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Prioritization of sub-catchments of a river basin using DEM and Fuzzy VIKOR

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Abstract

Fuzzy VIKOR, a decision making technique, is applied to prioritize 224 sub-catchments of Mahanadi Basin, India. Seven geomorphology based criteria viz., drainage density, bifurcation ratio, stream frequency, texture ratio, form factor, elongation ratio and circulatory ratio are estimated from five digital elevation models (DEMs). Triangular membership functions were formulated for each criterion for each sub-catchment which are based on individual values obtained from individual DEM's. Entropy method is employed for estimation of weights of criteria and a similar mechanism is followed while formulating triangular membership function for weights. Eight groups are formulated with a number of sub-catchments in each group as 5, 26, 69, 65, 29, 11, 12, 7 for taking up conservation measures. Effect of varying strategy weight, (v) on the ranking pattern is also studied and found that v value effects ranking pattern significantly.

Key words: digital elevation models, entropy, Fuzzy VIKOR, prioritization, sub-catchments

INTRODUCTION

Water is the most precious natural resource available on Earth. It is unequivocally one of the most important factors for the life to thrive and prosper. The steady rise of human and livestock population, urbanization, demands from other sectors and erratic rainfall have put pressure on this scarce resource and this pressure is likely to grow in the near future. It becomes imperative to form a strategy for effective, efficient and sustainable improving/development of catchments which are basis for water resources and land management. Alarmingly, problem of erosion is becoming more complex due to increasing human activities, deforestation, inadequate and poor farming practices and effects both quantity and quality of soil, accelerates sediment deposition in reservoirs, floodplains, and even impacts agriculture significantly. All these factors are eventually leading to deterioration of the quality of catchments in developing countries. Keeping this in view, catchments are expected to be improved such that expectations from them can be met. However, due to financial and other limitations, improvement, maintenance and management strategies cannot be implemented simultaneously for all the catchments necessitating prioritization. Accordingly, catchments which require earlier soil

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and water conservation treatment can be first improved and other catchments can follow as per their priority for improvements. Another lacuna for improvement is inadequate data availability of the catchments.

Water resources planners in the absence of adequate/precise/gauged data are employing geomorphological parameters (Rai *et al.* 2001; Kumar *et al.* 2017) i.e., linear parameters (Bifurcation Ratio, Drainage Density, Stream Flow Frequency and Texture Ratio) and shape parameters (Circulatory Ratio, Form Factor and Elongation Ratio) for characterizing the catchment and can be used as the basis for prioritizing the catchments. Kumar *et al.* (2017) mentioned that linear and shape parameters have a direct and inverse relationship with erodibility respectively. A higher value of linear parameters and low value of shape parameters represents higher erodibility (Raju & Nagesh Kumar 2013). Here prioritization or ranking is the process of arranging the catchments in the order of their importance, employing decision making algorithms facilitating the process of prioritization (Lee *et al.* 2015). Incorporating effective improvement strategies will not only lead to improvement of catchments over time, but will also enable to improve the socio-economic aspect of the area through the sustained generation of employment for the local population.

Complimentarily, digital elevation models' (DEMs) capability to yield more precise terrain information with much ease, accelerated the application of DEM based geomorphic models (Wolock & Price 1994; Williams *et al.* 2000). Noman *et al.* (2001) extensively reviewed delineation of flood plain from digital terrain models with various perspectives. Manfreda *et al.* (2011) highlighted the role of DEMs in detecting flood prone areas. They employed DEMs such as the ASTER global, Shuttle Radar Topography Mission (SRTM), and national elevation data to assess their sensitiveness to the chosen problem. They found that SRTM DEM is suitable for delineation of flood-prone areas. Yan *et al.* (2014) highlighted the role of DEMs as a main data source in the field of geomorphology. Papaioannou *et al.* (2015) analyzed the role of DEM derived geomorphological and hydrological attributes for identification of flood prone areas.

On the geomorphology aspects, Thakkar & Dhiman (2007) performed morphometric analysis and prioritization of eight watersheds of Mohr watershed, Gujarat, India. They also compared various morphological parameters. Rudraiah *et al.* (2008) studied part of Kagna river basin, Karnataka, India using remote sensing and geographical information systems (GIS). Javed *et al.* (2009) applied morphometric analysis for prioritization of sub-watersheds for Kanera watershed, Madhya Pradesh, India. Out of the seven sub-watersheds (SW1 to SW7), SW1 and SW6 qualified for high priority, whereas SW7 was categorized as medium priority. Deshmukh *et al.* (2011) analyzed eight watersheds (W1 to W8) adjacent to Narmada and Sher rivers for analysis of erodibility. It was found that the watersheds W5 and W6 were high and least degraded respectively. Javed *et al.* (2011) prioritized fourteen sub-watersheds (SW1 to SW14) of Jaggar watershed, Eastern Rajasthan based on morphometric analysis and land use/land cover categories. It was observed that only SW7 and SW10 fall under very high priority. Kanth & Hassan (2012) prioritized nineteen watersheds of Wular Catchment, India and a compound value was calculated for identifying highest, medium and low priority zones. Yasmin *et al.* (2013) performed morphometric analysis for Milli watershed, Karnataka, India using GIS. They found that GIS was useful for similar situations. Uniyal & Gupta (2013) prioritized twenty micro-watersheds (MW1 to MW20) of Bhilangana watershed of Uttarakhand, India and classified into high, medium and low priority for conservation and management. Raju & Nagesh Kumar (2013) applied TOPSIS for prioritizing twenty two micro-watersheds of Kherthal catchment, Rajasthan, India using seven geomorphological parameters. Entropy method was used to compute weights of geomorphological parameters. It was observed that the methodology adopted was found to be effective. Aher *et al.* (2014) identified critical and priority sub-watersheds in water scarce region of India and applied weighted sum analysis approach for ranking each hydrological unit. They found that 51.66% of sub-watersheds were in the moderately to highly susceptible zones.

