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Sub-Watersheds Prioritization for Groundwater Conservation Based on Drainage Morphometry using Geospatial Techniques: A Case Study of Seer Khad Watershed, Himachal Pradesh.

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Abstract

Groundwater is a vital resource for humans and an inseparable component of the hydrological cycle. Among the numerous elements of watershed prioritization, morphometric characteristics are critical for effective water resource planning and management using geospatial techniques. This research examines the Seer Khad Watershed for the prioritization of sub-watersheds. ASTER DEM (30m resolution) is used to extract watersheds and calculate morphometric parameters. This work employs the compound value method to rank the parameters derived from watershed morphometric analysis. SW-XV has the highest Rb value (6.0), which implies high geological control and low groundwater potential, whereas SW-XIII has the lowest Rb (1.53), indicating high groundwater potential. SW-XV has a Re value of 0.46, demonstrating an elongated basin with low groundwater potential, and SW-I has a Re value of 0.93, showing a nearly circular basin with high groundwater potential. The high Rn value (1.44) of SW-VIII indicates rugged terrain with low groundwater potential. The final results of this study revealed that out of 18 sub-watersheds (SWs), 15.37% area of watershed laying in very high priority zone (SW-II, X, XIII, XVII) need urgent attention for management, 14.17% area of watershed included in high priority zone (SW-VII, XI, XV) and three sub-watersheds viz. V, VI, and XVI constituted 16.57% area and are denoted as a zone of very low priority.

Keywords: Groundwater, Geospatial Techniques, Morphometry, Watershed Prioritization, Seer Khad Watershed.

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Introduction

Water is the blood of the Earth, and rivers are its veins (Zavoianu, 1985). All kinds of animals, trees, and insects directly depend on water. Together with land, water is the most critical resource that motivates development and other economic activities (Choudhari et al., 2018). Because of the scarcity of surface water sources in hilly areas, groundwater is an important natural resource essential for meeting water supply demands (Tiwari & Kushwaha, 2018). Groundwater means water below the surface of the Earth, which is recharged through the surface water bodies and drainage (Bharathkumar & Mohammed-Aslam, 2016). Explosive growth in urbanization, industrialization, population and other developmental activities both numerically and qualitatively decrease groundwater resources (Jayakumar et al., 2013). Due to its greater dependability as a source of water supply, particularly during summer, groundwater evaluation, development, and wise utilization should be emphasized more. Consequently, the proper research, management, and planning of limited groundwater sources through river basin prioritization are vital. (Rai et al., 2017; Prakash et al., 2019).

Morphometric analysis is defined as the calculation of the Earth's surface configuration and landform's dimension (Clarke, 1996). It is an important tool for studying hydrological systems (A. Kumar & Jayappa, 2011). Morphometric analysis ensures that drainage basin geometry is accurately described mathematically in terms of its shape, slope, structural control, rock permeability and diastrophism, geological and geomorphological history (Strahler, 1964). This study includes the three morphometric aspects viz. linear (Stream Order, Stream Length, Bifurcation Ratio, Stream Number), areal (Stream Frequency, Drainage Texture, Drainage Density, Circularity Ratio, Elongation Ratio) and relief (Slope, Basin Relief, Relief Ratio, Ruggedness Number).

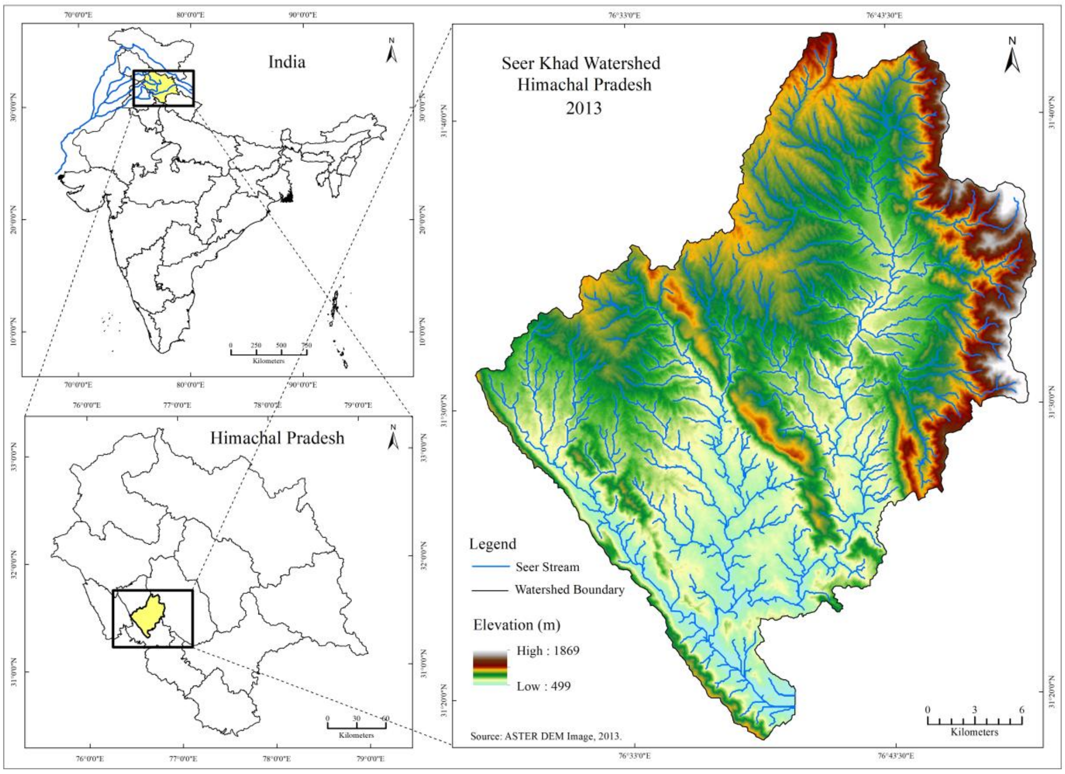
Remote Sensing and GIS techniques emerged as highly effective tools for analyzing stream networks, basin geometry, quantitative explanations of watershed morphology, and studies of watersheds through their prioritization (Bharathkumar & Mohammed-Aslam, 2016; Gemeda et al., 2019). This technique enables the examination of various morphometric characteristics and efficiently establishes the links between drainage morphometry and landform attributes (Parveen et al., 2012). In India, several researchers have used remote sensing and GIS techniques to prioritize drainage basins using morphometric analysis (Abhilash & Jayapal, 2018; Ahmad et al., n.d.; Farhan, 2017; Islam & Deb Barman, 2020; Parveen et al., 2012; Rai et al., 2018; Reddy et al., 2004; Sreedevi et al., 2009b; Subba Rao, 2009; Suma & Srinivasa, 2017; Sutradhar, 2020).

