5	5	5	3
L_g	0.20	0.20	0.33	0.33	0.33	0.33	1	3	3	3	5	3	5	3
F_s	0.20	0.20	0.20	0.33	0.33	0.33	0.33	1	3	3	3	5	3	3
D_t	0.14	0.20	0.20	0.33	0.33	0.33	0.33	0.33	1	3	3	3	3	3
R_c	0.11	0.14	0.20	0.33	0.33	0.33	0.33	0.33	0.33	1	3	3	3	3
R_f	0.11	0.11	0.14	0.20	0.20	0.20	0.20	0.33	0.33	0.33	1	3	3	0.33
C_c	0.11	0.11	0.11	0.14	0.20	0.20	0.33	0.20	0.33	0.33	0.33	1.00	3	0.33
R_e	0.11	0.11	0.11	0.14	0.14	0.20	0.20	0.33	0.33	0.33	0.33	0.33	1	0.33
R_b	0.11	0.11	0.14	0.20	0.33	0.33	0.33	0.33	0.33	0.33	3	3	3	1
Sum	3.50	6.52	9.44	12.69	17.54	20.27	25.07	29.87	34.67	41.33	58.67	65.33	70.00	50.00

SL is Average annual soil loss (t ha^{-1}yr^{-1}); S_y is Sediment yield (Mm^{3}yr^{-1}km^{-2}); SPR is Sediment production rate (ha-m 100 km^{-2}yr^{-1}); G is Annual groundwater recharge (mm); D_i is Drainage intensity (dimensionless); D_d is Drainage density (km km^{-2}); L_g is length of overland flow (km^{-1}); F_s is Stream frequency (km^{-2}); D_t is Drainage texture (km^{-1}); R_c is Circulatory ratio (dimensionless); R_f is Form factor (dimensionless); C_c is Compactness constant (dimensionless); R_e is Elongation ratio (dimensionless); R_b is Mean bifurcation ratio (dimensionless)

Table: 6
Computation of final weights for morphological, hydrological and groundwater recharge parameters in Andhiyarkhore catchment

	SL	S_y	SPR	G	D_i	D_d	L_g	F_s	D_t	R_c	R_f	C_c	R_e	R_b	Eigen vector	λ
SL	0.29	0.46	0.32	0.24	0.29	0.25	0.20	0.17	0.20	0.22	0.15	0.14	0.13	0.18	0.23	0.80
Sy	0.10	0.15	0.32	0.24	0.17	0.15	0.20	0.17	0.14	0.17	0.15	0.14	0.13	0.18	0.17	1.11
SPR	0.10	0.05	0.11	0.24	0.17	0.15	0.12	0.17	0.14	0.12	0.12	0.14	0.13	0.14	0.13	1.27
G	0.10	0.05	0.04	0.08	0.17	0.15	0.12	0.10	0.09	0.07	0.09	0.11	0.10	0.10	0.10	1.22
Di	0.06	0.05	0.04	0.03	0.06	0.15	0.12	0.10	0.09	0.07	0.09	0.08	0.10	0.06	0.08	1.34
Dd	0.06	0.05	0.04	0.03	0.02	0.05	0.12	0.10	0.09	0.07	0.09	0.08	0.07	0.06	0.07	1.31
Lg	0.06	0.03	0.04	0.03	0.02	0.02	0.04	0.10	0.09	0.07	0.09	0.05	0.07	0.06	0.05	1.33
Fs	0.06	0.03	0.02	0.03	0.02	0.02	0.01	0.03	0.09	0.07	0.05	0.08	0.04	0.06	0.04	1.29
Dt	0.04	0.03	0.02	0.03	0.02	0.02	0.01	0.01	0.03	0.07	0.05	0.05	0.04	0.06	0.03	1.18
Rc	0.03	0.02	0.02	0.03	0.02	0.02	0.01	0.01	0.01	0.02	0.05	0.05	0.04	0.06	0.03	1.16
Rf	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.05	0.04	0.01	0.02	1.04
Cc	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.04	0.01	0.01	0.93
Re	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.79
Rb	0.03	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.05	0.05	0.04	0.02	0.02	1.13
Sum	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.98