Iqbal & Sajjad (2014) prioritized five watersheds, D1A, D1B, D1C, D2A, D2B of Dudhganga catchment. It was found that D1C and D1A fall under high and medium priority respectively. Jaiswal *et al.* (2014) prioritized thirty six sub-watersheds of Benisagar dam catchment of Bundelkhand region, Madhya Pradesh, India and applied Saaty's analytical hierarchy process with nine erosion hazards for identification of environmentally stressed sub-watersheds. Similar studies were also reported by Jaiswal *et al.* (2015) using fuzzy Analytic Hierarchy Process.

Patel *et al.* (2015) identified suitable sites for thirteen mini-watersheds of Hathmati for identifying water harvesting structures and found that watershed number 2 was of maximum priority. Makwana & Tiwari (2016) prioritized nineteen sub-watersheds in the semi-arid middle region of Gujarat, India using the compound parameter. They used remote SRTM data for the analysis. They opined that prioritization helps to implement soil conservation measures. Chandniha & Kansal (2017) performed prioritization of nine sub-watersheds of Piperiya watershed, Hasdeo river basin and classified them into high, medium and low priorities. Singh & Singh (2017) made an effort to prioritize sub-watersheds of Dangri River watershed, Haryana, India based on Snyder's synthetic unit hydrograph and grouped them as high, medium and low soil-erosive. They compared the outcome with land use/ land cover and morphometric analysis. Patel *et al.* (2012), Zhang *et al.* (2015), Khanday & Javed (2016) and Kumar *et al.* (2017) performed similar studies.

It is observed that (a) most of the studies used geomorphological parameters for ranking of the watersheds without assigning any weightage to them (b) no study was reported in fuzzy environment for ranking of the watersheds in geomorphological perspective. In other words, no study was reported in Indian conditions where DEM data from five sources were used for computing geomorphological parameters and on the basis of which ranking of sub-catchments were performed in fuzzy environment.

Keeping the above observations from the literature review and practical aspects into consideration, the objectives of the present study are formulated as follows:

- To estimate geomorphological parameters, namely, Drainage Density, Bifurcation Ratio, Stream Frequency, Texture Ratio, Form Factor, Elongation Ratio and Circulatory Ratio for all the 224 sub-catchments of Mahanadi Basin, India using five different DEM sources, namely, GMTED2010 7.5 arc-sec, SRTM (30 m & 90 m), ASTER and CARTOSAT-1.
- To explore the applicability of (a) Entropy method for obtaining weights for the parameters (b) Fuzzy VIKOR (Vise Kriterijumska Optimizacija I Kompromisno Resenje), a decision making technique, to prioritize 224 sub-catchments of Mahanadi Basin in India.

Present paper covers introduction, case study, description of methods, results and discussion followed by conclusions.

CASE STUDY

Mahanadi basin lies between East longitudes 80° 30′ and 86° 50′, and North latitudes 19° 15′ and 23° 35′. The basin is broadly divided into three sub-basins; Upper, Middle and Lower consisting of 91, 88, 48 sub-catchments (totalling to 227) (Figure 1). The climate in the basin is predominantly sub-tropical. The annual rainfall trend based on 34 years of India Meteorological Department (IMD) grid data shows a trend towards an increase of about 100 mm of rainfall since 1971. The annual variability of rainfall in the basin indicates that the year 1994 had the highest annual rainfall of ~1,780 mm whereas 1979 had the least rainfall in the past 34 years (~900 mm). The climate is predominantly sub-tropical. April and May are the hottest months. Maximum temperature hovers upto 40 °C (Jalali 2015).