In the current study, sub-watersheds of the Sheer Khad River basin of Himachal Pradesh are prioritized and subjected to morphometric analysis. The drainage density, bifurcation ratio, stream length, stream frequency, elongation ratio, circulatory ratio and other watershed morphometric data are derived. The current study's objectives are (i) to extract morphometric parameters of Seer Khad Watershed using RS and GIS and (ii) to prioritize sub-watersheds based on groundwater potential and conservation measures.

Study Area

The Seer Khad (Stream) is located in the Shivalik Himalayas of the lower Satluj basin and drains into the Govind-Sagar Lake developed as the consequence of the Bhakra-Nangal Dam built-in 1962. The Seer Khad originated near Wah Devi , joined by Sukkar Khad from the right side near Jhanduta town and at last merged with Satluj near Silh village . Watershed of the river located between the 31˚18'25'' to 31˚42'52'' N latitude and 76˚ 26'47'' to 76˚49'5'' E longitude. The study area's elevation varies between 499 to 1869 m amsl. It constitutes an area of 791 sq. km and has a perimeter of 168 km. The whole study area is covered by four Survey of India toposheets (53A/10, 53A/11, 53A/14, 53A/15 on a scale of 1:50000). Watershed of the river is expanded into three districts, viz. Bilaspur, Hamirpur, and Mandi. The Bilaspur district covers the largest area, and the smallest is by Mandi.

Fig. 1 Location Map of Study Area

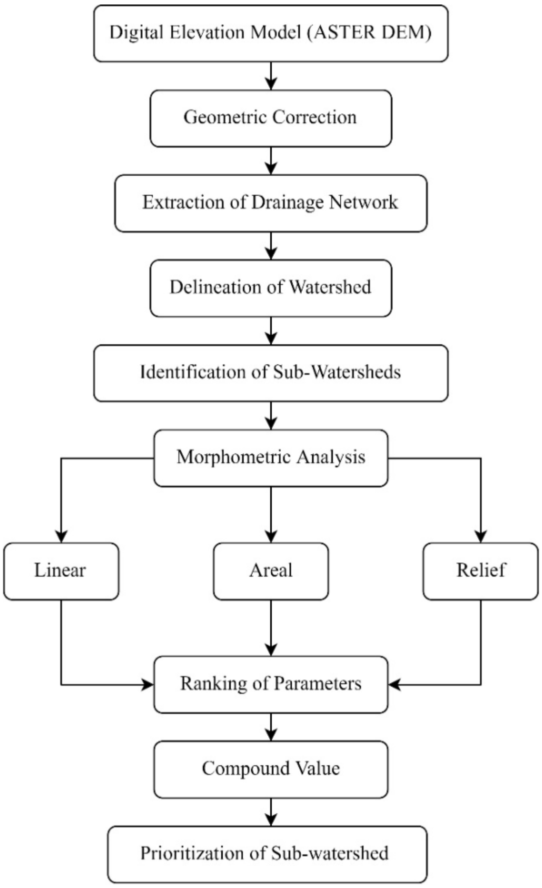


Methodology

This study intended to prioritize the sub-watersheds of the Seer Khad. Survey of India (SOI) topographical maps (53A/10, 53A/11, 53A/14, 53A/15 on a scale of 1:50000) are used to extract the base map of the Seer Khad drainage basin. ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM (Digital Elevation Model) is used to delineate the drainage basin boundary of Seer Khad and prepare slope and contour maps. ASTER DEM is freely available on USGS Earth Explorer (https://earthexplorer.usgs.gov/) with one arc-second resolution and a grid cell size of about 30 m. After the geometric and radiometric correction, the satellite image (ASTER DEM) is georeferenced using the ArcGIS programme and projected to UTM, WGS 1984, Zone 43/N. In order to extract the drainage network, the first step is to fill in the gaps present in the DEM and then compute slope, flow direction, flow accumulation, and stream order. This process is done with the help of tools from spatial analyst and the ArcHydro section of the Arctool box. Horton's (1945) laws are used to analyze drainage networks, and Strahler's (1964) stream ordering approach is used to determine the order of the streams (A. Kumar & Jayappa, 2011). The sub-basins' various morphometric parameters (linear, areal, and relief) according to their suitability for assessing groundwater conditions, are estimated using recognized mathematical methods (A. Kumar &

Jayappa, 2011), shown in Table 1. After the computation of all morphometric parameters, their compound value is ranked for sub-watersheds prioritization. A detailed flow chart of methodology is depicted in Fig. 2.

Fig. 2 Flow Chart of Methodology



Slope & Geology

Geologically Pre-Cambrian to Quaternary rock formations make up the watershed's landmass. Undifferentiated Proterozoic rocks include carbonaceous phyllite, schist, gneiss, quartzite, and marble (Fig. 3). The slope is also a vital aspect that controls the runoff. North Eastern part of the watershed has steep slopes, and the middle part has gentle slopes (Fig. 4). Steep slopes have a low potential for groundwater availability because of high runoff, and gentle slopes have a high probability of groundwater presence beneath the surface.

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Fig. 3 Regional Geology and Lithology