SL is Average annual soil loss (t ha^{-1}yr^{-1}); S_y is Sediment yield (Mm^{3}yr^{-1}km^{-2}); SPR is Sediment production rate (ha-m 100 km^{-2}yr^{-1}); G is Annual groundwater recharge (mm); D_i is Drainage intensity (dimensionless); D_d is Drainage density (km km^{-2}); L_g is length of overland flow (km^{-1}); F_s is Stream frequency (km^{-2}); D_t is Drainage texture (km^{-1}); R_c is Circulatory ratio (dimensionless); R_f is Form factor (dimensionless); C_c is Compactness constant (dimensionless); R_e is Elongation ratio (dimensionless); R_b is Mean bifurcation ratio (dimensionless); E is principal eigen vector; λ is the final priority weights for different soil and water management parameters

northern upper reach of the catchment, with mean slope of 3.26% for the catchment (Table 1). In general, the number of streams in different watersheds varies based on the area and slope of the watershed from minimum of 6 in SW-35 to maximum of 30 in SW-22, with mean of 16 streams per watershed for the catchment (Table 1). The total length of stream in each watershed varies from minimum of 10.4 km for SW-5 to maximum of 86.8 km for SW-25, with 37.3 km mean length of streams per watershed in the catchment (Table 1). The variation in different morphological, hydrological and ground water recharge parameters across different watersheds of Andhiyarkhore catchment is given in Table 7. The drainage intensity of watershed varies widely from 0.28 (SW-33) to 0.86 (SW-5), indicating a spatial and temporal difference in the drainage from each watershed (Table 7). The drainage density varies from 0.66 (SW-2) to 1.06 (SW-26), and length of overland flow varies from 0.47 (SW-26) to 0.76 (SW-2) resulting in a poorly drained basin with a

Table: 7
Statistics of computed values of morphological, hydrological and groundwater recharge parameters for each watershed in Andhiyarkhore catchment