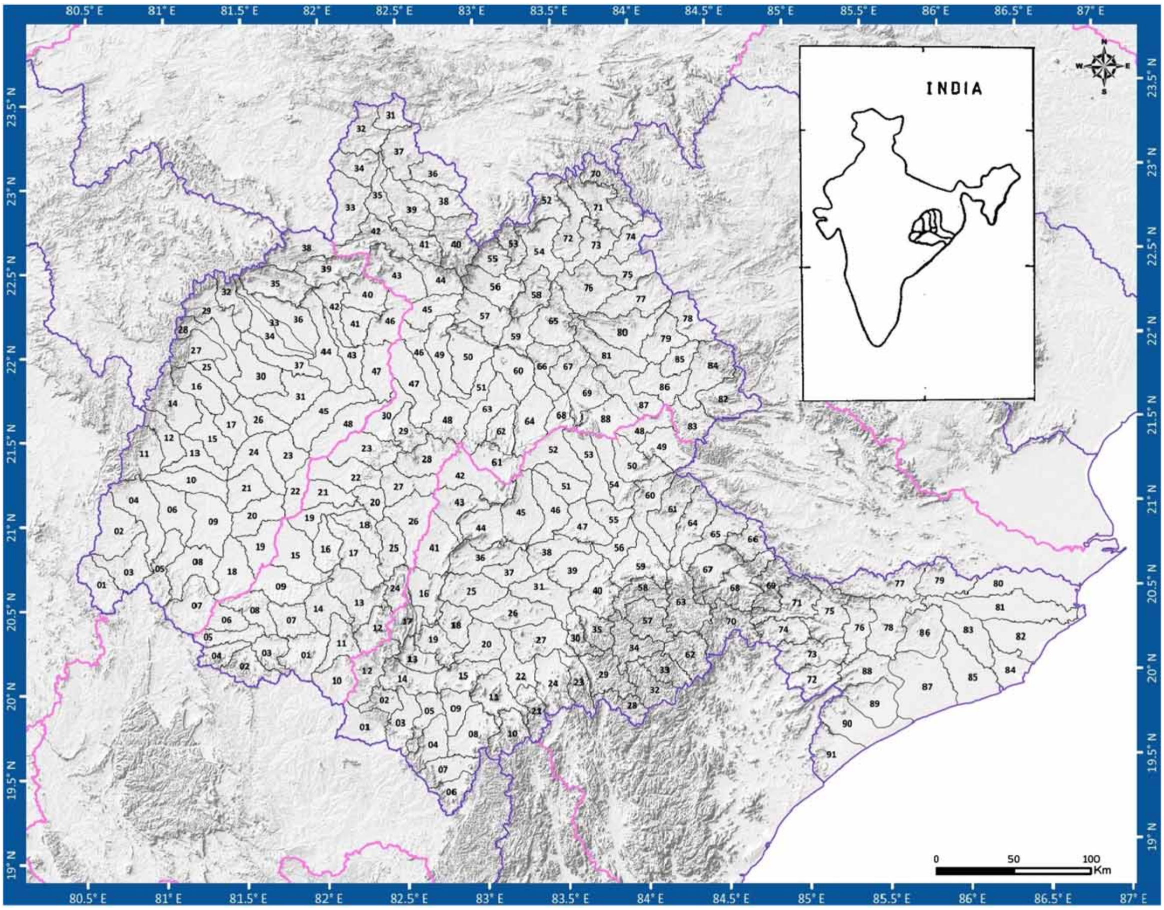

Figure 1 | Mahanadi Basin.

The Land Use/Land Cover (LULC) study of the basin for the year 2005–2006 shows 23 LULC classes. DEM data from GMTED2010 DEM (7.5 arc-sec; spatial resolution 231.525), SRTM DEM (1 arc-sec, 30.87 m; 3 arc-sec, 92.61 m), ASTER Global DEM (30.87 m) and CARTOSAT-1 DEM (30.87 m) are used for the analysis. Three sub-catchments, 21, 53 and 183 are not considered due to lack of data resulting in only 224 sub-catchments taken up for the present study. The Mahanadi basin has varying topography with the lowest elevation in coastal reaches and highest elevation found in Northern hills. The basin is divided into 11 elevation zones based on SRTM DEM. Major part of the plain region of the Mahanadi basin falls under the 200–400 m elevation zone. The middle Mahanadi sub-basin comprises of both high hilly terrain in its North-Eastern part and central table land which divides the Mahanadi middle and lower sub-basins. The elevation of middle Mahanadi sub-basin ranges between 500–1,000 m. Major part of the basin is covered with agricultural land and accounts for around 54.27% of the total basin area.

METHODS EMPLOYED AND METHODOLOGY

GIS analysis

GIS analysis was performed on all the DEM datasets for delineating sub-catchments which include Georeferencing, shape file creation, joining of DEM tiles and terrain pre-processing (repeated for 224 sub-catchments and for all DEM datasets).

Counting of streams

The number of streams present in each sub-catchment were counted for the estimation of geomorphological parameters (Refer Table 1). A program was developed for auto-counting of streams present in each sub-catchment. The output of the model gives information about each stream segment present in a catchment along with its stream order. This information was utilized to count number of streams present in each stream order. The point at which streams join another stream is called a node. In modern days, GIS programs can efficiently assign a unique number to each node present in stream network. 'From node number' is the point from which stream segment has originated. 'To node number' is the point at which a stream segment is terminating.

Table 1 | Mathematical expressions of geomorphological parameters (Raju & Nagesh Kumar 2013)

Parameter	Mathematical expression	Units
Basin length (L_b)	$1.312A^{0.568}$	km
Drainage density (D_d)	$\frac{L}{A}$	km^{-1}
Bifurcation ratio (R_b)	$\frac{N_u}{N_{u+1}}$	No units
Stream frequency (F_u)	$\frac{N'}{A}$	km^{-2}
Texture ratio (T)	$\frac{N_1}{P}$	km^{-1}
Form factor (R_f)	$\frac{A}{L_b^2}$	No units
Elongation ratio (R_e)	$1.128\frac{A^{0.5}}{L_b}$	No units
Circulatory ratio (R_c)	$12.57\frac{A}{P^2}$	No units

A = Area of catchment (Km^2); P = Perimeter of catchment (Km); L = Total length of stream segments of all orders (Km); N_u & N_{u+1} = Number of streams of a given order u and u + 1; N′ = Total number of stream segments of all orders; N_1 = Number of stream segments of first order.

