Environmental Earth Sciences

Hydrological response based watershed prioritization using geospatial techniques: A case study from semi-arid region of Western India

--Manuscript Draft--

Manuscript Number:	ENGE-D-16-00957R2
Full Title:	Hydrological response based watershed prioritization using geospatial techniques: A case study from semi-arid region of Western India
Article Type:	Original Manuscript
Corresponding Author:	BHAVANA Naren UMRIKAR, Ph.D. Savitribai Phule Pune University Pune, Maharashtra INDIA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Savitribai Phule Pune University
Corresponding Author's Secondary Institution:	
First Author:	Ajaykumar Kadam
First Author Secondary Information:	
Order of Authors:	Ajaykumar Kadam
	BHAVANA Naren UMRIKAR, Ph.D.
	RN Sankhua
Order of Authors Secondary Information:	
Funding Information:	
Abstract:	Watersheds from semi-arid regions are generally more sensitive to both hydrological processes and sustainability of water resources than humid regions. Hence it is necessary to determine the response of watersheds to hydrological processes for development and management plans. Keeping this in view, a study has been undertaken to assign ranks based on hydrological responses to eight sub-watersheds within Shivganga River basin, representative of high relief region of Western Ghats of India, experiencing speedy and haphazard development. Seven influencing factors were considered namely Drainage density, Geology, Slope, Landform classification, Land use/land cover, Rainfall and Runoff (DGSLR) for prioritization. The thematic layers generated for these parameters were reclassified by assigning weights according to their response to hydrological processes. Analytical Hierarchical Process (AHP) has been used to avoid the biasness involved while assigning weights to each thematic parameter. The Area Weighted Average (AWA) index was computed for each theme and DGSLR index value was obtained for each sub-watershed. Because of proximity of Western Ghats, the study area is highly influenced by steep slopes, thin soil cover and poor vegetation growth. About 43.06% of the watershed area depicts high priority and near about 15% area falls under moderate response to hydrologic processes being relatively plain and thus increase in water residence time which is favourable for infiltration/percolation. This outcome of the study regarding prioritization for land degradation and sensitivity would be gainfully used by the decision makers and planners in implementing resource (soil and water) conservation measures.
Response to Reviewers:	Dear Sir, The file is attached.

Respected Sir

I am submitting the manuscript entitled 'Hydrological response based watershed prioritization using Geospatial techniques: A case study from Semi-arid Region of Western India' for your kind perusal.

This is the case study of Shivganga River Basin from Deccan Volcanic Province of Maharashtra, India. This region suffers from severe water scarcity due to the presence of hard rock and vagaries of monsoon. The watershed development programs are taken on priority to resolve the issues.

On this background, the hydrological response based sub watershed wise priority ranking is performed in the present research.

Kindly consider the article for publication,

Thanking you

Mrs. Bhavana Umrikar

List of response to the reviewers comment

Reviewer 1:

1. Title is changed as per suggestion given by Reviewer.
2. **As per your comment the change has been indicated in red text.**
3. The structure of the manuscript is revised as per suggestion given by Reviewer. The whole manuscript is extensively rewrote and improved both in style and grammar. Language corrections are rectified.
4. Methodology is revised and clearly presented in paper
5. The explanation of DGSLR index was "categorized into four classes is given in paper.
6. The sentence 'study area receives a large amount of rainfall due to the western Ghat escarpment' is revised
7. The "geomorphology" is changed to "landform classification" as per suggestion given by Reviewer
8. The clarification regarding the details of the DEM generation is given in the paper.
9. Acronyms like "TRMM" "IRS" "LISS" and "NRSC" are given in full, as per suggestion, satellite rainfall data (TRMM) ground truth data is used in the study.
10. "Arc-GIS" is revised as "ArcGIS"
11. "Mini-watershed" is changed to "sub-watershed" as per suggestion given by Reviewer.
12. A same value (0.41 to 2.51) is deleted from text.
13. Landform classifications confirmed in the field validation and also using satellite image and DEM as per suggestion given by Reviewer.
14. Tables are revised as suggestion given by Reviewer.
15. A criterion for this classification of slope is given text.
16. "AHP" is added in method section as suggestion given by Reviewer.
17. "The" is removed from "Satty (1990)" sentence.
18. The "Consistency Ratio" and RI is explained in the text
19. The sentence headward, gully is revised.
20. The "moderate" is explained in the text
21. Acknowledgement is changed as per suggestion given by Reviewer.
22. Fig. 1. The scale bar is revised
23. Fig of drainage density and geology is separated as per suggestion given by Reviewer.

24. The Fig is rearranged in Sub-panel as per suggestion given by Reviewer.

As per reviewer’s suggestion we improved writing style and gave clear explanation to our original contribution.

The new changes in paper are marked in red colour.

Hydrological response based watershed prioritization using geospatial techniques: A case study from semi-arid region of Western India

Ajaykumar Kadam*, Bhavana N. Umrikar**, R N Sankhua***

* Department of Environmental Science, SavitribaiPhule Pune University

** Department of Geology,Savitribai Phule Pune University

*** Central Water Commission, New Delhi

Abstract Watersheds from semi-arid regions are generally more sensitive to both hydrological processes and sustainability of water resources than humid regions. Hence it is necessary to determine the response of watersheds to hydrological processes for development and management plans. Keeping this in view, a study has been undertaken to assign ranks based on hydrological responses to eight sub-watersheds within Shivganga River basin, representative of high relief region of Western Ghats of India, experiencing speedy and haphazard development. Seven influencing factors were considered namely **D**rainage density, **G**eology, **S**lope, **L**andform classification, **L**and use/land cover, **R**ainfall and **R**unoff (DGSLR) for prioritization. The thematic layers generated for these parameters were reclassified by assigning weights according to their response to hydrological processes. Analytical Hierarchical Process (AHP) has been used to avoid the biasness involved while assigning weights to each thematic parameter. The Area Weighted Average (AWA) index was computed for each theme and DGSLR index value was obtained for each sub-watershed. Because of proximity of Western Ghats, the study area is highly influenced by steep slopes, thin soil cover and poor vegetation growth. About 43.06% of the watershed area depicts high priority and near about 15% area falls under moderate response to hydrologic processes being relatively plain and thus increase in water residence time which is favourable for

infiltration/percolation. This outcome of the study regarding prioritization for land degradation and sensitivity would be gainfully used by the decision makers and planners in implementing resource (soil and water) conservation measures.

Keywords Hydrological response watershed prioritization AHP GIS Western Ghats.

Introduction

Hydrological response of a semi-urbanized watershed depends mainly upon climatic, physiographic, geological, geomorphologic and land use features (Kumar and Mishra 2015; Wang et al. 2015). The semi-urbanized/urbanized watersheds show changes in drainage network, stream discharge, surface runoff, base flow patterns and subsurface recharge, which considerably affect the regional surface and groundwater availability (He and Hogue 2012; Shah et al. 2012; Maxwell et al. 2014). Population growth, rapid urbanisation and industrialisation, the expansion of agriculture, tourism development and climate change put water under increasing stress in Western Ghats region. (Kadam et al. 2012; Sajinkumar and Anbazhagan 2015; Samal et al. 2015). Thus, it becomes imperative to study the probable impact of high relief, modified drainage network, rising inhabitants and changing land use pattern on hydrologic processes (stream discharge, base flow, surface runoff and infiltration rates) specifically in arid to semi-arid environments (Jyrkama and Sykes 2007; Abdulla et al. 2009; Kuriakose et al. 2009; Jiang et al. 2015; Alvarado et al. 2016; Vollmer et al. 2016). Keeping this in view, the prioritization of sub watersheds from Shivganga River basin has been performed for accurate and timely mapping, monitoring and evaluation of water resources for sustainable development (Aher et al. 2014; Mushtaq et al. 2015; Alvarado et al. 2016).

Classification, characterization and prioritization study gives prime idea about the qualitative aspects of watershed (Misra et al. 2015; Umrikar, 2016). It also gives the percentage of highly affected pockets inside the watershed and the causative parameters behind the high runoff/soil draining down (Rabu and Askaran 2013; Molina-Navarro et al. 2015). When the analysis is done on the sub/micro-watershed level, then the holistic picture initially generated for the whole watershed changes because of the subtleness in execution (Kinthada et al. 2013; Patel et al. 2013; Sujatha et al. 2014).