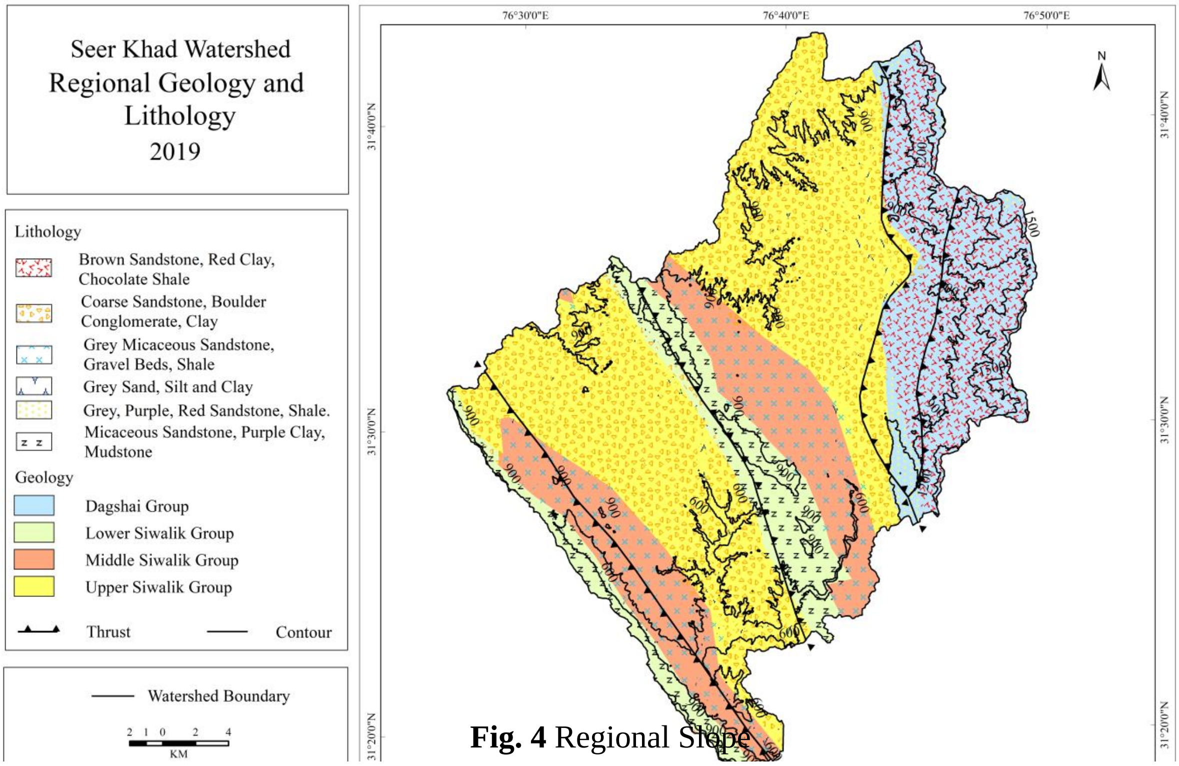
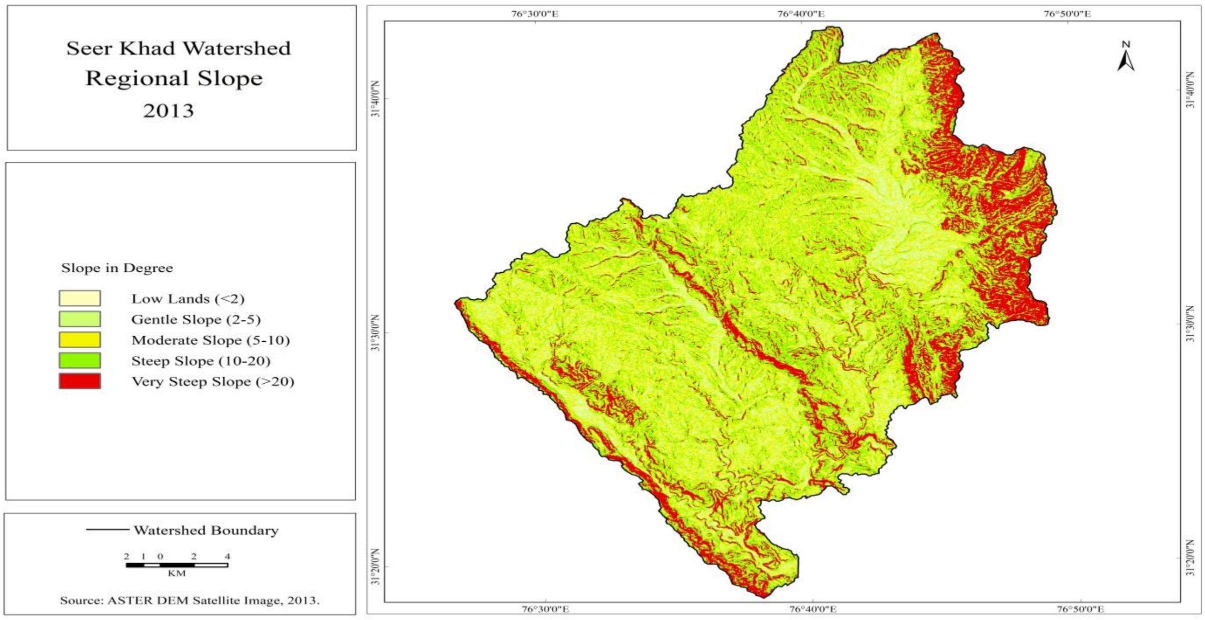


Fig. 4 Regional Slope



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Results and discussions

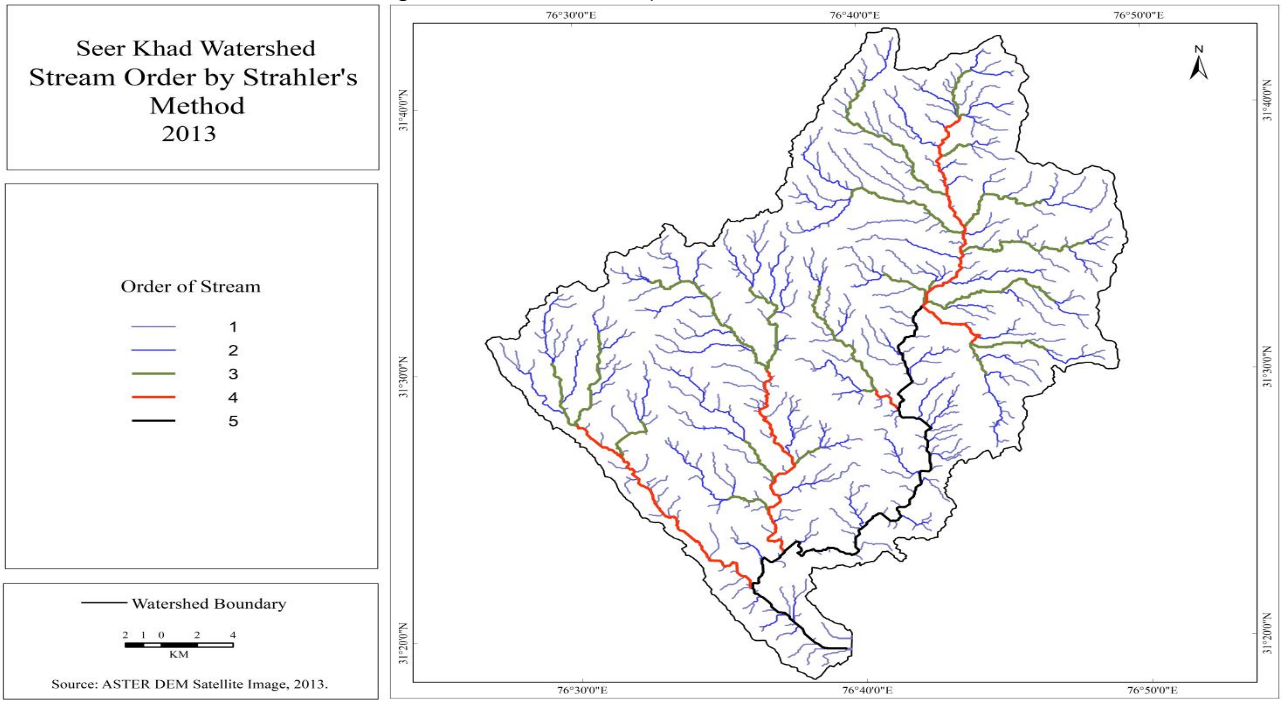
The study area is defined using ASTER DEM image, and then it is subdivided into 18 sub-watersheds using the ArcGIS software and coded as SW-I to SW-XVIII. The linear, areal and relief aspects are measured.