Entropy method

Entropy method is employed to obtain weights of the geomorphological criteria (Raju & Nagesh Kumar 2014). Steps of the methodology are as follows:

1. Formulation of payoff matrix (Array of sub-catchments and geomorphological criteria) and computation of normalized payoff matrix (p_{ij}); i and j respectively represent sub-catchments (1,2,…m) and criteria (1,2,…n)
2. Entropy value for each geomorphological criteria j,

$$E_j = -\frac{1}{\ln(m)}\sum_{i=1}^{m} p_{ij}\ln(p_{ij}) \tag{1}$$

3. Computation of degree of diversification of criteria

$$D_j = 1 - E_j \tag{2}$$

4. Computation of weights of criteria

$$w_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \tag{3}$$

Fuzzy VIKOR

The first priority sub-catchment is obtained through Fuzzy VIKOR. Brief methodology of fuzzy VIKOR is as follows: ('f' was added before the variable to represent it as fuzzy variable) (Wu *et al.* 2016):

1. Input the fuzzy payoff matrix, fx_{ij} in triangular membership function form (l_{ij}, m_{ij}, u_{ij}) consisting of sub-catchments and criteria.
2. Identify fuzzy best value ff_j^* and worst value ff_j^{**} for each criterion; for example in case of maximization, such as benefit perspective, $ff_j^* = (l_j^*, m_j^*, u_j^*) = \text{Maximum } (l_{ij}, m_{ij}, u_{ij})$ and $ff_j^{**} = (l_j^{**}, m_j^{**}, u_j^{**}) = \text{minimum } (l_{ij}, m_{ij}, u_{ij})$; In case of minimization, such as cost perspective, $ff_j^* = (l_j^*, m_j^*, u_j^*) = \text{Minimum } (l_{ij}, m_{ij}, u_{ij})$ and $ff_j^{**} = (l_j^{**}, m_j^{**}, u_j^{**}) = \text{maximum } (l_{ij}, m_{ij}, u_{ij})$
3. Computation of normalized fuzzy difference

$$fd_{ij} = \frac{ff_j^* - fx_{ij}}{u_j^* - l_j^{**}} (\text{Maximization perspective}) \tag{4}$$

$$fd_{ij} = \frac{fx_{ij} - ff_j^*}{u_j^{**} - l_j^*} (\text{Minimization perspective}) \tag{5}$$

4. Computation of index values $fS_i(S_i^l, S_i^m, S_i^u)$ and $fR_i(R_i^l, R_i^m, R_i^u)$ representing the separation measures for sub-catchment A_i from the best and worst values (Lee *et al.* 2015).

$$fS_i = \sum_{j=1}^{n} (w_l, w_m, w_u) \otimes (d_{ijl}, d_{ijm}, d_{iju}) \tag{6}$$

$$fR_i = Max\ (w_l, w_m, w_u) \otimes (d_{ijl}, d_{ijm}, d_{iju}) \tag{7}$$

5. Computation of values of summation operator fQ_i, using the Equation (8)

$$fQ_i = v\left[\frac{fS_i - fS_{\min}}{S_{\max}^u - S_{\min}^l}\right] + (1-v)\left[\frac{fR_i - fR_{\min}}{R_{\max}^u - R_{\min}^l}\right] \tag{8}$$

where

$$fS_{\min} = Min\ fS_i = (S_{\min l}, S_{\min m}, S_{\min u}) \tag{9}$$

$$fR_{\min} = Min\ fR_i = (R_{\min l}, R_{\min m}, R_{\min u}) \tag{10}$$

$$S_{\max}^u = MaxS_i^u;\ S_{\min}^l = MinS_i^l \tag{11}$$

$$R_{\max}^u = MaxR_i^u;\ R_{\min}^l = MinR_i^l \tag{12}$$

v represents maximum group utility strategy weight and (1-v) is the weight of the individual regret function. v varies from 0 to 1. Defuzzification of fQ_i yields

$$Q_i = \frac{(fQ_{il} + fQ_{im} + fQ_{iu})}{3} \tag{13}$$

which provides crisp value. Lower Q_i value based sub-catchment is preferred for analysis and can be given priority for taking up soil and conservation improvements.

The flowchart of the approach developed is presented in Figure 2.