The Analytical Hierarchy Process (AHP) is the most commonly used MCDA tool that includes hierarchical structures to represent a problem and then develops priorities amongst the alternatives based on the judgment of the user (Saaty, 1980). The process involves defining the unstructured problem, developing matrix, pair-wise comparison, computation of relative weights, consistency check and finally acquiring overall rating for obtaining accurate results. The geospatial techniques in conjunction with AHP have been used by many researchers to study the watershed characteristics (Rahman et al. 2012; Kumar and Mishra 2015; Samal et al 2015; Alvarado et al. 2016; Vollmer et al. 2016) and reported that watershed prioritization using geospatial technique is proficient method for understanding the problems related to soil and water resources in a particular region.

The watershed from Western Ghats gets influenced by high relief, high rainfall, elevated surface runoff and top soil wearing down. Due to the presence of rocky terrain, proximity to Western Ghats, highly dissected / undulating topography and being a representative high relief watershed of basaltic region of western India, Shivganga watershed, has been selected as the study area. In this study, the prioritization of sub-watersheds in Shivganga river basin has been done based on hydrological response by applying geospatial tools with AHP techniques, which is vital for developing watershed management plans and necessary precautionary measures.

Data and methodology

Study area

The Shivganga River basin in Pune district, Maharashtra, situated on the eastern slopes of Western Ghats, extending from 73°44'1.13"E to 73°56'17.94"E longitudes and 18°13'36.05"N to 18°24'7.46"N latitudes has been selected for the study. The index map showing location of the study area has been given in Fig 1.Shivganga river originates in the foothills of Western Ghats and further meets Gunjawani river at village Mohari Budrukh. This area spreads over 176.92 km^2 and occupied mostly by agriculture. The study area shows moderate to steep slope with elevation ranging from 1264 m (in western part) to 590 m (in southern most part) having the elevation difference of 674 m. The area experiences modest to highest surface runoff and high evapotranspiration rate. The single-encrusted soil layer covers more than half of the watershed area. High percentage of mountainous area, which is roofed with different plant communities that form various types of forest vegetation along with agricultural activities, especially sugarcane, strawberry plantation, vegetables and rice at the lower reaches of watershed comprises the green cover in the area. The temperature varies from 39°C during summer to about 10°C during winter. The average annual precipitation is about 950 mm, and occurs from June to September. (IMD, 2015).

Fig.1 Location map of the study area showing hydrological soil group (HSG) and drainage

Datasets

In the present study, following data are used.

i) Spatial data

a. Digital Elevation Model (30 m resolution) was downloaded from ASTER (Advanced Space borne Thermal Emission and Reflection) GDEM (Global Digital Elevation Model)
b. Satellite Image of Indian Remote Sensing (IRS) Linear Imaging Self-Scanning System (LISS) – III, 23.5 m resolution, January, 2015
c. Tropical Rainfall Measuring Mission (TRMM) rainfall data from 0.5 deg grid
d. Soil atlas and information of soil characteristics of the study area was obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) Nagpur,
e. Landform classification is prepared from National Atlas & Thematic Mapping Organisation, Kolkatta
f. Survey of India (SOI) toposheet no. 47F/15 and 47F/16 with 1:50,000 scale.

ii) Non-Spatial data

a. Climatic data was acquired from India Meteorological Department (IMD), Pune
b. Geological data available with Geological Survey of India (GSI), Pune

Methodology

Preparation of thematic layers

The SOI toposheets were scanned and geo-referenced with GCS 1984 projection to assign real-world coordinates to each pixel of the raster were used to derive base, contour and drainage map. The Global Digital Elevation Model (GDEM) was updated using contour layer and validated with Differential Global Positioning System (DGPS) surveyed points. Further, slope was derived from DEM using ArcGIS 3D-Analyst tool. Landuse/landcover map of 1:50,000 scale was derived from digital satellite data using supervised classification. On the basis of texture, the soil in the study area was classified into three types- sandy loam (49.63%) representing Hydrological Soil Group (HSG)-B, sandy clay loam (42.37%) having HSG-C and loamy sand (8.01%) covering HSG-D group (Fig. 1).

Thematic layers of seven parameters namely; Drainage density, Geology, Slope, Landform classification, Landuse/landcover, Rainfall and Runoff (DGSLR) were generated in raster format in GIS environment. In the present study, the Shivganga watershed has been divided into 8 sub-watersheds for prioritization study being one of the well-known bio-diversity hotspots in Western Ghat, Maharashtra. The flow chart for methodology adopted in the present study is shown in the figure 2.

Fig. 2 Flow chart for methodology adopted in the present study.

Drainage density

Drainage density is the function of slope, topography, landform, geology, soil and land use pattern (Horton, 1945,Strahler, 1964). High drainage density area gives quick response to hydrological processes, in other words, it shows high surface runoff, low groundwater potential with less recharge. The dendritic drainage pattern observed in the area reveals uniform response of basaltic lithology and sub-parallel to parallel drainage was seen at places reflected control of steep slopes and lineaments.

Drainage density is the fraction of total stream length of all orders divided by the whole area of the basin. It shows how closely spaced stream channels are present within a watershed and gives a possible surface water overflow (Samal et al 2015). The rock permeability is inversely proportional to drainage density, as drainage density increases the surface runoff of the area also increases. The drainage density decreases from mountainous to flat terrain due to reduction in the degree of dissection, decrease in slope gradient and the length of streams increases correspondingly. The average drainage density of each sub-watershed was calculated for prioritization. Deriving drainage density and relating it with surface runoff and rock permeability helps in understanding the hydrological response of area under consideration. The lower weights were assigned to the low drainage density area and vice versa.

Geology

The study area comprises of poor to moderately weathered basaltic flows of Wai Subgroup from Western Ghat area having thin tuffaceous layers separating simple flow units. Five different formations were found in Wai Subgroup hierarchically from base to top are Poladpur, Ambenali, Mahabaleshwar, Panhala and Desur each separated by marker Giant Plagioclase Basalt (GPB) flows (Beane et al. 1986). The feature layer of geology was prepared by integrating the field traverses taken along the streams, road cuttings and ghat sections with the map published by Geological Survey of India (scale 1:250,000).

Slope

The study area is divided into seven slope classes following the norms of integrated mission for sustainable development(IMSD, 1995).Very steep (>35%), moderately Steep (15–35%), Steep (10–15%), moderately Gentle (5–10%), Gentle (3–5%) Very gentle (1–3%) and nearly level/ Flat (0–1%).The water percolation/infiltration is the function of slope which also depends upon the thickness of soil cover and lithology of the area (Kadam et al. 2012; Sarma and Saikia 2012; Sajinkumar and Anbazhagan 2015). The category having highest slope range is given maximum weight due to high relief topography, or steeper slopes, where more run-off and less infiltration takes place (Nag and Ghosh 2013).While the category with least slope values is assigned smallest weight due to un-dissected topography, relatively low surface run-off indicative of plain terrain (Wang et al. 2015).

Landuse/landcover

The land use/land cover pattern plays prime role in governing hydrological set up of the watershed. Landuse layer was prepared from the Linear Imaging Self-Scanner (LISS) – III image of Indian Remote Sensing (IRS) from National Remote Sensing Centre, Hyderabad. The highest weight is assigned to urban/ waste land and lowest for the forest /agriculture land and water bodies to give inputs to rate the hydrological processes.

Landform classification

The landform classification map was prepared by using the pitch, texture, dimension, outline and alliance character of ground features observed on satellite imagery, DEM and on the basis of field datasets collected during fieldwork. Landform classes of study area are namely buried pediment, rolling pediment plain, plateau fringe surface and remnants. Buried pediments are moderately weathered with their thickness greater than rolling pediment plain. Landform classification was validated with hill shade map generated from GDEM using ArcGIS software.

Rainfall

Rainfall has the significant role in deciding the hydrological response of any region (Adiat et al 2012). Rainfall accounts the amount of water that would be accessible to infiltrate into the groundwater system flow or as a surface runoff (Agarwal and Garg 2015). The Tropical Rainfall Measuring Mission (TRMM) data has been downloaded and interpolated by Kriging method to generate the rainfall map. The areas falling under high rainfall zone with steep slopes trigger surface runoff rate.