Estimation of Linear Aspects

Stream Order

Strahler's method of stream order is used in this study. Higher stream order is associated with greater discharge (Ozdemir & Bird, 2009) and is controlled by the watershed's shape, size, and distribution (Haghipour et al., 2012). Lower-order streams are short-lived, whereas higher-order streams are mostly perennial (Zavoianu, 1985). The Seer Khad drainage basin has the highest stream order of five based on Strahler's method (Fig. 5). Table 2 shows that the Seer Khad Watershed is divided into eighteen sub-watersheds (SWs). Among them, twelve SWs have third order viz. SW-I, III, IV, V, VI, VIII, XI, XII, XIII, XIV, XVI, XVIII and six SWs have fourth order SW-II, VII, IX, X, XV, XVII (Fig. 6).

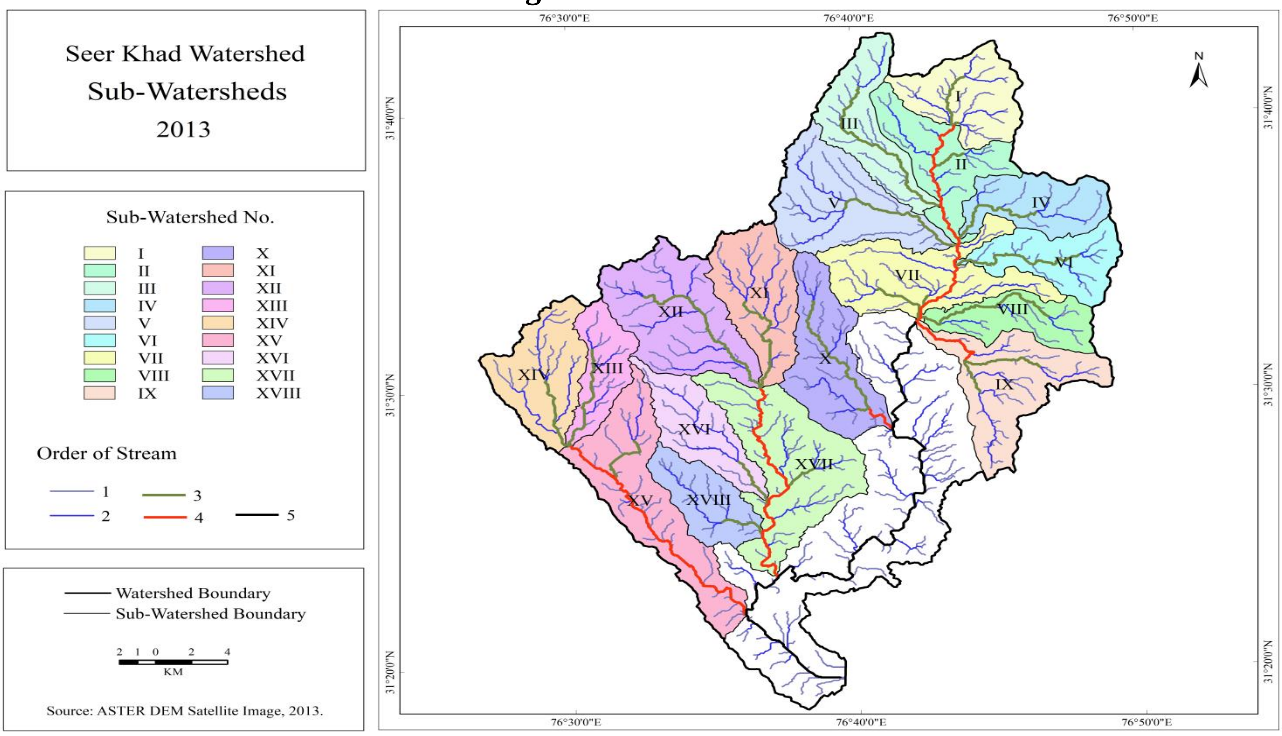
Fig. 5 Stream Order by Strahler's Method



Stream Number

The count of stream channels in a given order is known as the stream number (Horton, 1945). A higher stream number indicates low permeability and infiltration (Hajam et al., 2013). Stream features are consistent with Horton's first law, sometimes known as the "law of stream numbers", which stipulates that "the number of streams of different orders in a given drainage basin tends to closely approximate an inverse geometric ratio" (Farhan, 2017). Table 2 represents that the SKW has 495 streams in all, of which 390, 73, 23, and 9 have 1st, 2nd, 3rd and 4th order, respectively. The SW-XVII has the highest stream number, i.e. 48, and SW-IV has the lowest stream number, i.e. 16. The number of streams in 1st order is highest for all sub-watersheds and decreases as the stream order increase.

Fig. 6 Sub-Watersheds



Stream Length

A shorter stream means the runoff path will follow a steep slope, and vice versa (Wakode et al., 2014). A small number of longer stream lengths are often developed where the bedrocks are permeable, while a larger number of small stream lengths are formed where the rock material is less permeable (Asode et al., 2016). It is clear from Table 3 that the length of the 1st, 2nd, 3rd and 4th order streams is 391.16, 185.66, 134.03 and 60.21 km, respectively, and the total stream length of SKW is 777.06 km. The length of all the streams is highest in SW-VII (76.06 km) and lowest in SW-VIII (25.23 km). Therefore, the SW-VIII has a low gradient and high groundwater potential.

Bifurcation Ratio

The Bifurcation Ratio (Rb) is the ratio of the number of streams of a particular order (N_u) to the number of streams of the subsequent higher order (N_{u+1}) (Schumm, 1956b). Horton (1945) defines "the Rb parameter as a morphological index of relief and dissection". A smaller Rb value means the streams are branched sequentially, and the drainage basin is lined with uniform materials (Pakhmode et al., 2003; Manu and Anirudhan, 2008). Table 2 analysis reveals that the average Rb of SKW is 3.69, the SW-XV has the highest bifurcation ratio of 6.00, and SW-XIII has the lowest bifurcation ratio of Thus, 1.53. SW- XV has hilly terrain as compared to SW-XIII.

Table 2 Linear Morphometric Parameters (Stream Number and Bifurcation Ratio)

SW	Stream Number (Nu) of Different Order (u)				Σ Nu	Bifurcation ratio (Rb)			Mean Rb
	1	2	3	4		Rb1	Rb2	Rb3	
I	22	3	1	0	26	7.33	3.00	0.00	3.44
II	18	5	1	4	28	3.60	5.00	0.25	2.95
III	16	1	1	0	18	16.00	1.00	0.00	5.67
IV	11	4	1	0	16	2.75	4.00	0.00	2.25
V	24	3	1	0	28	8.00	3.00	0.00	3.67
VI	17	3	1	0	21	5.67	3.00	0.00	2.89
VII	26	7	2	1	36	3.71	3.50	2.00	3.07
VIII	14	4	1	0	19	3.50	4.00	0.00	2.50
IX	29	6	2	1	38	4.83	3.00	2.00	3.28
X	27	5	2	1	35	5.40	2.50	2.00	3.30
XI	26	5	1	0	32	5.20	5.00	0.00	3.40
XII	29	7	1	0	37	4.14	7.00	0.00	3.71
XIII	13	4	3	0	20	3.25	1.33	0.00	1.53
XIV	16	4	1	0	21	4.00	4.00	0.00	2.67
XV	30	2	1	1	34	15.00	2.00	1.00	6.00
XVI	15	2	1	0	18	7.50	2.00	0.00	3.17
XVII	40	6	1	1	48	6.67	6.00	1.00	4.56
XVIII	17	2	1	0	20	8.50	2.00	0.00	3.50
SKW*	390	73	23	9	495	5.34	3.17	2.56	3.69