Watershed code	*SL*	S_y	*SPR*	*G*	D_i	D_d	L_g	F_s	D_t	R_c	R_f	C_c	R_e	R_b
SW-1	26.80	1.13	1.91	98.94	0.43	0.78	0.64	0.34	0.50	0.50	0.26	1.42	0.57	2.75
SW-2	26.63	0.99	2.08	100.32	0.46	0.66	0.76	0.30	0.44	0.53	0.26	1.37	0.58	3.50
SW-3	59.13	1.14	1.32	85.87	0.52	0.76	0.66	0.40	0.49	0.43	0.24	1.53	0.56	2.63
SW-4	25.54	1.33	1.85	68.58	0.41	1.00	0.50	0.41	0.40	0.48	0.30	1.44	0.62	2.25
SW-5	20.35	0.89	0.74	66.38	0.86	0.86	0.58	0.74	0.44	0.37	0.18	1.65	0.47	2.00
SW-6	20.63	0.96	2.06	80.00	0.65	0.76	0.66	0.49	0.45	0.51	0.33	1.40	0.65	2.25
SW-7	39.51	0.79	2.24	82.89	0.71	0.75	0.67	0.54	0.56	0.61	0.41	1.28	0.72	2.75
SW-8	19.35	1.08	2.05	61.42	0.49	0.74	0.68	0.36	0.60	0.52	0.27	1.38	0.59	4.08
SW-9	26.32	1.11	0.07	63.84	0.54	0.79	0.63	0.42	0.40	0.25	0.21	1.98	0.51	3.25
SW-10	24.45	0.88	0.36	109.38	0.45	0.96	0.52	0.43	0.26	0.32	0.14	1.76	0.42	5.00
SW-11	23.27	0.40	0.31	96.63	0.54	0.94	0.53	0.51	0.49	0.31	0.38	1.80	0.70	4.50
SW-12	21.85	0.38	1.31	75.07	0.44	0.95	0.53	0.42	0.55	0.42	0.34	1.55	0.66	3.13
SW-13	37.50	0.54	0.43	71.44	0.54	0.79	0.63	0.43	0.46	0.33	0.34	1.75	0.66	3.25
SW-14	25.55	1.26	1.87	41.59	0.48	0.83	0.60	0.40	0.75	0.69	0.41	1.20	0.72	3.25
SW-15	16.29	0.93	2.37	61.39	0.65	0.81	0.62	0.52	0.76	0.62	0.56	1.27	0.84	3.13
SW-16	28.44	1.00	1.88	54.17	0.57	0.79	0.63	0.45	0.80	0.69	0.44	1.20	0.75	3.25
SW-17	16.74	1.49	2.36	77.58	0.55	0.88	0.57	0.48	0.75	0.58	0.47	1.31	0.77	3.15
SW-18	18.65	0.71	2.35	63.88	0.67	0.75	0.67	0.50	0.61	0.61	0.51	1.28	0.81	2.58
SW-19	20.63	0.78	2.48	63.28	0.62	0.74	0.68	0.45	0.70	0.62	0.64	1.27	0.90	2.85
SW-20	56.54	0.88	1.94	49.20	0.51	0.73	0.68	0.37	0.36	0.48	0.40	1.44	0.71	2.00
SW-21	44.00	0.91	2.20	46.72	0.44	1.05	0.48	0.46	0.43	0.56	0.32	1.33	0.64	2.00
SW-22	38.71	1.24	0.22	52.50	0.49	0.89	0.56	0.44	0.56	0.30	0.21	1.84	0.51	3.65
SW-23	20.42	1.20	2.18	67.82	0.45	0.99	0.51	0.45	0.69	0.68	0.64	1.22	0.90	3.42
SW-24	16.79	1.52	1.60	81.43	0.33	1.00	0.50	0.33	0.75	0.74	0.44	1.17	0.75	4.00
SW-25	10.35	1.29	1.42	56.44	0.47	0.89	0.56	0.42	0.55	0.76	0.46	1.14	0.77	2.75
SW-26	20.18	0.97	0.98	60.53	0.58	1.07	0.47	0.61	0.64	0.84	0.48	1.09	0.78	2.25
SW-27	33.89	1.14	1.64	80.04	0.48	0.90	0.56	0.43	0.49	0.46	0.26	1.48	0.58	3.50
SW-28	18.05	1.17	0.32	53.27	0.37	0.90	0.56	0.33	0.45	0.32	0.18	1.78	0.48	3.05
SW-29	7.33	1.68	2.32	66.87	0.33	1.02	0.49	0.33	0.51	0.58	0.43	1.31	0.74	2.92
SW-30	6.10	1.11	1.71	55.23	0.35	0.88	0.57	0.31	0.29	0.47	0.20	1.45	0.50	2.50
SW-31	15.63	1.19	0.02	58.14	0.40	1.00	0.50	0.40	0.36	0.21	0.17	2.16	0.47	3.25
SW-32	7.45	1.07	0.46	55.38	0.35	0.93	0.54	0.33	0.28	0.34	0.13	1.72	0.40	8.00
SW-33	15.43	1.01	0.05	51.68	0.28	0.85	0.59	0.24	0.20	0.24	0.09	2.03	0.34	8.00
SW-34	9.42	0.93	0.92	57.57	0.38	0.96	0.52	0.37	0.32	0.39	0.15	1.60	0.43	2.00
SW-35	9.67	0.73	0.84	49.58	0.33	0.88	0.57	0.29	0.23	0.38	0.20	1.63	0.50	5.00
SW-36	10.57	1.05	0.27	56.50	0.32	0.92	0.54	0.29	0.30	0.31	0.23	1.81	0.54	5.50
SW-37	8.41	1.46	1.70	61.61	0.47	0.87	0.57	0.41	0.60	0.47	0.27	1.47	0.59	3.38
SW-38	10.74	1.44	1.22	56.49	0.30	0.92	0.54	0.28	0.47	0.42	0.20	1.55	0.50	3.38
SW-39	11.01	1.38	2.18	59.47	0.30	1.00	0.50	0.30	0.47	0.58	0.30	1.32	0.62	2.75
SW-40	12.20	0.91	1.94	56.26	0.47	0.98	0.51	0.45	0.61	0.51	0.22	1.40	0.53	3.42
SW-41	11.63	1.00	1.68	45.60	0.46	1.02	0.49	0.47	0.84	0.73	0.52	1.17	0.82	3.00
SW-42	13.78	0.76	1.77	59.23	0.46	0.82	0.61	0.38	0.64	0.71	0.43	1.19	0.74	3.25
SW-43	13.97	0.87	0.44	71.22	0.45	0.78	0.64	0.36	0.39	0.33	0.15	1.73	0.44	3.75
SW-44	12.36	0.66	0.96	99.85	0.41	0.80	0.63	0.33	0.30	0.39	0.22	1.60	0.52	2.00
SW-45	13.46	0.73	2.02	101.97	0.41	0.86	0.58	0.35	0.48	0.51	0.29	1.40	0.61	2.38
SW-46	12.95	0.77	0.66	62.71	0.30	0.91	0.55	0.27	0.28	0.36	0.18	1.67	0.48	9.00
SW-47	13.17	0.79	0.16	63.14	0.29	0.89	0.56	0.26	0.25	0.28	0.18	1.88	0.48	2.50
SW-48	12.43	0.66	2.08	88.97	0.42	0.71	0.70	0.30	0.45	0.65	0.40	1.24	0.72	2.25
SW-49	10.81	0.83	2.01	83.65	0.31	0.91	0.55	0.28	0.40	0.52	0.23	1.38	0.54	6.00
SW-50	9.32	1.09	0.09	71.02	0.54	0.87	0.57	0.47	0.47	0.26	0.14	1.96	0.43	3.25
SW-51	12.49	0.83	0.19	84.52	0.36	0.78	0.64	0.28	0.26	0.29	0.18	1.86	0.48	2.25
Minimum	6.10	0.38	0.02	41.59	0.28	0.66	0.47	0.24	0.20	0.21	0.09	1.09	0.34	2.00
Maximum	59.13	1.68	2.48	109.38	0.86	1.07	0.76	0.74	0.84	0.84	0.64	2.16	0.90	9.00
Mean	19.94	1.00	1.34	68.38	0.46	0.87	0.58	0.40	0.48	0.48	0.31	1.51	0.61	3.45
SD	11.81	0.28	0.81	16.50	0.12	0.10	0.07	0.10	0.16	0.16	0.14	0.26	0.14	1.52
Skewness	1.61	0.15	-0.33	0.77	0.88	0.00	0.42	0.97	0.31	0.27	0.67	0.53	0.28	2.16
CV	0.59	0.28	0.60	0.24	0.26	0.11	0.12	0.24	0.34	0.33	0.45	0.18	0.23	0.44