Runoff

The SCS-CN method for runoff calculation is based on the Hydrologic Soil Group (HSG) and Antecedent Moisture Conditions (AMC). The AMC were calculated by total precipitation in the 5-day spell previous to storm. The surplus overland flow through storm occasion enhances, as the soil saturates due to precipitation in early spell. Since the precipitation statistics used in this study was taken from single weather station available in the proximity, so the curve numbers were calculated from AMC-II only. The surface runoff is calculated by using Equation 1 and 2.

$$\text{Runoff} = \frac{(\text{Rainfall} - 0.2\ \text{S})^2}{\text{Rainfall} + 0.8\text{s}} \qquad \text{If Rainfall} > 0.2\text{S} \qquad (1)$$

$$\text{Runoff} = 0 \qquad \text{If Rainfall} \leq 0.2\text{S} \qquad (2)$$

Where S is potential maximum soil retentionand for Indian condition,

$$\text{S} = (25400/\text{CN}) - 254(\text{mm}) \qquad (3)$$

Here, curve numbers were weighed with reverence to the watershed area (generally < 15 km^2) using Equation 4.

$$\text{CN}_\text{w} = \frac{\sum(\text{CNi X Ai})}{\text{A}} \qquad (4)$$

Where,

CNw= weighted curve number,

CNi= curve number from 1 to any number N,

Ai= area with curve number CNi; and

A= total area of the watershed.

ArcCN-Runoff extension tool of ArcGIS was used for correct and exact quantification of runoff. Land use/land cover thematic layer and polygon of soil groups have been used in ARC-CN runoff.

Analytical Hierarchy Process (AHP)

In the present study AHP is used to understand the influence of each factor of DGSLR model on hydrological processes. AHP has been preferred due to its ability to analyse multiple dataset and facilitate decision making process by performing pair-wise comparison of each criterion (Kaliraj et al. 2013; Langemeyer et al. 2016). The AHP includes comparison of importance between factors, normalisation and computing consistency ratio. The rating scale suggested by Satty (1990) is based on the values from 1 to 9 for assessing the comparative weight of every variable with other through pair wise diagonal matrix. The smallest value i.e. 1 depicts similar importance of both parameters, whereas 9 depicts dominantly important. In this study, the power of significance among two variables are filled in a matrix using ground truth, topographic set up, area knowledge and field specialist's opinion. The principal Eigen value has been computed to assess the consistency of weights. The normalisation tool is helpful in removing any biased approach during the assignment of weights to influencing factors which may affect the result. The normalization of weights assigned to each parameter is done by using Eigen vector and further validated for consistency by using Consistency Ratio (*CR*) formula. The value obtained for *CR* must be less than or equal to 0.1 to be considered as consistent and thereby reducing any subjectivity involved in the process of assigning the weights (Nasiri et al. 2013; Jaiswal et al. 2015). To compute the Consistency Ratio, first the Consistency Index (CI) has been computed (Eq. 5) from the pair-wise comparison matrix of all the parameters.

$$CI = (\lambda max - n) / (n-1) \text{........... (Eq. 5)}$$

Where, λmax is the average number of consistency vector and n is the number of factors considered. The Consistency Ratio (CR) has been computed using the Equation 6.

$$CR = CI / RI \text{........... (Eq. 6)}$$

Where, *RI* is the random index whose value depends on the number of factors compared (n), provided by Saaty (2008).

Area Weighted Analysis of DGSLR parameters

Since each parameter possess various sub-classes, Area Weighted analysis is calculated for each parameter separately. Area Weighted average (AWA) example equation for drainage density is as follows

$$AWA\ (Dd) = \frac{(A_1 * Wi + A_2 * Wi + A_3 * Wi + A_4 * Wi + A_5 * W_i)}{(A_1 + A_2 + A_3 + A_4 + A_5)} \text{........... (Eq. 7)}$$

Where, A is the % area under respective sub-class of drainage density like very high drainage density, high drainage density etc. *Wi* is the final weight obtained from multiplication of overall weightage (*W*) of drainage density obtained from AHP and Percentage Relative weight (*i*) of each sub-class of drainage density layer.

DGSLR Index

For deriving the DGSLR Index (**D**rainage density, **G**eology, % **S**lope, **L**andform classification, **L**and use / **L**and cover, **R**ainfall and **R**unoff) summation of Area weighted average derived for each thematic layer was computed (Eq. 7).

$$DGSLR = [(AWA_{Dd}) + (AWA_G) + (AWA_S) + (AWA_L) + (AWA_R)] \ldots\ldots\ldots\ldots\ldots \text{(Eq. 7)}$$

where, Dd is drainage density; G is geology; S is slope percent; L is landform classification, landuse/landcover and R is Rainfall, runoff. The DGSLR index parameters are termed as hydrological response factors and have been used for prioritization of sub-watersheds. Prioritization scaling of all the eight sub-watersheds of Shivganga watershed was achieved on the basis of DGSLR index values. The sub-watershed with the maximum DGSLR index value was given the highest priority.

Results and discussion

River basin delineation into micro/sub watersheds and their prioritization is the preliminary step for development, planning and management of natural resources. In the present study, priority ranking of sub-watersheds using geospatial technique has been performed to determine the hydrological stress. Sub watershed wise layers of drainage density, geology, slope, landform classification, landuse/landcover, rainfall and runoff were generated. Area (in percentage) under various sub-classes of these parameters for sub watersheds is given in table 1. It has been observed that sub-watershed 1 and 3 show very high drainage density covering 81.05% and 80.05% area respectively. The drainage density of study area ranges from 0.41 to 2.51 km/km^2 (Fig. 3a). This is due to proximity of Western Ghats resulting in enhanced runoff and overland flow. The basaltic flows from the study area have been divided into Diveghat Formation exposed towards lower part of the river basin, which is overlain by Purandargarh Formation covering periphery of river basin (Fig. 3b).The sub watershed 7 shows 40.34% area having more than 15% **slope** (Fig. 3c). Steep slopes in sub-watershed 1, increases the stream flow velocity, high erosion, less overland flow and quick surface water flow into streams contributing to high peaks in hydrograph**.**

A plane and levelled surface of buried pediment with moderately thick overload of weathered/transported matter covering the area of 74.95 sq km (43.06%) mainly occupies the northern region of the study area. Below the buried pediments and plateau fringe surface and remnants, the depositional rolling pediment plain landform has been formed due to various fluvial depositional processes. Rolling pediment plains are found in the southern part of the study area occupying about 8.14% of the total area. Alluvium and colluvium deposits have been observed near third and fourth order streams, indicate good groundwater recharge zone (Fig. 3d).

Plateau fringe surface is observed above the buried pediment. It occupies 68.06 km2 (39.11%) of total area representing less recharge and high surface runoff. Plateau surface remnants are scattered in the northern part of study area, covers 9.69% of total area shows very less groundwater potential with high slopes. The vegetative growth is low in this part of area. The study area falls in semi-arid basaltic region which was classified into eight types of landuse/ landcover (Fig. 3e) namely the agriculture (14.07 %), fallow land (31.07%), built-up land (6.38%), water bodies (0.57 %), forest (14.27%), vegetation (13.48%) and waste land (19.16%). It shows that large part of the area comprises of fallow land followed by irrigated crop land (harvested crops like Rice, Bajara, Peas, and Maize). Forest cover is observed at high elevation, in the peripheral areas representing river catchment. The sub-watershed 7 and 8 show less amount of rainfall result into less water to infiltrate into sub-surface(Fig.3f).

Fig. 3 (a) Drainage density, (b) Geology, (c) % Slope (d) landform classcification (e) land use/land cover, (f) rainfall (DGSLR) map of the study area

The buried pediment and rolling piedmont areas with soil group D accounts very high runoff potential (516.33- 958.89 mm). HSG- D category covering agricultural and fallow land depicts moderate runoff potentiality (354.15-516.32 mm). The hills roofed by woodland with soil group B shows slightest runoff prospective (36.87- 84.58 mm) (Fig.4). The plateau fringe surface having HSG-B with the allocation of reserved forest status exhibits low runoff potential zone (84.59- 199.15 mm). Highest surface runoff potential was found in the eastern part as well as lower reaches of the river, where majority of surface water bodies were observed.

Fig. 4 Runoff (mm) map of the study area.

Weight allocation using AHP

Considering relative importance of each parameter with other, a comparison matrix has been prepared (Table 2). The normalized score and average weight obtained have been presented in Tables 3. As the seven parameters were considered in the decision, the random consistency index (RI) is 1.32 (Table 4).The principal eigen value (λmax) and consistency index (CI) have been assessed as 8.56 and 0.038 respectively. The consistency ratio for the present decisions has been computed as 0.029 or 2.9 %, which is less than 10 %, hence it shows a realistic level of consistency in the pair-wise comparison, which approves the assigned weights. The Eigen value/score obtained by the AHP was converted into percent influence for that factor.

Table 2 Pair wise comparison matrix for the AHP process

Table 3 Normalized Score Table

Table 4 Random index values.