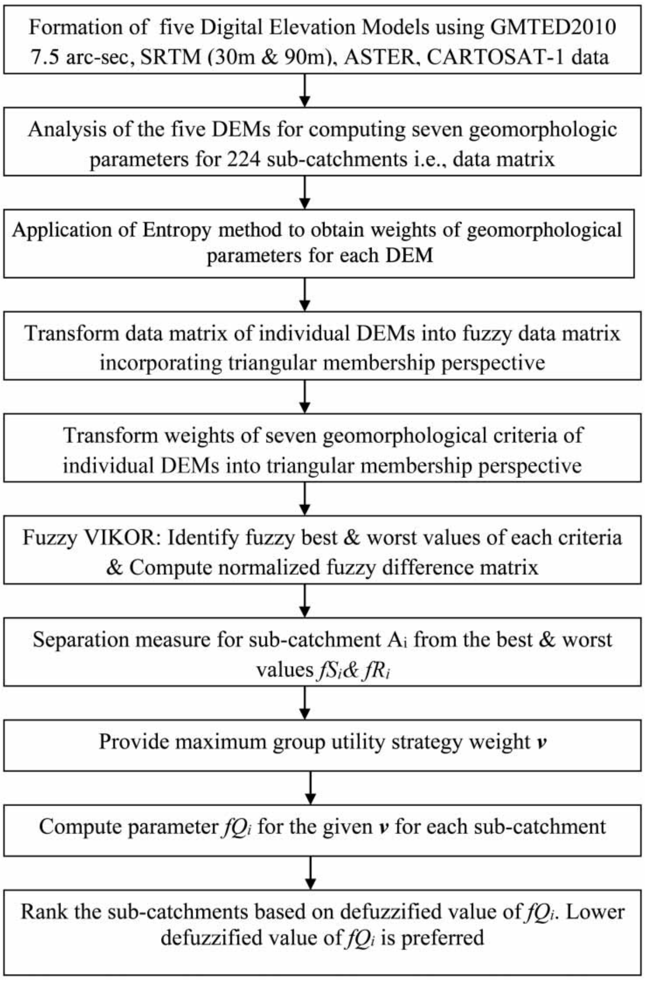

Figure 2 | Flow chart of Fuzzy VIKOR Methodology.

RESULTS AND DISCUSSION

Estimation of geomorphological parameters and weights

Total number of pixels present in DEM raster was estimated using GIS software and procedure mentioned above is used for finding the area, perimeter and length of each sub-catchment. MatLab (www.mathworks.com) based program was developed for computation of the seven geomorphological parameters for all 224 sub-catchments based on the information in Table 1. Minimum and maximum values obtained among 5 DEMs for Drainage density, Bifurcation ratio, Stream Frequency, Texture Ratio, Form Factor, Elongation Ratio and Circulatory Ratio respectively are (0.053, 0.107), (2, 13), (0.002, 0.051), (0.008, 0.23), (0.211, 0.263), (0.519, 0.579), (30.25, 108.3) and corresponding differences are (0.054, 11, 0.049, 0.222, 0.052, 0.06, 78.05). Significant variation is observed for some geomorphological parameters across all DEM sets. The present study aims at handling the variation in fuzzy environment for better modeling of the case study and suggests a methodology where variation is observed in similar situations elsewhere.

Weights of criteria related to each DEM are computed using entropy method (Equations (1)–(3)). Table 2 presents weights of the various parameters for the 5 DEM sources. It is observed that texture ratio, bifurcation ratio and stream frequency contribute around 85% of total weightage whereas remaining four criteria contribute around 15% while ranking sub-catchments. In all the DEM sources, Texture ratio, bifurcation ratio and stream frequency are occupying first three positions.

Table 2 | Weights of geomorphological criteria

Parameter	GMTED2010 7.5 arc-sec	SRTM90	SRTM30	ASTER	CARTOSAT-1	Triangular membership function perspective
Drainage density	0.0472	0.0420	0.0429	0.0502	0.0445	(0.042, 0.0445, 0.0502)
Bifurcation ratio	0.2890	0.2907	0.2697	0.2564	0.3009	(0.2564, 0.2890, 0.3009)
Stream frequency	0.2043	0.2186	0.2337	0.2058	0.2020	(0.2020, 0.2058, 0.2337)
Texture ratio	0.3576	0.3578	0.3609	0.3789	0.3563	(0.3563, 0.3578, 0.3789)
Form factor	0.0046	0.0041	0.0042	0.0049	0.0044	(0.0041, 0.0044, 0.0049)
Elongation ratio	0.0012	0.0010	0.0011	0.0012	0.0011	(0.001, 0.0011, 0.0012)
Circulatory ratio	0.0962	0.0857	0.0875	0.1025	0.0908	(0.0857, 0.0908, 0.1025)

Membership function formulation

Triangular membership functions are proposed to handle the deviation of geomorphological parameters obtained from the 5 DEMs. For example, bifurcation ratios obtained for DEMs 1 to 5 for sub-catchment 2 are 3.1667, 3.1667, 3.2407, 3.119, 3.4643 and these values are arranged in the ascending order 3.119, 3.1667, 3.1667, 3.2407, 3.4643. While formulating in triangular membership form, first, third and last values are chosen as the elements representing lower, middle and upper (l, m, u) i.e., (3.119, 3.1667, 3.4643). Similar process is repeated for all the seven parameters for all the 224 sub-catchments respectively. Similar procedure is adopted for weights of criteria for formulation of triangular membership. These are presented as part of Table 2.