SL is Average annual soil loss (t $ha^{-1}yr^{-1}$); S_y *is* Sediment yield ($Mm^3yr^{-1}km^{-2}$); *SPR* is Sediment production rate (ha-m 100 $km^{-2}yr^{-1}$); *G* is Annual groundwater recharge (mm); D_i is Drainage intensity (dimensionless); D_d is Drainage density (km km^{-2}); L_g is length of overland flow (km^{-1}); F_s is Stream frequency (km^{-2}); D_t is Drainage texture (km^{-1}); R_c is Circulatory ratio (dimensionless); R_f is Form factor (dimensionless); C_c is Compactness constant (dimensionless); R_e is Elongation ratio (dimensionless); R_b is Mean bifurcation ratio (dimensionless) delayed hydrologic response. The stream frequency varies from 0.24 (SW-33) to 0.74 (SW-5) indicating poor drainage development and more overland flow in the watersheds. The drainage texture varies from 0.2 (SW-33) to 0.84 (SW-41) indicating huge variation in the morphology of streams per unit area of watershed. The circulatory ratio varies from 0.21 (SW-31) to 0.83 (SW-26), which indicates no structural disturbance in the geology and poor control on hydrologic response of watersheds. The shape factor varies from 1.56 (SW-23) to 10.76 (SW-33) and elongation ratio varies from 0.34 (SW-33) to 0.9 (SW-23), which signifies a huge variation in shape of watersheds. The compactness coefficient varies from 1.09 (SW-26) to 2.16 (SW-31), which indicates coarse drainage pattern in watersheds. The mean bifurcation ratio varies from 2 (SW-34) to 9 (SW-46), which specifies that drainage is significantly affected by geology.