The final scores were obtained for all the influencing parameters, where it has been observed that the weight corresponding to rainfall is highest (1.76) in the present study (Table 5). The AHP weightage was multiplied by percentage relative weight to acquire the final weights. The weights assigned to sub criteria of drainage density ranges from 3.00 to 0.60 for very high to very low drainage density respectively (Table 5).

Table 5 Final weights calculated using AHP for influencing parameters

The area weighted average for drainage density calculated is as follows

$$AWA_{Dd} = \frac{(81.05 * 3.0 + 11.17 * 2.40 + 6.33 * 1.80 + 1.44 * 1.20)}{100} = 2.83$$

Similarly, AWA value was obtained for other influencing parameters. It was found that the DGSLR index value has maximum of 30.12 and a minimum of 27.32 (Table 6). Thus, the sub-watershed with highest DGSLR index value receives the highest priority (first rank), the next compound parameter value receives second rank and likewise the ranking of each sub-watershed has been ascertained. The sub-watershed 8 indicated highest priority ranking with DGSLR index value 30.12 and Sub-watershed 6 received lowest priority ranking with DGSLR index value 27.32 (Table 6). The highest value of priority ranking in the sub-watershed 8 (Fig. 5) signifies the greater extent of hydrological response (less recharge, high runoff, and high erosion).

Table 6 DGSLR index value and final ranking of sub-watersheds

Fig 5 Sub watershed wise ranking map based on hydrological response for the study area

These priority ranking values were then categorized into four classes based on the equal interval method, which depict four various zones of hydrological processes. Based on these values, the prioritization classes are made namely, Very High priority, High priority, Medium priority and Low priority (Fig 6).

Fig. 6. Scatter plot of final DGSLR index value.

Table 7 Prioritization of sub-watersheds

DGSLR compound index values indicate that the most influencing factors to hydrological processes are ,Precipitation (0.25), Slope (0.19), and Landuse/landcover (0.14) followed by landform classification (0.11), runoff (0.10) and drainage density (0.09). It is pertinent to note that very high priority area lies near outlet of watershed as well as upper reach of watershed. It covers 33.12% of total area having steep slope with high drainage density in sub-watershed 3, 7 and 8 (Fig. 7). The resultant vulnerability map also indicates that the high priority area covers about 43.06% of the total area indicating high surface runoff, high drainage density, poor vegetation cover, high overland flow, more erosion, low recharge with less groundwater potential. It was found that sub-watershed originated from Western Ghat region falls under high / immediate concern and needs appropriate development and management strategies to effectively reduce the high runoff and erosion. The moderate priority in context of hydrological processes covers 15.82% area, which indicates moderate recharge rate / moderate groundwater potential. The low priority watershed lies in the central part of the watershed and covers 8.0% of total watershed area.

Fig 7. Watershed prioritization map of Shivgnaga watershed based on hydrological response

4. CONCLUSION

In this study, the eight sub-watersheds of Shivganga river basin were ranked on the basis of hydrologic responses vis-a-vis erosion vulnerability due to existing geology, drainage density, disposition of slopes, landform types, land use pattern, rainfall and runoff. The ranking was performed through geospatial method formulating DGSLR index using structured technique of AHP, which provided a comprehensive and rational framework for casing a decision problem to identify the most vulnerable sub-watersheds. The AHP tool applied for determination of weights of different sub-watersheds concluded that this method can be gainfully implemented in inaccessible/remote regions, where field data/ground based data scarcity is experienced for estimating hydrological response of sub-watersheds. The very high to high priority areas (76.18%) can be put under intensified soil conservation measures implementation program. It has also been found that the sub-watersheds under very high and high priority are on higher slopes. The moderate to low priority watersheds lies in the central part of the basin and cover 23.82% of total watershed area. Identification and prioritization of these areas is an important tool in natural resource management and planning because it allows researchers to implement conservation strategies more rationally and sustainably. Identification of measures and necessity of implementation in the most vulnerable areas is an issue to be addressed in future research. The example displayed in this study, based on available information, spatial data and expert's knowledge, could be replicated in similar such watersheds from Western Ghats.

ACKNOWLEDGEMENT: The authors are thankful to Prof. N. R. Karmalkar, Head, Department of Environmental Sciences and Prof. D. C. Meshram, Head, Department of Geology, S.P. Pune University, for extending help to use the department laboratory for computing facilities. Authors thankfully acknowledge the anonymous reviewers for their valuable comments to improve the quality of manuscript.

5. REFERENCES

Abdulla F, Eshtawi T, Assaf H (2009) Assessment of the Impact of Potential Climate Change on the Water Balance of a Semi-arid Watershed. Water Resources Management 23:2051–2068. doi: 10.1007/s11269-008-9369-y

Adiat KAN, Nawawi MNM, Abdullah K (2012) Assessing the accuracy of GIS-Bases elementary multicriterio decision analysis as a spatial prediction tool-A case of predicting potential zone of sustainable groundwater resources. J Hydrol 440–441:75–89

Agarwal R, Garg PK (2015) Remote Sensing and GIS Based Groundwater Potential & Recharge Zones Mapping Using Multi-Criteria Decision Making Technique. Water Resources Management. doi: 10.1007/s11269-015-1159-8

Aher PD, Adinarayana J, Gorantiwar SD (2014) Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: A remote sensing and GIS approach. Journal of Hydrology 511:850–860. doi: 10.1016/j.jhydrol.2014.02.028

Alvarado A, Esteller M V., Quentin E, Expósito JL (2016) Multi-Criteria Decision Analysis and GIS Approach for Prioritization of Drinking Water Utilities Protection Based on their Vulnerability to Contamination. Water Resources Management 30:1549–1566. doi: 10.1007/s11269-016-1239-4

Beane JE, Turner CA, Hooper PR, et al (1986) Stratigraphy, composition and form of the Deccan Basalts, Western Ghats, India. Bulletin of Volcanology 48:61–83. doi: 10.1007/BF01073513

He M, Hogue TS (2012) Integrating hydrologic modeling and land use projections for evaluation of hydrologic response and regional water supply impacts in semi-arid environments. Environmental Earth Sciences 65:1671–1685. doi: 10.1007/s12665-011-1144-3

IMSD (1995) Technical guidelines, integrated mission for sustainable development, national remote sensing center (NRSC) Department of Space, Government of India

Jaiswal RK, Ghosh NC, Galkate RV, Thomas T (2015) Multi Criteria Decision Analysis (MCDA) for Watershed Prioritization. Aquatic Procedia 4:1553–1560. doi: 10.1016/j.aqpro.2015.02.201

Jiang Y, Liu C, Li X, Liu L, Wang H (2015) Rainfall-runoff modeling, parameter estimation and sensitivity analysis in a semiarid catchment. Environmental Modelling & Software 67:72–88. doi: 10.1016/j.envsoft.2015.01.008

Jyrkama MI, Sykes JF (2007) The impact of climate change on spatially varying groundwater recharge in the grand river watershed (Ontario). Journal of Hydrology 338:237–250. doi: 10.1016/j.jhydrol.2007.02.036

Kadam AK, Kale SS, Pande NN, Pawar NJ, Sankhua RN (2012) Identifying Potential Rainwater Harvesting Sites of a Semi-arid, Basaltic Region of Western India, Using SCS-CN Method. Water Resources Management 26:2537–2554. doi: 10.1007/s11269-012-0031-3

Kaliraj S, Chandrasekar N, Magesh NS (2013) Identification of potential groundwater recharge zones in Vaigai upper basin, Tamil Nadu, using GIS-based analytical hierarchical process (AHP) technique. Arabian Journal of Geosciences 7:1385–1401. doi: 10.1007/s12517-013-0849-x

Kinthada NR, Gurram MK, Eedara A (2013) Remote sensing and GIS in the geomorphometric analysis of micro- watersheds for hydrological Scenario assessment and characterization - A study on Sarada river watershed , Visakhapatnam district , India. 4:195–212.