Ranking/grouping of the sub-catchments

MatLab based Fuzzy VIKOR code is developed for ranking the 224 sub-catchments based on the formulated payoff matrix in a fuzzy environment. Various steps employed in ranking/grouping the sub-catchments are as follows:

Main aim of normalized fuzzy difference matrix is to make the data dimensionless. This is required when different features are simultaneously considered. High values of first four criteria, Drainage Density, Bifurcation Ratio, Stream Frequency, Texture Ratio are preferred whereas low values of Form Factor, Elongation Ratio and Circulatory Ratio are preferred (Kumar *et al.* 2017). Accordingly, normalized fuzzy difference matrix values are computed (Equations (4) and (5)).

Bifurcation Ratio values for sub-catchment 1 are (2.556, 2.6111, 2.6111). Ideal (f_j^*) and anti-ideal (f_j^{**}) values for each Bifurcation Ratio are found to be (11, 12, 13) and (2, 2, 2) and accordingly u_j^* and l_j^{**} values are chosen as 13 and 2. Based on Equation (4), normalized fuzzy difference value is:

$$fd_{ij} = \frac{ff_j^* - fx_{ij}}{u_j^* - l_j^{**}} = \frac{(11, 12, 13) - (2.556, 2.6111, 2.6111)}{13 - 2} = \frac{(11 - 2.6111, 12 - 2.6111, 13 - 2.556)}{11}$$

or (0.7626, 0.8535, 0.9495). Similar computations yield normalized fuzzy difference matrix values for other parameters. Equations (6)–(13) were applied for 224 sub-catchments using the described methodology for computing fS_i, fR_i, fQ_i. Lower Q_i is preferred and ranking is performed accordingly. Table 3 presents ranking pattern/grouping of the sub-catchments.

Table 3 | Ranking pattern/grouping of the sub-catchments (for $v = 0.5$)

Group	Number of catchments	List of Sub-catchments	Q value	Improvement Priority ranking
1	5	26, 44, 47, 158, 179	0.03–0.09	1
2	26	2, 5, 11, 18, 30, 34, 36, 37, 38, 40, 78, 96, 108, 130, 141, 142, 148, 149, 153, 174, 175, 183, 190, 197, 200,220	0.10–0.15	2
3	69	3, 4, 6, 7, 9, 14, 16, 20, 22, 23, 28, 29, 35, 39, 45, 48, 52, 55, 59, 61, 63, 69, 71, 73, 74, 79, 82, 85, 86, 88, 93, 98, 99, 100, 103, 104, 106, 109, 111, 113, 117, 118, 122, 123, 126, 128, 135, 137, 138, 143, 156, 159, 160, 161, 163, 164, 167, 169, 172, 178, 180, 185, 186, 195, 196, 201, 203, 211, 212	0.16–0.20	3
4	65	1, 8, 10, 12, 13, 15, 19, 21, 24, 25, 27, 31, 46, 49, 50, 53, 54, 56, 57, 60, 67, 68, 72, 76, 80, 81, 83, 89, 91, 94, 102, 105, 107, 114, 120, 121, 125, 129, 133, 140, 144, 145, 151, 154, 157, 166, 168, 170, 171, 173, 177, 181, 184, 191, 192, 193, 194, 198, 204, 205, 206, 207, 219, 221, 222	0.21–0.25	4
5	29	17, 43, 51, 62, 65, 77, 84,90, 95, 101, 110, 115, 116, 119, 124, 127, 132, 136, 146, 165, 176, 182, 189, 199, 202, 208, 209, 218, 223	0.26–0.30	5
6	11	33, 41, 58, 87, 134, 147, 150, 152, 188, 214, 216	0.31–0.35	6
7	12	66, 70, 75, 92, 112, 131, 139, 155, 187, 210, 213, 224	0.36–0.40	7
8	7	32, 42, 64, 97, 162, 215, 217	0.41–0.45	8

It is observed that Q_i values for most of the catchments are almost same with minute differences. Keeping this in view, grouping of the catchments is performed instead of ranking based on the range of Q_i values. A total of eight groups are formulated with number of catchments in each group as 5, 26, 69, 65, 29, 11, 12, 7 respectively. Highest number of catchments are falling in group 3 and 4 with a Q value range of 0.16–0.20 & 0.21–0.25. It is observed that group 1 can be explored for improvement on a priority basis and accordingly other groups can be improved as noted in Table 3.

Ranking method proposed here facilitates prioritization of sub-catchments. These sub-catchments based on their priority can be provided suitable conservation measures which ultimately are expected to provide sustainable water management practices in the Mahanadi river basin. Some of the conservation measures that can be explored are check dams, initiation of woody plants, masonry stone bunds construction, gullies reforestation, ponds and embankments. However, precise information on the magnitude and rates of erosion and sedimentation and socioeconomic and environmental effects are key to success in implementing sustainable soil conservation programs.

Sensitivity analysis

Effect of strategy weight (v) in fuzzy VIKOR on the ranking pattern is also studied and presented in Table 4. Values of 'v' are varied from 0 to 1. It is found that sub-catchment 158 occupied first position (for v values 0 to 0.6) whereas sub-catchment 179 occupied first position (for v values 0.7 to 0.8) and sub-catchment 11 in case of v values of 0.9 to 1. In case of second position, these are sub-catchment 47 (v values from 0 to 0.3) and 179 (from 0.4 to 0.6). To our knowledge, this is the first application of fuzzy VIKOR for ranking sub-catchments in Mahanadi Basin using morphological data explored from five DEM sources.