(* Seer Khad Watershed)

Table 3 Linear Morphometric Parameters (Stream Length and Stream Length Ratio)

SW	Stream Length (Lu) of Different Order (u)				Σ Lu	Stream length ratio RL (Lu/Lu - 1)			Mean RL
	1	2	3	4		2/1	3/2	4/3	
I	23.42	11.45	4.57	0.00	39.44	0.49	0.40	0.00	0.30
II	15.66	9.57	5.22	9.87	40.32	0.61	0.55	1.89	1.02
III	24.3	3.85	12.63	0.00	40.78	0.16	3.28	0.00	1.15
IV	13.83	5.81	7.32	0.00	26.96	0.42	1.26	0.00	0.56
V	32.01	13.28	8.66	0.00	53.95	0.41	0.65	0.00	0.36
VI	16.24	3.8	9.22	0.00	29.26	0.23	2.43	0.00	0.89
VII	30.16	15.97	6.1	6.94	59.17	0.53	0.38	1.14	0.68
VIII	14.44	6.59	9.69	0.00	30.72	0.46	1.47	0.00	0.64
IX	22.31	15.14	7.58	5.32	50.35	0.68	0.50	0.70	0.63
X	25.66	10.41	10.43	2.33	48.83	0.41	1.00	0.22	0.54
XI	21.79	15.25	7.93	0.00	44.97	0.70	0.52	0.00	0.41
XII	25.73	18.41	12.03	0.00	56.17	0.72	0.65	0.00	0.46
XIII	12.08	6.1	9.13	0.00	27.31	0.50	1.50	0.00	0.67
XIV	17.4	15.25	5.39	0.00	38.04	0.88	0.35	0.00	0.41
XV	30.79	4.98	4.11	18.03	57.91	0.16	0.83	4.39	1.79
XVI	16.43	11.36	3.8	0.00	31.59	0.69	0.33	0.00	0.34
XVII	40.52	10.86	6.96	17.72	76.06	0.27	0.64	2.55	1.15
XVIII	14.39	7.58	3.26	0.00	25.23	0.53	0.43	0.00	0.32
SKW	397.16	185.66	134.03	60.21	777.06	0.47	0.72	0.45	0.55

Estimation of Areal Aspects

Stream Frequency (Fs)

The ratio of the total number of streams (Nu) of all orders in a catchment to the basin area is defined as the stream frequency (Horton, 1945). Higher surface runoff, steeper ground surface, impermeable subterranean layer, thin flora, high relief and poor potential for infiltration are all indicators of high Fs values (Horton 1945; Obi Reddy et al. 2004). Seer Khad Watershed (SKW) has 0.85 streams per square kilometer, and the variation in Fs from 0.57 (SW-III) to 0.97 (SW-XIII) indicates that SW-XIII produces more runoff as compared to SW-III and has a low potential for groundwater availability.

Drainage Density (Dd)

Drainage Density (Dd) is the total length of all streams divided by the drainage basin's area (Horton 1932, 1945). Drainage density (Dd) is varied according to weather and flora (Ozdemir &

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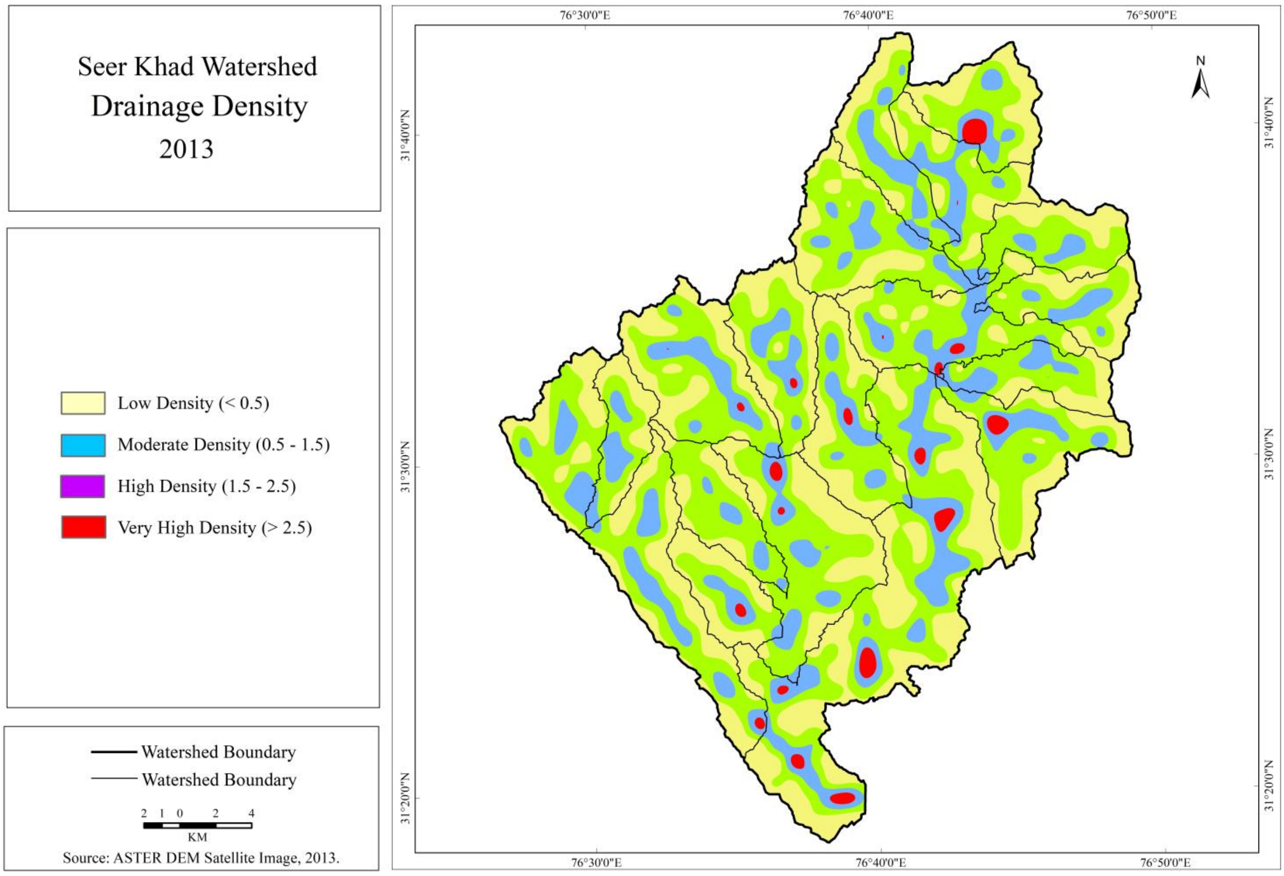
Bird, 2009), rocks and soil qualities, altitude, and stages of landscape evolution (Moglen et al., 1998). The higher Dd value denotes a high runoff rate and, consequently, a low infiltration capacity (Prasad et al., 2008; Kumar & Jayappa, 2011) and the area is unsuitable for groundwater development. However, for lower Dd, groundwater aquifers have a greater probability of recharge (Mohanty & Behera, 2010; Rudraiah et al., 2008). Table 4 demonstrates that the Seer Khad watershed has drainage density of 1.20 per km^2. The stream density is lowest in SW-IV and highest in SW-VII (Fig. 7).