Krois J, Schulte A (2014) GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru. Applied Geography 51:131–142. doi: 10.1016/j.apgeog.2014.04.006

Kumar S, Mishra A (2015) Critical Erosion Area Identification Based on Hydrological Response Unit Level for Effective Sedimentation Control in a River Basin. 1749–1765. doi: 10.1007/s11269-014-0909-3

Kuriakose SL, Devkota S, Rossiter DG, Jetten VG (2009) Prediction of soil depth using environmental variables in an anthropogenic landscape, a case study in the Western Ghats of Kerala, India. Catena 79:27–38. doi: 10.1016/j.catena.2009.05.005

Langemeyer J, Gómez-baggethun E, Haase D, Scheuer S, Elmqvist T (2016) Environmental Science & Policy Bridging the gap between ecosystem service assessments and land-use planning through Multi-Criteria Decision Analysis (MCDA). Environmental Science and Policy. doi: 10.1016/j.envsci.2016.02.013

Maxwell RM, Putti M, Meyerhoff S, et al (2014) Water Resources Research. Water resources research 50:1531–1549. doi: 10.1002/2013WR013725.Received

Misra AK, Pachouri A, Kaur A (2015) Watershed Management Structures and Decision Making Frameworks. Water Resources Management 29:4849–4861. doi: 10.1007/s11269-015-1094-8

Molina-Navarro E, Hallack-Alegría M, Martínez-Pérez S, Ramírez-Hernández J, Mungaray-Moctezuma A, Sastre-Merlín A (2015) Hydrological modeling and climate change impacts in an agricultural semiarid region. Case study: Guadalupe River basin, Mexico. Agricultural Water Management. doi: 10.1016/j.agwat.2015.10.029

Mushtaq A, Dar AQ, Rather NA, Din SAUD (2015) Watershed management of dal lake catchment (J & K) based on erosion intensity hazard using geospatial technique.

80:31028–31034.

Nasiri H, Boloorani AD, Sabokbar HAF, Jafari HR, Hamzeh M, Rafii Y (2013) Determining the most suitable areas for artificial groundwater recharge via an integrated PROMETHEE II-AHP method in GIS environment (case study: Garabaygan Basin, Iran). Environmental monitoring and assessment 185:707–18. doi: 10.1007/s10661-012-2586-0

Patel DP, Gajjar CA, Srivastava PK (2013) Prioritization of Malesari mini-watersheds through morphometric analysis : a remote sensing and GIS perspective. Environ Earth Sci (2013) 69:2643–2656. doi: 10.1007/s12665-012-2086-0

Rabu PP, Askaran RB (2013) Drainage Morphometry of Upper Vaigai River Sub-watershed , Western Ghats , South India Using Remote Sensing and GIS. 82:519–528.

Rahman MA, Rusteberg B, Gogu RC, Ferreira JPL, Sauter M (2012) A new spatial multi-criteria decision support tool for site selection for implementation of managed aquifer recharge. Journal of environmental management 99:61–75. doi: 10.1016/j.jenvman.2012.01.003

Sajinkumar KS, Anbazhagan S (2015) Geomorphic appraisal of landslides on the windward slope of Western Ghats, southern India. Natural Hazards 75:953–973. doi: 10.1007/s11069-014-1358-2

Saaty TL (2008) Decision making with the analytic hierarchy process.International journal of services sciences 1: 83-98.

Samal DR., Gedam SS. & Nagarajan R.(2015) GIS based drainage morphometry and its influence on hydrology in parts of Western Ghats region , Maharashtra , India. Geocarto International 37–41. doi: 10.1080/10106049.2014.978903

Sarma S, Saikia T (2012) Prioritization of Sub-watersheds in Khanapara-Bornihat Area of Assam-Meghalaya (India) Based on Land Use and Slope Analysis Using Remote

Sensing and GIS. Journal of the Indian Society of Remote Sensing 40:435–446. doi: Doi 10.1007/S12524-011-0163-6

Shah II, Survey G, Agency D (2012) Influence of Geological and Geomorphological Characteristics on Groundwater Occurrence in Deccan Basalt Hard Rock Area of Tawarja river Sub-Basin. Development 4:440–447.

Singh WR, Jain MK (2015) Continuous Hydrological Modeling using Soil Moisture Accounting Algorithm in Vamsadhara River Basin, India. Journal of Water Resource and Hydraulic Engineering 4:398–408. doi: 10.5963/JWRHE0404011

Sujatha ER, Selvakumar R, Rajasimman B (2014) Watershed prioritization of Palar sub-watershed based on the morphometric and land use analysis. Journal of Mountain Science 11:906–916. doi: 10.1007/s11629-012-2628-7

Umrikar B.N. (2016) Morphometric analysis of Andhale watershed, Taluka Mulshi, District Pune, India., Jour. Appl Water Sci. Springer Online, pp. 1-13, DOI 10.1007/s13201-016-0390-7

Vollmer D, Pribadi DO, Remondi F, Rustiadi E, Regameyb AG (2016) Prioritizing ecosystem services in rapidly urbanizing river basins: A spatial multi-criteria analytic approach. Sustainable Cities and Society 20:237–252. doi: 10.1016/j.scs.2015.10.004

Wang K, Zhang Q, Chen YD, Singh VP (2015) Effects of land-use/cover change on hydrological processes using a GIS/RS-based integrated hydrological model: case study of the East River, China. Hydrological Sciences Journal 60:1724–1738. doi: 10.1080/02626667.2014.949723

Zhan X, Huang ML (2004) ArcCN-Runoff: An ArcGIS tool for generating curve number and runoff maps. Environmental Modelling and Software 19:875–879. doi: 10.1016/j.envsoft.2004.03.001

Figure

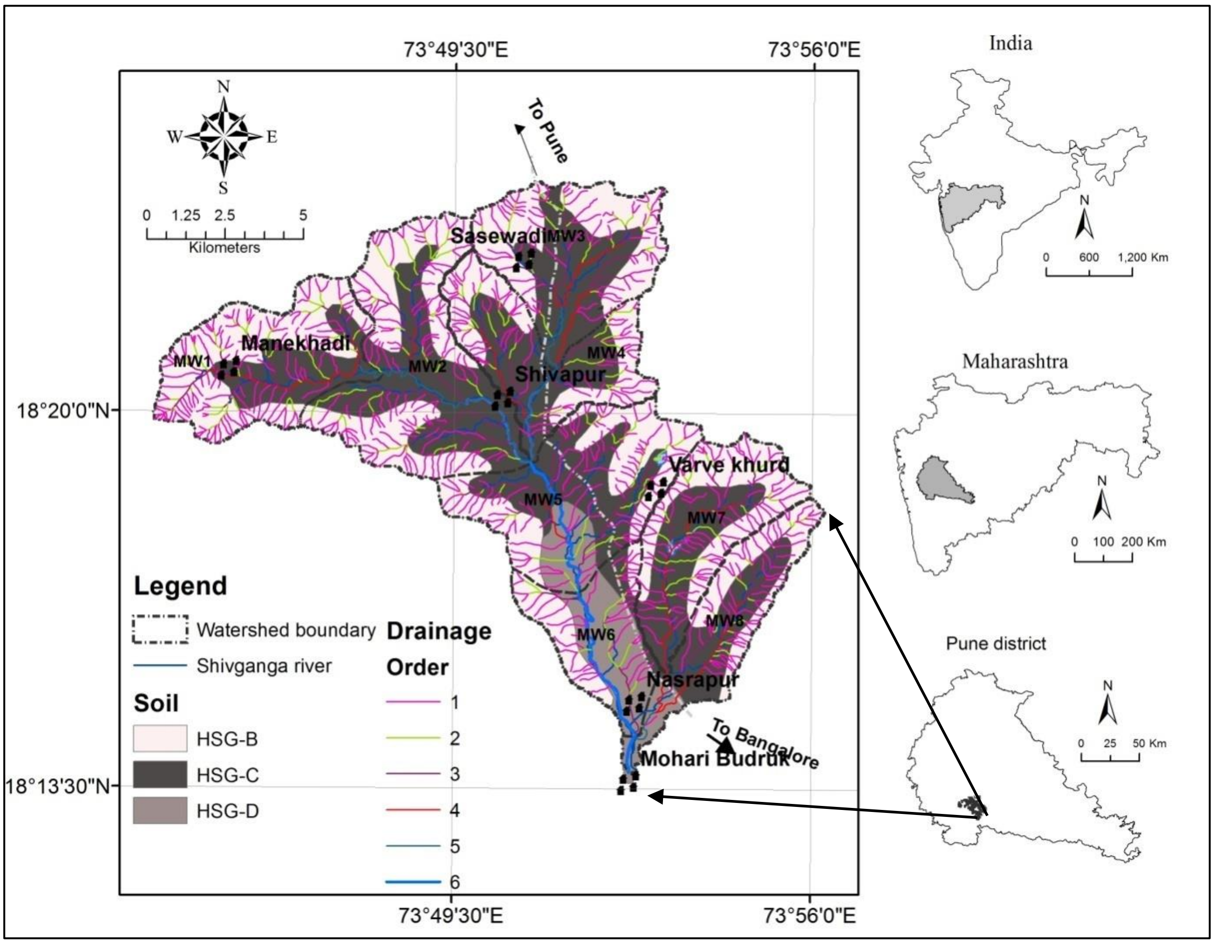

Fig.1 Location map of the study area showing hydrological soil group (HSG) and drainage