The mean annual soil loss from each watershed varies from minimum of 6.10 t $ha^{-1}yr^{-1}$ for SW-30 to maximum of 59.13 t $ha^{-1}yr^{-1}$ for SW-3, with mean annual soil loss of 19.94 t $ha^{-1}yr^{-1}$ for Andhiyarkhore catchment (Table 7). The mean annual soil loss is occurring at an average rate of 44.18 t ha^{-1} from 259.19 km^2 (11.83%) from very high priority watersheds, which are critically prone to soil erosion hazard. The watersheds in northern part of the catchment with higher slope and barren land use are more prone to soil erosion hazard. The sediment yield from the watershed varies from minimum of 0.38 $Mm^3km^{-2}yr^{-1}$ for SW-12 to maximum of 1.68 $Mm^3km^{-2}yr^{-1}$ for SW-29, with mean sediment yield of 1 $Mm^3km^{-2}yr^{-1}$ for Andhiyarkhore catchment. The mean sediment production rate of 2.19 ha-m 100 $km^{-2}yr^{-1}$ from 639.3 km^2 (29.31%) under very high and high priority watersheds need immediate attention for SWC works. The sediment yield from watershed is directly affected by the morphological parameters of the watershed. The sediment production rate varies from minimum of 0.02 ha-m 100 $km^{-2}yr^{-1}$ for SW-31 to 2.48 ha-m 100 $km^{-2}yr^{-1}$ for SW-19, with mean sediment production rate of 1.34 ha-m 100 $km^{-2}yr^{-1}$ for Andhiyarkhore catchment. The mean sediment yield of 1.6 $Mm^3km^{-2}yr^{-1}$ from 137.77 km^2 (6.31%) of very high priority watersheds need protection against sediment losses to downstream areas of the Andhiyarkhore catchment. The sediment production rate is directly proportional to land use in the watershed and its morphology.

The annual groundwater recharge for watershed varies from minimum of 41.6 mm for SW-14 and maximum of 109.3 mm for SW-10, with mean annual groundwater recharge of 68.3 mm for Andhiyarkhore catchment (Table 7). The mean annual groundwater recharge for 849.79 km^2 (38.96%) area of the catchment is only 4.13% of average annual rainfall, which indicates that the groundwater resources are depleting at a faster rate, which need to be augmented through artificial recharge. The north-western part of the Andhiyarkhore catchment has poor natural groundwater recharge, whereas in central part of the catchment the groundwater table is falling rapidly due to huge exploitation by dense population and intensively irrigated agricultural land.

The analytical hierarchical process comparison matrix of morphological, hydrological and groundwater recharge parameters is filled based on the intensity of importance of different parameters with respect to each other using Saaty's rating as given in Table 3. The random consistency index was obtained as 1.58 from Table 4 as the fourteen parameters were considered for priority decision for Andhiyarkhore catchment. The normalised values of different parameters used to determine normalized principal eigen vector and computation of final weights for morphological, hydrological and groundwater recharge parameter are presented in Table 5. The principal eigen value and consistency index were estimated to be 15.98 and 0.152, respectively as given in Table 6. The consistency ratio for the existing comparison matrix was observed to be acceptable at 9.66% (within 10% limit), and hence the final weights acquired were used for priority assessment. The average annual soil loss had highest weight of 0.23 and elongation ratio the minimum weight of 0.01. The priority sequence of the parameters was average annual soil loss, annual sediment yield, annual sediment production rate (hydrological parameters), annual groundwater recharge and morphological parameters. The values and statistics for the morphological, hydrological and groundwater recharge parameters for each watershed are given in Table 7. Based on the study, nine watersheds - SW-18, SW-16, SW-26, SW-19, SW-5, SW-23, SW-15, SW-17, SW-7 - and covering an area of 325.70 km^2 (15%) in Andhiyarkhore catchment can be classified as of very high priority, and therefore urgently require SWC measures. The very high priority watersheds are in north-western part of the Andhiyarkhore catchment followed by high priority in northern and north-central parts of the catchment. The details regarding the watersheds categorized in different priority classes alongwith corresponding total area in Andhiyarkhore catchment are given in Table 8. The prioritisation of the watersheds under different priority classes has been shown in Fig. 2.