Fig. 7 Drainage Density



Drainage Texture (Dt)

"Drainage Texture" refers to the total number of stream segments of all orders along the basin's perimeter (Horton, 1945). Drainage texture is calculated by multiplying Dd and Fs (Sreedevi et al., 2009). Smith (1950) distinguished five types of drainage texture (Dt): very coarse (less than 2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8), and very fine (> 8) (Vishwas, 2021). When drainage density is low, coarse drainage texture results, and when drainage density is high, fine drainage texture results (Ozdemir & Bird, 2009). The very coarse texture allows for good subsurface material permeability and infiltration capacity, resulting in a lower runoff rate and significant groundwater recharge (Hajam et al., 2013). SW-IV has the least drainage texture (0.60), while SW-XIII has the greatest (1.29) (Table 4).

Form Factor (Ff)

The form factor (Ff) is defined as the ratio of the basin area (A) to the squared basin length (L) (Horton 1932, 1945). The Ff value ranges from zero (extremely elongated) to one (perfect circular shape). Watersheds with high Ff values experience short-duration peak flows. Table 4 shows that SW-XV has the lowest Ff, whereas SW-I has the highest Ff. Thus, high peak flow will be observed in SW-XV for a short duration.

Elongation Ratio (Re)

The elongation ratio (Re) is defined as the ratio of the diameter of a circle with the same area as the basin (A) to the length of the basin (Lb) (Schumm, 1956b). Strahler (1964) asserted that Re values range between 0.6 and 1.0 under various geological and environmental conditions. A higher Re value signifies the existence of intense denudational activities in the basin, with higher efficiency for infiltration and low runoff (Kumar & Jayappa, 2011). The SW-I has a nearly circular shape compared to other sub-watersheds with a Re value of 0.93. l SW-XV has the 0.46 Re and is elongated in shape (Table 4).

Table 4 Areal Morphometric Parameters (Area, Perimeter, Basin Length, Form Factor, Elongated Ratio, Circulatory Ratio, Shape Factor, Drainage Density, Stream Frequency, Drainage Texture.)

SW	Area in sq. km	Perimeter in km	Basin Length in km	Ff	Re	Rc	Dd	Fs	Dt
I	31.28	27	6.10	0.84	0.93	0.54	1.26	0.83	1.05
II	32.03	39	11.62	0.24	0.55	0.26	1.26	0.87	1.10
III	31.44	35	11.90	0.22	0.53	0.32	1.30	0.57	0.74
IV	26.82	28	8.94	0.34	0.65	0.43	1.01	0.60	0.60
V	45.95	37	10.76	0.40	0.71	0.42	1.17	0.61	0.72
VI	26.96	29	9.22	0.32	0.64	0.40	1.09	0.78	0.85

VII	44.43	51	8.23	0.66	0.91	0.21	1.33	0.81	1.08
VIII	24.25	29	9.41	0.27	0.59	0.36	1.27	0.78	0.99
IX	43.79	43	9.10	0.53	0.82	0.30	1.15	0.87	1.00
X	39.18	36	12.87	0.24	0.55	0.38	1.25	0.89	1.11
XI	36.04	32	11.08	0.29	0.61	0.44	1.25	0.89	1.11
XII	50.50	37	10.88	0.43	0.74	0.46	1.11	0.73	0.81
XIII	20.55	27	10.02	0.20	0.51	0.35	1.33	0.97	1.29
XIV	34.61	31	10.03	0.34	0.66	0.45	1.10	0.61	0.67
XV	52.90	50	17.87	0.17	0.46	0.27	1.09	0.64	0.70
XVI	27.13	32	12.21	0.18	0.48	0.33	1.16	0.66	0.77
XVII	57.63	49	12.71	0.36	0.67	0.30	1.32	0.83	1.10
XVIII	22.92	24	8.07	0.35	0.67	0.50	1.10	0.87	0.96
SKW	648.39	167.54	43.20	0.35	0.66	0.29	1.20	0.85	1.02

Circularity Ratio (Rc)

The circularity ratio is defined as the ratio of the basin's surface area (A) to the surface area of a circle with the same perimeter (P) as the basin (Strahler, 1964). A value of 0.0 indicates an extremely elongated shape, while 1.0 indicates a circular shape (Miller, 1953; Schumm, 1956b). Young, mature, and old stages of the catchment's geomorphic cycle are represented by low, medium, and high values of Rc (Farhan, 2017; Sameena et al., 2009). As summarized in Table 5, the SW-VII has the lowest circularity ratio value, indicating a highly elongated sub-watershed with homogenous and permeable geological materials. In contrast, low relief with the impervious surface gives a high value of Rc in SW-I.

Estimation of Relief Aspects

Basin Relief

Basin relief (Bh) is the elevation difference between a watershed's highest and lowest points (Schumm, 1956b). The basin relief (Bh) parameter strongly influences streams gradient, affecting flooding patterns and the amount of sediment transported (Farhan, 2017). The SW-IX has a high Bh value (1.19 km), which indicates that the drainage basin has a low probability of groundwater occurrence. As shown in Table 5, the SW-V has the lowest basin relief value, and the Seer Khad Watershed has a basin relief value of 1.37 km.

Relief Ratio (Rr)

The relief ratio (Rr) is defined as a dimensionless height-length ratio between the relief of the basin (Bh) and the length of the basin (Lb) (Schumm, 1956b). High values are associated with hilly regions, while low values are associated with pediplains and valleys (Sreedevi et al., 2009). There is a strong correlation between basin relief and drainage frequency, as well as between stream frequency and channel slope, which result in rapid discharges (Gopalakrishna et al., 2004). In this study, the relief ratio ranges from 0.03 (SW-V) to 0.13 (SW-IV & IX), as in Table 5.