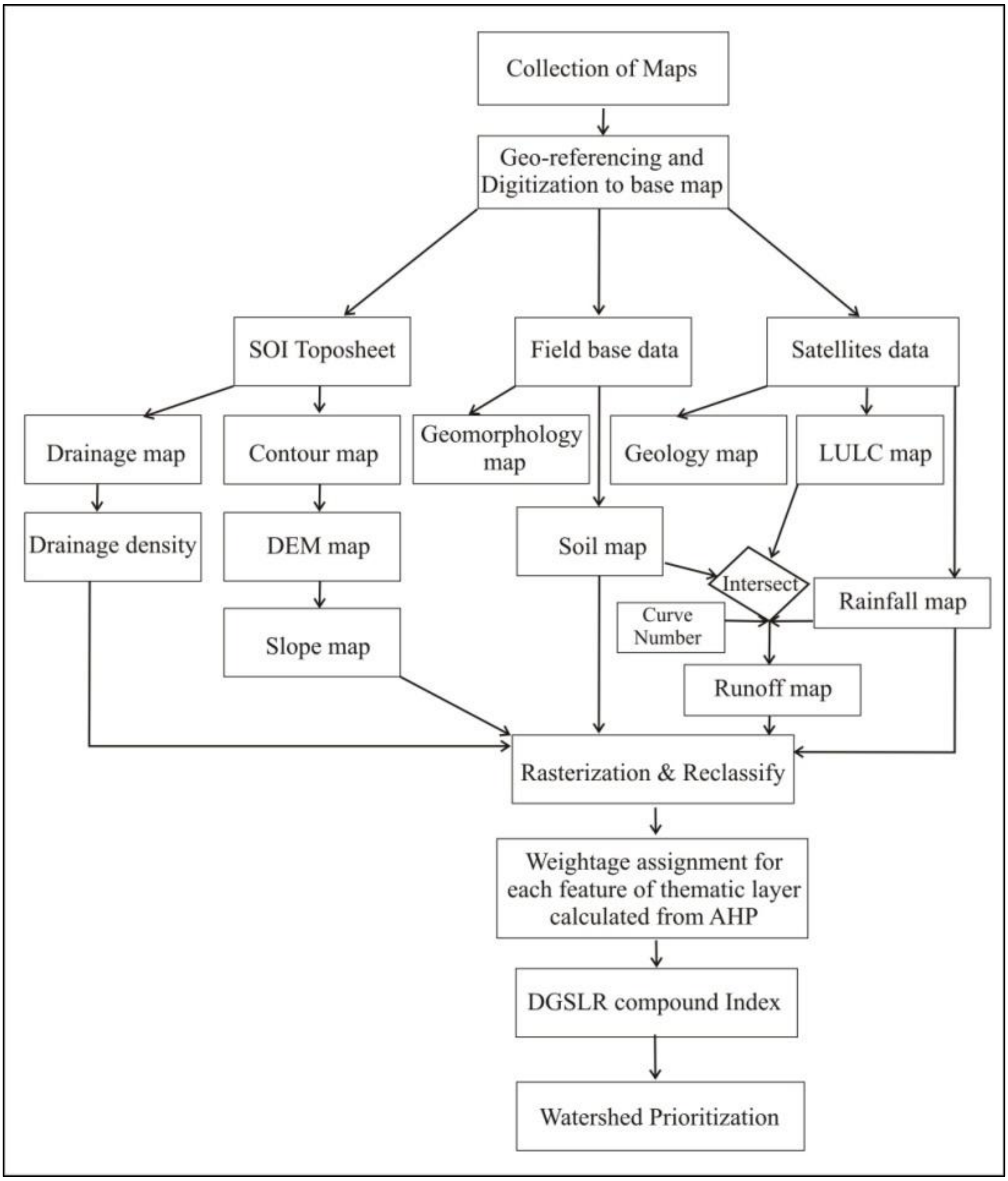

Fig. 2 Flow chart for methodology adopted in the present study.

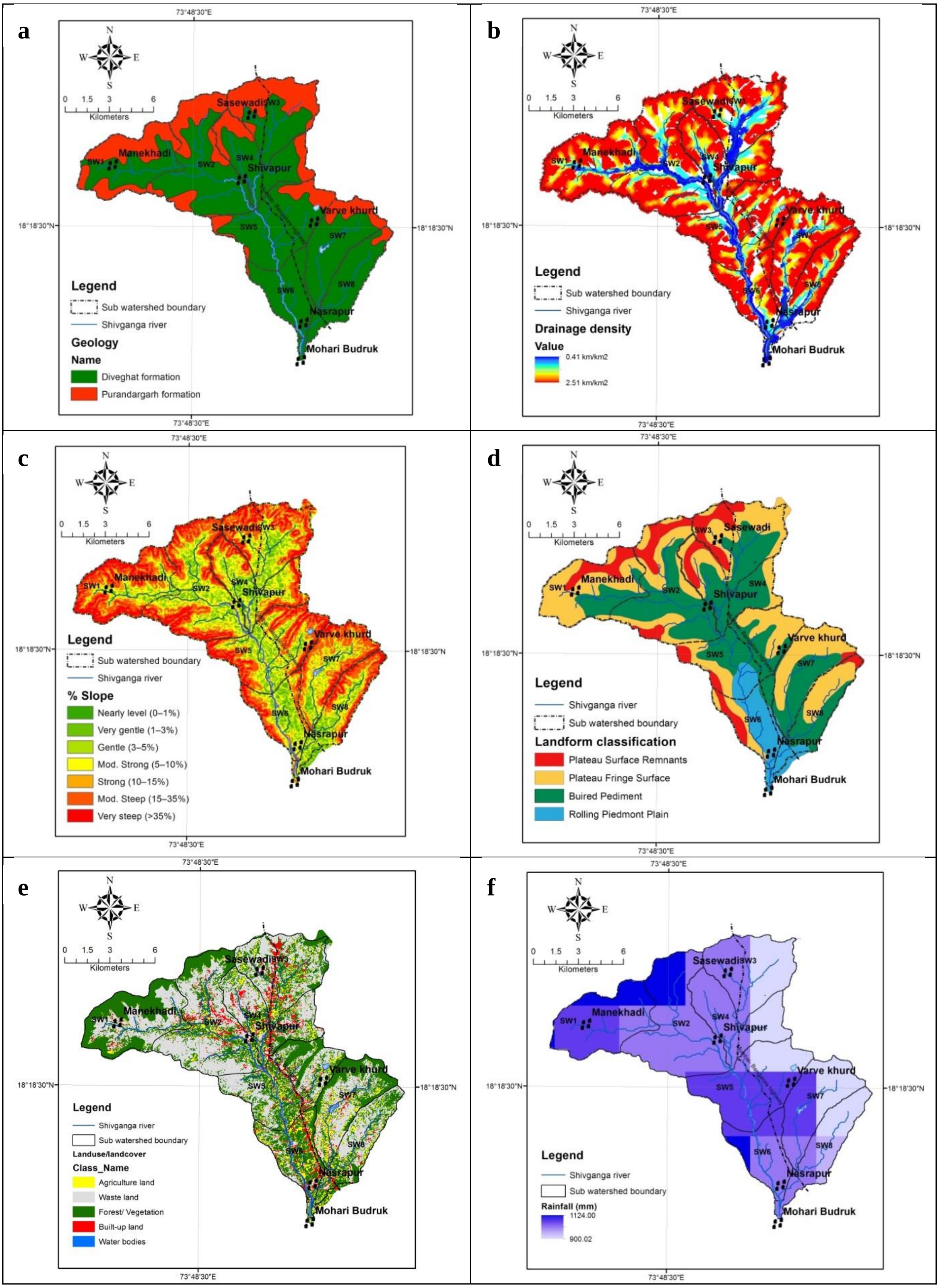

Fig. 3 (a) Drainage density, (b) Geology, (c) % Slope (d) Landform classcification (e) Land use/land cover, (f) Rainfall (DGSLR) map of the study area