4. CONCLUSIONS

The SAHP based decision support tool was found acceptable in multi-criteria based watershed prioritization. This study shows that nine watersheds (SW-18, SW-16, SW-26, SW-19, SW-5, SW-23, SW-15, SW-17, SW-7) and covering an area of 325.70 km^2 (15%) in Andhiyarkhore catchment have very high priority for SWC measures. The very high priority gets validated with high average annual soil loss, sediment yield, sediment production rate and poor groundwater recharge estimated in nine watersheds. The very high priority watersheds also have higher land slope, more intense rainfall and dense drainage network ensuing

Table: 8
Watersheds under different priority class in Andhiyarkhore catchment

Priority	Watersheds	Area (km^2)
Very High	SW-18, SW-16, SW-26, SW-19, SW-5, SW-23, SW-15, SW-17, SW-7	325.7
High	SW-4, SW-10, SW-37, SW-1, SW-11, SW-29, SW-21, SW-14, SW-27, SW-41, SW-6, SW-3, SW-24	569.3
Moderate	SW-48, SW-49, SW-39, SW-9, SW-12, SW-13, SW-50, SW-45, SW-42, SW-20, SW-22, SW-25, SW-40, SW-8, SW-2	714.8
Low	SW-30, SW-34, SW-33, SW-44, SW-28, SW-46, SW-43, SW-38, SW-32, SW-31	428.0
Very Low	SW-47, SW-35, SW-51, SW-36	143.0
Total		2181.0

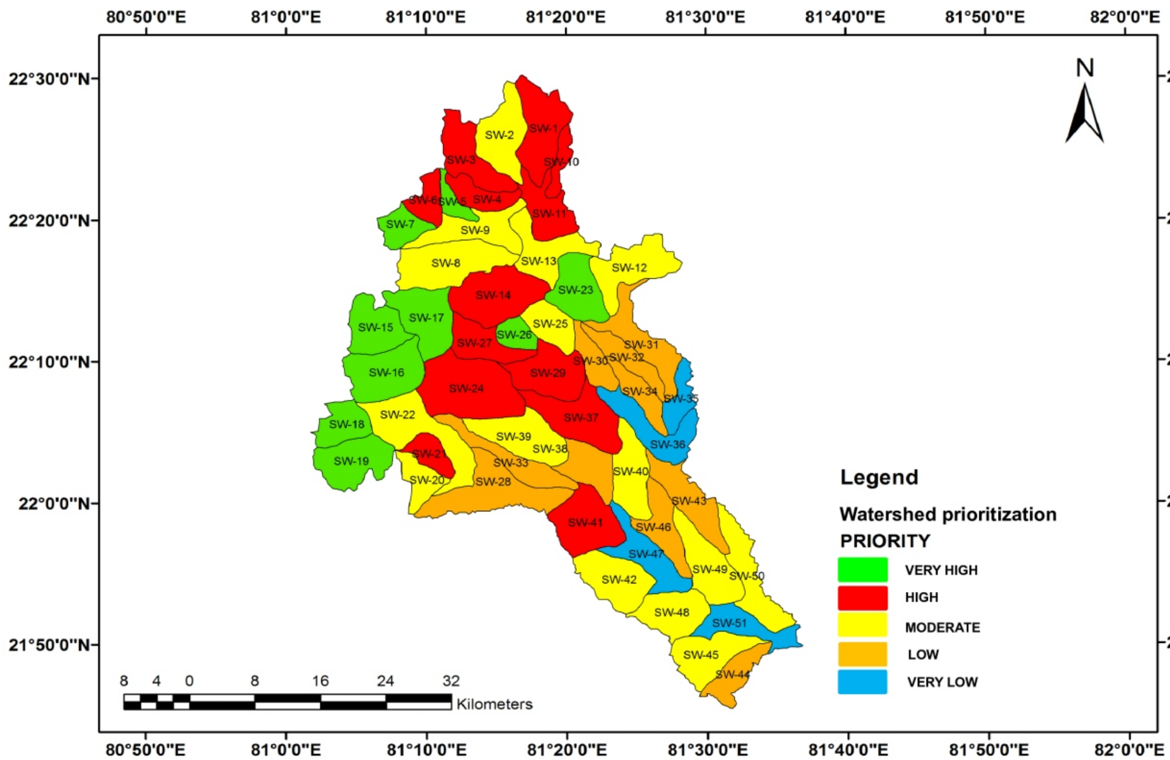

Fig. 2. Priority of delineated watersheds in Andhiyarkhore catchment

aggravated soil erosion and easy transportation of sediment. A specifically developed catchment area treatment plan entailing mechanical and biological measures is required to be immediately implemented in these nine watersheds.

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