Table 5 Relief Morphometric Parameters (Basin Relief, Relief Ratio and Ruggedness Number)

SW	Max 'H'	Min 'h'	Basin relief (R) (H-h) (m)	Basin relief (R) (H-h) (km)	Longest Axis 'L' (km)	Relief Ratio (Rr)	Ruggedness Number (Rn) (R X Dd) (km)
I	1534	809	725	0.725	6.1	0.12	0.91
II	1389	707	682	0.682	11.62	0.06	0.86
III	1224	729	495	0.495	11.9	0.04	0.64
IV	1850	711	1139	1.139	8.94	0.13	1.15
V	1039	707	332	0.332	10.76	0.03	0.39
VI	1609	696	913	0.913	9.22	0.10	0.99
VII	1404	674	730	0.73	8.23	0.09	0.97
VIII	1808	674	1134	1.134	9.41	0.12	1.44
IX	1869	674	1195	1.195	9.1	0.13	1.37
X	1084	613	471	0.471	12.87	0.04	0.59
XI	1074	643	431	0.431	11.08	0.04	0.54
XII	1083	643	440	0.44	10.88	0.04	0.49
XIII	987	622	365	0.365	10.02	0.04	0.49
XIV	1032	622	410	0.41	10.03	0.04	0.45
XV	955	502	453	0.453	17.87	0.03	0.50
XVI	924	575	349	0.349	12.21	0.03	0.41
XVII	1086	525	561	0.561	12.71	0.04	0.74
XVIII	938	543	395	0.395	8.07	0.05	0.43
SWK	1869	499	1370	1.37	43.2	0.03	1.65

Ruggedness Number (Rn)

The ruggedness number (Rn) is a dimensionless parameter that is calculated by multiplying the basin relief (Bh) by the drainage density (Strahler, 1964). Rn values are typically higher in mountainous regions having a tropical climate and abundant rainfall with active geomorphic processes (Farhan, 2017). Table 5 shows that SW-VIII has the highest Rn (1.44) and SW-V has the lowest Rn (0.39) value. Thus, SW-VIII has a low potential for groundwater because of hilly terrain with steep slopes.

Prioritization of Sub-Watersheds

For prioritization, the drainage basin is divided into 18 sub-basins. A weighting value/rank is provided to each morphometric parameter, and then the values for each sub-basin are averaged to achieve a compound value (Deepika et al., 2013). In Table 6, the highest value among the sub-basins is ranked as ‘1’ for linear / area parameters; the next higher value is ranked as ‘2’ and so on. On the contrary, the lowest value for the shape parameters is classified as ‘1’; the next lower value is ranked as ‘2’ and so on. Based on the total compound value, the highest priority (1) is awarded to the most deficient subbasins for groundwater prospects, the next higher priority (2) is assigned to the next highest value, and so on. The final priority number (18) indicates that the sub-basin has the greatest groundwater potential (S. Biswas et al., 1999; Deepika et al., 2013; A. Kumar & Jayappa, 2011). By applying the above methodology, the author found that SW-I, SW-XI and SW-II have the highest priority of 1, 2 and 3, respectively, representing the low groundwater potential. The SW-XIV, SW-V and SW-XI have the lowest priority of 18, 17 and 16, respectively, which denotes the high groundwater potential. The map of sub-watershed prioritization based on morphometric parameters is given in Fig. 8.

Table 6 The Sub-Watershed Wise Prioritization Based on Morphometric Parameters.

SW	Nu	Rb	Ff	Re	Rc	Dd	Fs	Dt	Rn	Compound Value	Final Priority
I	10	7	18	18	18	6	8	7	6	10.89	13
II	8	13	6	6	2	7	4	4	7	6.33	1
III	16	2	4	4	6	4	18	14	9	8.56	9
IV	18	17	10	10	13	18	17	18	3	13.78	17
V	9	5	14	14	12	10	15	15	18	12.44	12
VI	11	14	9	9	11	17	11	11	4	10.78	7
VII	4	12	17	17	1	1	9	6	5	8.00	10
VIII	15	16	7	7	9	5	10	9	1	8.78	8
IX	2	10	16	16	4	12	6	8	2	8.44	16
X	5	9	5	5	10	9	2	2	10	6.33	2
XI	7	8	8	8	14	8	3	3	11	7.78	5
XII	3	4	15	15	16	13	12	12	13	11.44	14
XIII	13	18	3	3	8	2	1	1	14	7.00	4
XIV	12	15	11	11	15	15	16	17	15	14.11	18
XV	6	1	1	1	3	16	14	16	12	7.78	6
XVI	17	11	2	2	7	11	13	13	17	10.33	11
XVII	1	3	13	13	5	3	7	5	8	6.44	3
XVIII	14	6	12	12	17	14	5	10	16	11.78	15

Priority Zones

For priority zonation, sub-watersheds (SWs) are divided into five zones. The SWs with a compound value less than seven are included in the very high priority zone (VHPZ) category, and SWs with a compound value greater than eleven are included in the very low priority zone (VLPZ) category. VHPZ indicate that the area requires more attention to manage groundwater, whereas VLPZ is the area with good groundwater availability and consequently needs less attention. The prioritization zones of the seer khad watershed are given in Fig.9.

Table 7 Prioritization Zones of Seer Khad Watershed.

Sr. No.	Priority Zone	Area in km^2	Area in %
1	Very High	121.56	15.37
2	High	112.09	14.17
3	Medium	95.17	12.03
4	Low	188.52	23.83
5	Very Low	131.05	16.57