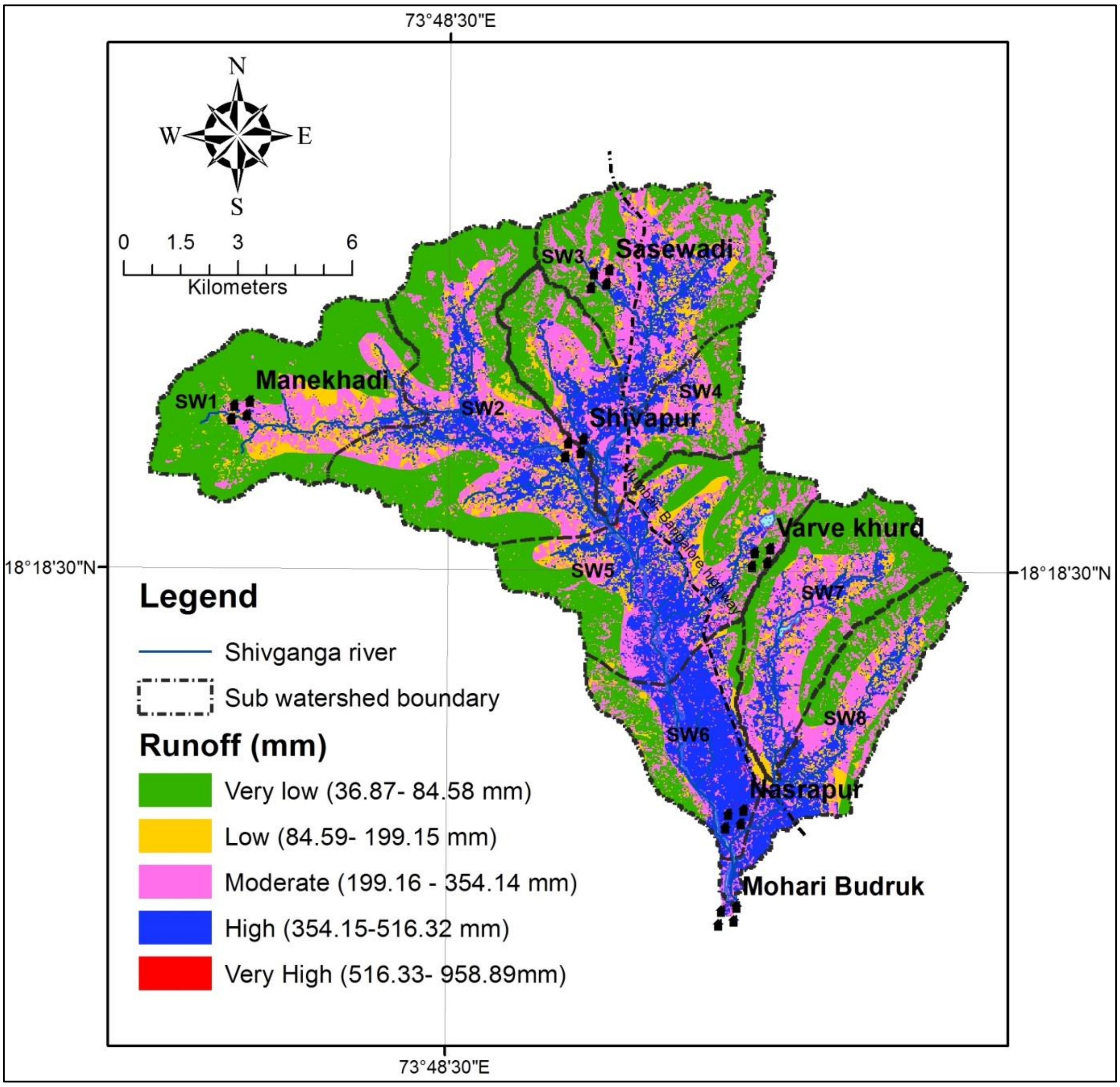

Fig. 4 Runoff (mm) map of the study area.

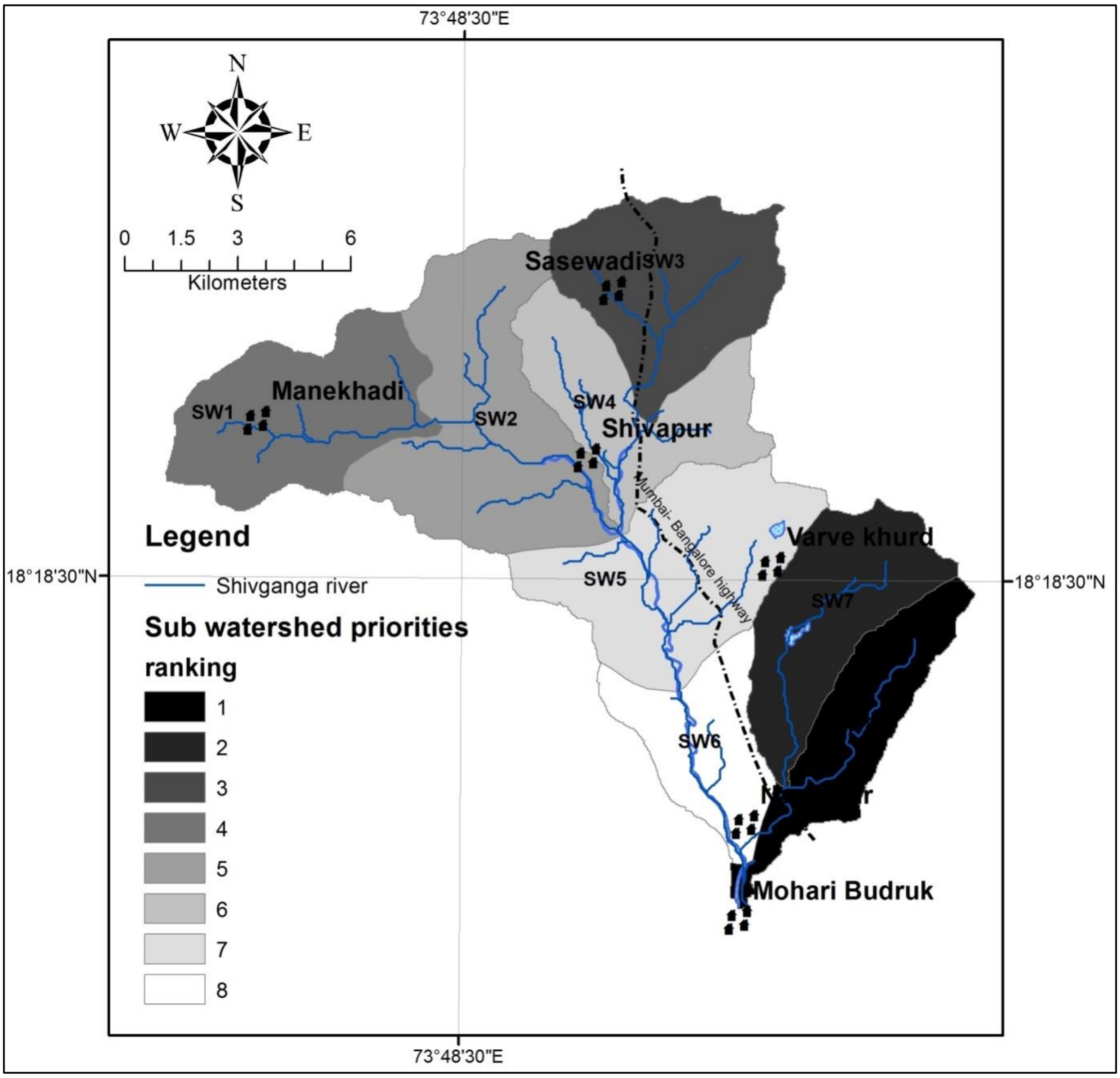

Fig 5 Sub watershed wise ranking map based on hydrological response for the study area