Table 4 | Effect of strategy weight on the top 5 sub-catchments

Rank	$v = 0$	$v = 0.1$	$v = 0.2$	$v = 0.3$	$v = 0.4$	$v = 0.5$	$v = 0.6$	$v = 0.7$	$v = 0.8$	$v = 0.9$	$v = 1.0$
1	158	158	158	158	158	158	158	179	179	11	11
2	47	47	47	47	179	179	179	158	11	2	2
3	44	44	179	179	47	47	47	26	158	179	179
4	130	179	44	44	44	26	26	11	26	26	200
5	179	130	130	130	26	44	11	2	2	200	26
6	128	128	30	26	130	175	36	36	36	36	36
7	190	30	175	175	175	130	44	47	200	158	158
8	100	175	26	30	5	36	2	200	47	175	175
9	30	190	5	5	30	5	175	175	175	47	141
10	126	5	128	197	36	30	200	44	141	141	5

The methodology proposed in the present study utilizes only the topographic information to prioritize the sub-catchments. This method can be easily applied to areas which do not have sufficient data for detailed hydraulic studies.

CONCLUSIONS

In this study, data from five DEM sources i.e., GMTED2010 7.5 arc-sec, SRTM90, SRTM30, ASTER and CARTOSAT-1 were used to calculate the 7 geomorphological parameters for 224 sub-catchments of Mahanadi basin. Fuzzy VIKOR, was utilized for prioritizing the sub-catchments. Eight groups of sub-catchments were formulated for possible implementation of conservation measures for the chosen strategy weight of 0.5. However, careful selection of strategy weight is essential for meaningful inferences from the present study. Present study is preliminary work initiated to evaluate the study area in terms of sub-catchments prioritization. This will be followed by field validation which is targeted as further study.

REFERENCES

Aher, P. D., Adinarayana, J. & Gorantiwar, S. D. 2014 Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: a remote sensing and GIS approach. *J. Hydrol.* **511**, 850–860, DOI:10.1016/j.jhydrol.2014.02.028.

Chandniha, S. K. & Kansal, M. L. 2017 Prioritization of sub-watersheds based on morphometric analysis using geospatial technique in Piperiya watershed, India. *Appl. Water Sci.* **7**(1), 329–338, DOI:10.1007/s13201-014-0248-9.

Deshmukh, D. S., Chaube, U. C., Tignath, S. & Pingale, S. M. 2011 Geomorphological analysis and distribution of badland around the confluence of Narmada and Sher river, India. *Eur. Water* **36**, 15–26.

Iqbal, M. & Sajjad, H. 2014 Watershed prioritization using morphometric and land use/land cover parameters of Dudhganga catchment Kashmir valley India using spatial technology. *J. Geophys. Remote Sens.* **3**(1), 1–12, DOI:10.4172/2169-0049.1000115.

Jaiswal, R. K., Thomas, T., Galkate, R. V., Ghosh, N. C. & Singh, S. 2014 Watershed prioritization using Saaty's AHP based decision support for soil conservation measures. *Water Resour. Manage.* **28**(2), 475–494, DOI:10.1007/s11269-013-0494-x.

Jaiswal, R. K., Ghosh, N. C., Lohani, A. K. & Thomas, T. 2015 Fuzzy AHP based multi criteria decision support for watershed prioritization. *Water Resour. Manage.* **29**(12), 4205–4227, DOI:10.1007/s11269-015-1054-3.

Jalali, A. 2015 *Prioritization of Sub-Catchments of Mahanadi Basin Based on Geomorphology*. M.Tech Dissertation, Indian Institute of Science, Bangalore.

Javed, A., Khanday, M. Y. & Ahmed, R. 2009 Prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS techniques. *J. Indian Soc. Remote Sens.* **37**(2), 261–274, DOI:10.1007/s12524-009-0016-8.

Javed, A., Khanday, M. Y. & Rais, S. 2011 Watershed prioritization using morphometric and land use/land cover parameters: a remote sensing and GIS based approach. *J. Geol. Soc. India* **78**(1), 63–75, DOI:10.1007/s12594-011-0068-6.

Kanth, T. A. & Hassan, Z. 2012 Morphometric analysis and prioritization of watersheds for soil and water resource management in Wular catchment using geo-spatial tools. *Int. J. Geol. Earth Environ. Sci.* **2**(1), 30–41.

Khanday, M. Y. & Javed, A. 2016 Prioritization of sub-watersheds for conservation measures in a semi-arid watershed using remote sensing and GIS. *J. Geol. Soc. India* **88**(2), 185–196, DOI:10.1007/s12594-016-0477-7.

Kumar, L., Khalkho, D., Katre, P. & Nigam, G. K. 2017 Prioritization of sub watersheds using morphometric analysis: a remote sensing and GIS perspective. *Int. J. Innov. Res. Sci. Eng. Technol.* **6**(1), 135–146, DOI:10.15680/IJIRSET.2017.0601017.

Lee, G., Jun, K. S. & Chung, E. S. 2015 Group decision-making approach for flood vulnerability identification using the fuzzy VIKOR method. *Nat. Hazards Earth Syst. Sci.* **15**, 863–874, DOI:10.5194/nhess-15-863-2015.