Fig. 8 Sub-Watershed Wise Prioritization Based on Morphometric Parameters

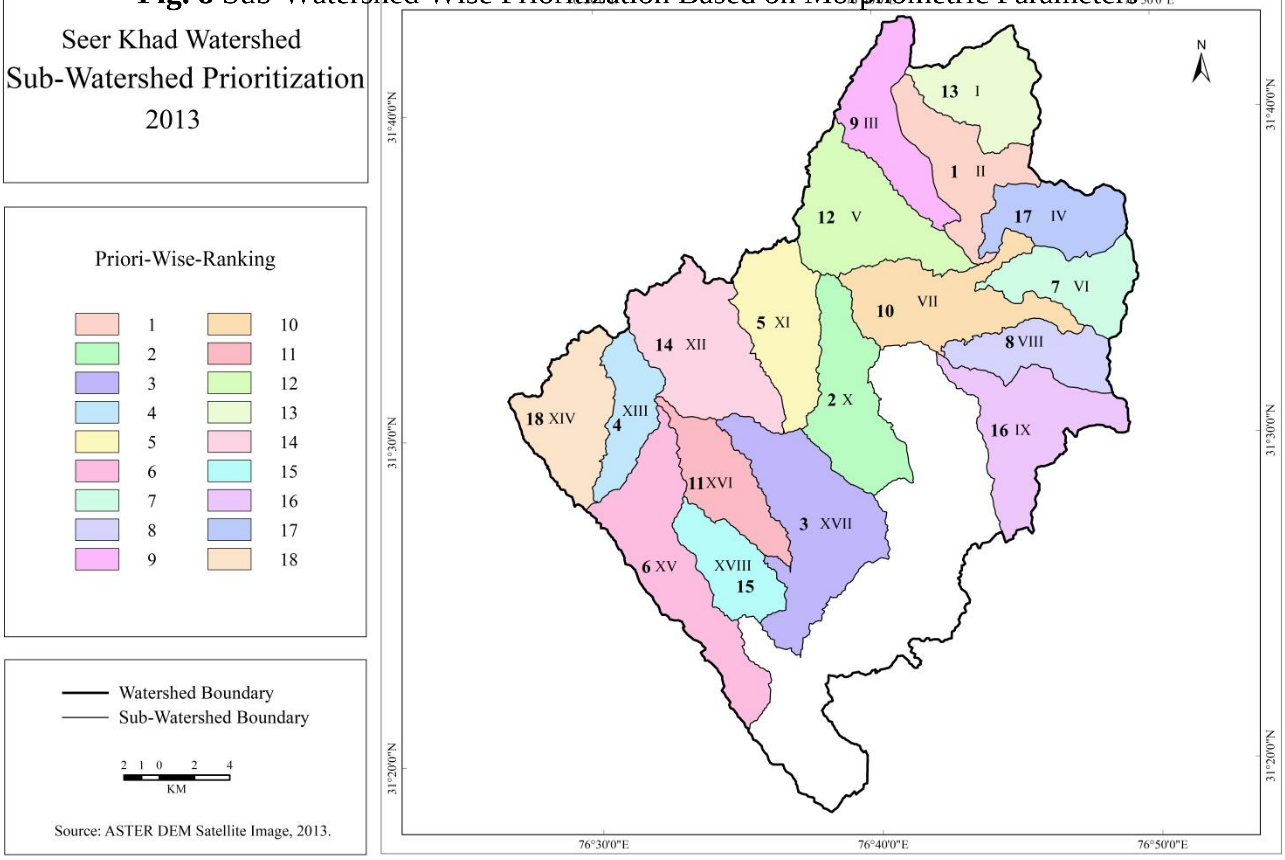


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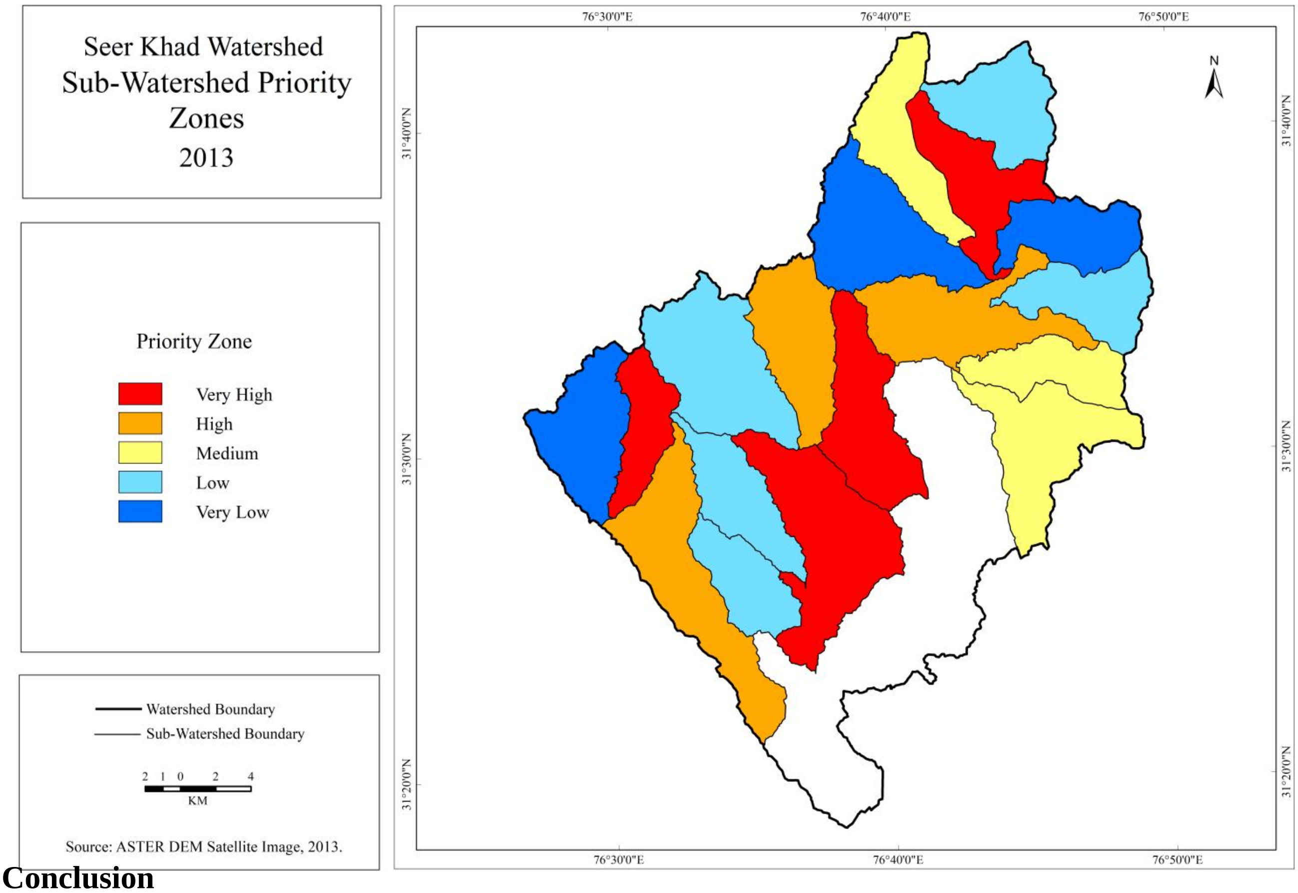
Fig. 9 Prioritization Zones of Seer Khad Watershed.



Conclusion

Prioritization of sub-watersheds is a critical process for the long-term development and maintenance of watersheds. This study used RS and GIS to characterize the watershed's morphometric parameters (linear, areal, and shape). The Seer Khad's sub-watersheds are prioritized based on nine morphometric parameters. The compound values technique, which classifies sub-watersheds based on their groundwater potential, is used to identify groundwater deficit and surplus zones based on morphometric aspects used in this study. The drainage network of SKW and all the SWs denotes a dendritic pattern. The high drainage density is found in the areas where numenour smaller order streams merged. SW-XV has a Re value of 0.46, demonstrating an elongated basin with low groundwater potential, and SW-I has a Re value of 0.93, showing a nearly circular basin with high groundwater potential. The high Rn value (1.44) of SW-VIII indicates rugged terrain with low groundwater potential. The results show that 15.37% area of watershed laying in very high priority zone (SW-II, X, XIII, XVII) need urgent attention for management, 14.17% area of watershed include in high priority zone (SW-VII, XI, XV), and three sub-watersheds viz. V, VI, and XVI constituted 16.57% area with high groundwater potential. High-priority zones should be managed first, followed by low-priority zones. The methodology employed in the study for watershed ranking focuses primarily on the need for groundwater protection and restoration, identifying the regions of major concern for land degradation and rejuvenation of water resources. Such studies assist decision-makers in recognizing priority SW, which requires fast adaptation of appropriate soil and water conservation practices in the study region.

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