Makwana, J. & Tiwari, M. K. 2016 Prioritization of agricultural sub-watersheds in semi- arid middle region of Gujarat using remote sensing and GIS. *Environ. Earth Sci.* **75**, 137, DOI:10.1007/s12665-015-4935-0.

Manfreda, S., Leo, M. D. & Sole, A. 2011 Detection of flood-prone areas using digital elevation models. *J. Hydrol. Eng.* **16**(10), 781–790, DOI:10.1061/(ASCE)HE.1943-5584.0000367.

Noman, N. S., Nelson, E. J. & Zundel, A. K. 2001 A review of automated flood plain delineation from digital terrain models. *J. Water Resour. Plann. Manage.* **127**(6), 394–402, DOI:10.1061/(ASCE)0733-9496(2001)127:6(394).

Papaioannou, G., Vasiliades, L. & Loukas, A. 2015 Multi-Criteria analysis framework for potential flood prone areas mapping. *Water Resour. Manage.* **29**, 399–418, DOI:10.1007/s11269-014-0817-6.

Patel, D. P., Dholakia, M., Naresh, N. & Srivastava, P. K. 2012 Water harvesting structure positioning by using geo-visualization concept and prioritization of mini-watersheds through morpho-metric analysis in the lower Tapi basin. *J. Indian Soc. Remote Sens.* **40**(2), 299–312, DOI:10.1007/s12524-011-0147-6.

Patel, D. P., Srivastava, P. K., Gupta, M. & Nandhakumar, N. 2015 Decision support system integrated with geographic information system to target restoration actions in watersheds of arid environment: a case study of Hathmati watershed, Sabarkantha district, Gujarat. *J. Earth Sys. Sci.* **124**(1), 71–86, DOI:10.1007/s12040-014-0515-z.

Rai, S. P., Kumar, V. & Goyal, V. C. 2001 *Geomorphology and Soil Erosion in Juni Nadi Watershed, District Udhampur, J& K.* National Institute of Hydrology, Roorkee, Report No. CS/AR-4/2000-2001, pp. 1–29.

Raju, K. S. & Nagesh Kumar, D. 2013 Prioritization of micro-catchments based on morphology. *Proc. Inst. Civil Eng. Water Manage.* **166**(WM7), 367–380. DOI/10.1680/wama.11.00076.

Raju, K. S. & Nagesh Kumar, D. 2014 *Multicriterion Analysis in Engineering and Management.* Prentice Hall of India, New Delhi.

Rudraiah, M., Govindaiah, S. & Vittala, S. S. 2008 Morphometry using remote sensing and GIS techniques in the sub-basins of Kagna river basin, Gulburga district, Karnataka, India. *J. Indian Soc. Remote Sens.* **36**(4), 351–360, DOI:10.1007/s12524-008-0035-x.

Singh, N. & Singh, K. K. 2017 Geomorphological analysis and prioritization of sub-watersheds using Snyder's synthetic unit hydrograph method. *Appl. Water Sci.* **7**(1), 275–283, DOI:10.1007/s13201-014-0243-1.

Thakkar, A. K. & Dhiman, S. D. 2007 Morphometric analysis and prioritization of miniwatersheds in Mohr watershed, Gujarat using remote sensing and GIS techniques. *J. Indian Soc. Remote Sens.* **35**(4), 313–321, DOI:10.1007/BF02990787.

Uniyal, S. & Gupta, P. 2013 Prioritization based on morphometric analysis of Bhilangana watershed using spatial technology. *Int. J. Remote Sens. Geosci.* **2**(1), 49–57.

Williams, W. A., Jensen, M. E., Winne, J. C. & Redmond, R. L. 2000 An automated technique for delineating and characterizing valleybottom settings. *Environ. Monit. Assess.* **64**(1), 105–114, DOI:10.1023/A:1006471427421.

Wolock, D. M. & Price, C. V. 1994 Effects of digital elevation model map scale and data resolution on a topography-based watershed model. *Water Resour. Res.* **30**(11), 3041–3052, DOI:10.1029/94WR01971.

Wu, Z., Ahmad, J. & Xu, J. 2016 A group decision making framework based on fuzzy VIKOR approach for machine tool selection with linguistic information. *Appl. Soft Comput.* **42**, 314–324, DOI:10.1016/j.asoc.2016.02.007.

Yan, K., Tarpanelli, A., Balint, G., Moramarco, T. & Baldassarre, G. D. 2014 Exploring the potential of SRTM topography and radar altimetry to support flood propagation modeling: Danube case study. *J. Hydrol. Eng.* **20**(2), 04014048, DOI:10.1061/(ASCE)HE.1943-5584.0001018.

Yasmin, K., Polisgowdar, B. S., Kumar, U. S., Ayyangoudar, M. S. & Rao, K. N. 2013 Morphometric analysis of Milli watershed of Raichur district using GIS techniques. *Karnataka J. Agric. Sci.* **26**(1), 92–96.

Zhang, H. Y., Shi, Z. H., Fang, N. F. & Guo, M. H. 2015 Linking watershed geomorphic characteristics to sediment yield: evidence from the Loess Plateau of China. *Geomorphology* **234**, 19–27, DOI:10.1016/j.geomorph.2015.01.014.