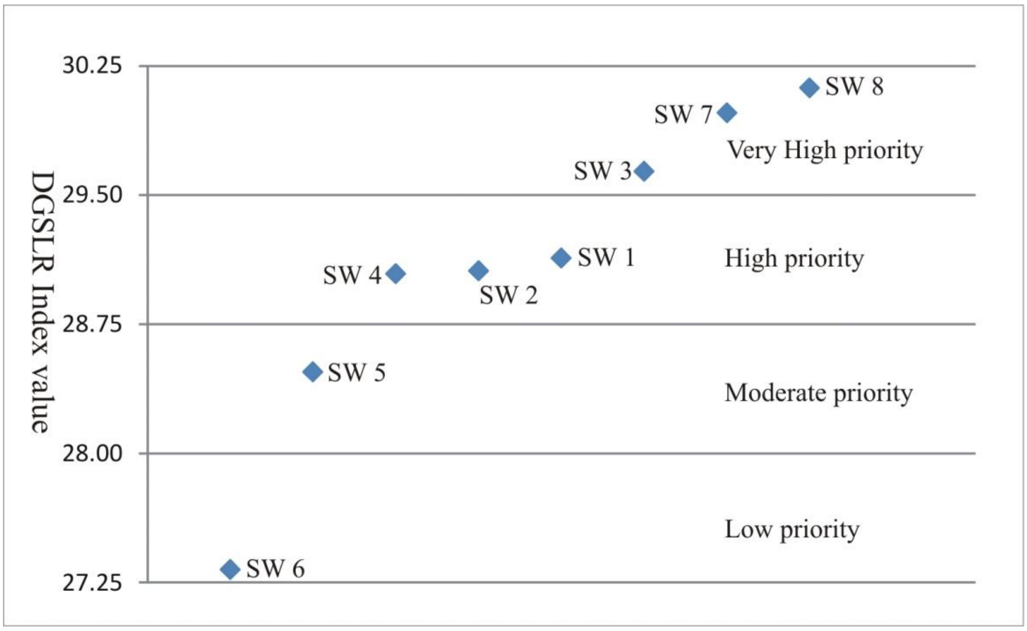

Fig. 6 Scatter plot of final DGSLR index value.

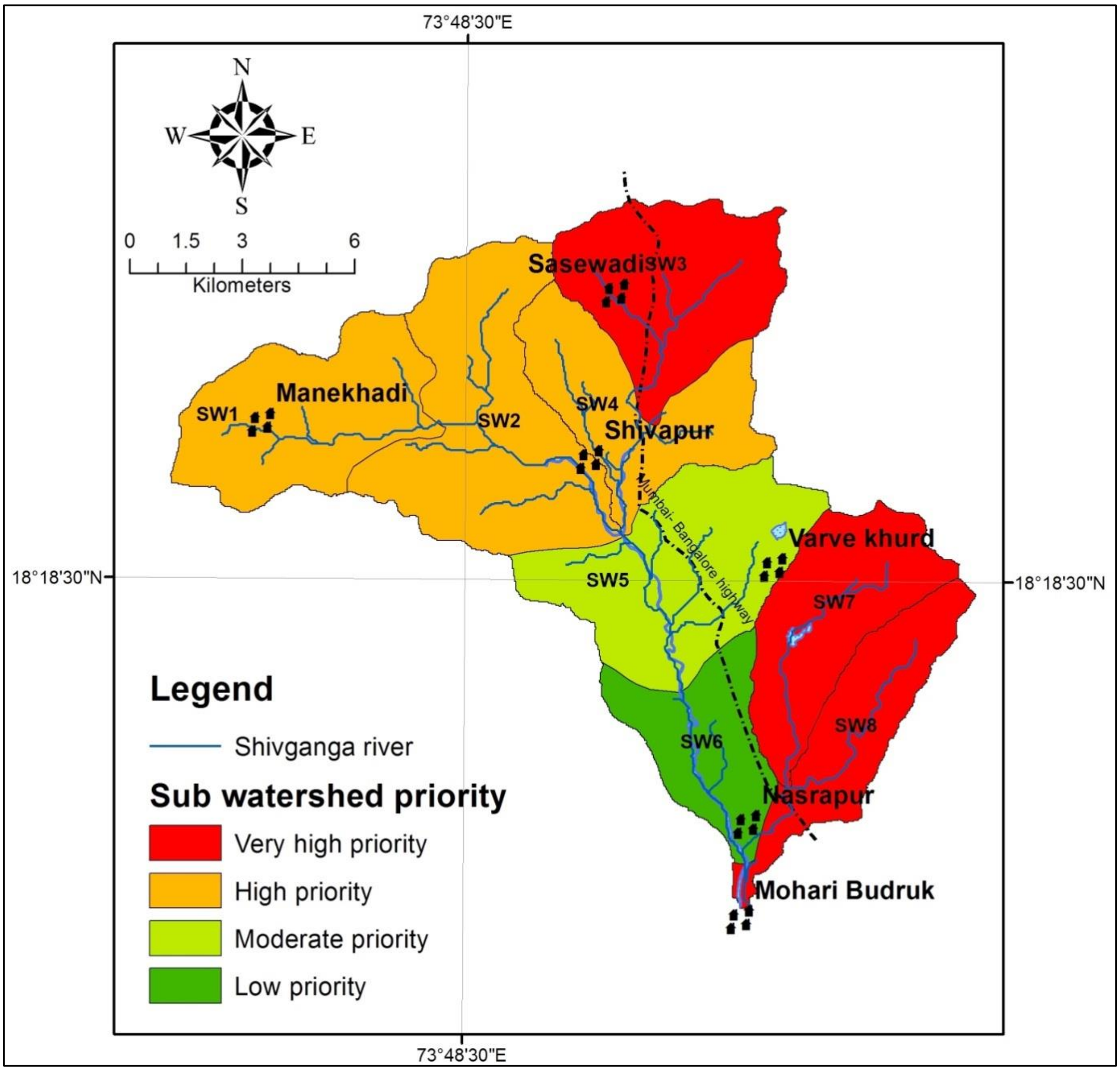

Fig 7 Watershed prioritization map of Shivgnaga watershed based on hydrological response

Table

Table 1 Area (in percentage) under various thematic layer sub-classes

a. Drainage density	Sub-watershed							
	1	2	3	4	5	6	7	8
Very High (>2.46 km/km^2)	81.05	75.03	80.05	72.29	76.44	76.24	78.49	76.52
High (1.84 - 2.46 km/km^2)	11.17	14.64	9.93	15.66	14.86	7.70	11.56	10.41
Moderate (1.24-1.84 km/km^2)	6.33	3.19	6.43	6.28	2.95	2.02	8.50	7.94
Low (0.47-1.24 km/km^2)	1.44	7.05	3.59	5.62	1.56	3.00	1.45	3.18
Very low (0- 0.467 km/km^2)	--	0.08	--	0.15	4.19	11.05	--	1.95
b. Geology								
Diveghat Formation	48.26	68.21	46.32	70.55	81.29	98.83	78.57	93.89
Purandargarh Formation	51.74	31.79	53.68	29.45	18.71	1.17	21.43	6.11
c. % Slope								
Nearly level (0–1%)	1.81	0.61	1.29	2.08	1.70	4.04	0.62	3.26
Very gentle (1–3%)	9.30	7.16	6.87	10.45	8.73	16.74	4.57	16.54
Gentle (3–5%)	15.31	12.25	10.40	18.11	16.15	22.05	11.42	23.58
Mod. Strong (5–10%)	21.88	19.85	18.56	25.88	19.04	21.25	29.88	30.76
Strong (10–15%)	11.10	8.53	10.96	10.54	7.60	8.11	13.18	14.32
Mod. Steep (15–35%)	25.74	27.00	31.84	18.48	24.34	18.35	33.22	10.00
Very steep (>35%)	14.87	24.60	20.09	14.46	22.43	9.45	7.12	1.55
d. Landform classification								
Plateau surface remnants	16.52	15.57	21.67	11.48	38.62	19.07	51.04	4.32
Plateau fringe surface	59.98	32.07	43.08	30.58	6.00	15.09	2.00	39.92
Buried Pediment	23.50	52.35	35.25	57.94	44.13	11.57	46.22	38.95
Rolling Piedmont Plain	--	--	--	--	11.25	54.27	0.75	16.90
e. Land use / land cover								
Waste land	39.44	57.94	50.72	54.49	41.47	26.59	39.56	44.38
Forest/vegetation	51.41	16.08	11.99	9.08	23.18	20.83	35.70	18.97
Agriculture land	6.44	24.17	33.47	33.13	33.39	49.41	22.83	35.16
Water bodies	0.06	0.28	0.66	0.66	0.78	0.56	1.25	0.54
Built-up land	2.65	1.53	3.17	2.64	1.17	2.61	0.65	0.96
f. Rainfall								
< 900mm	--	--	--	34.00	26.39	--	45.34	40.58
900mm-975mm	--	--	--	--	--	--	--	24.62
975mm- 1050mm	20.07	74.84	49.76	66.00	4.87	62.33	14.09	34.81
1050mm-1100mm	56.83	1.66	50.24	--	68.74	25.67	40.57	--
>1100mm	23.10	23.50	--	--	--	12.00	--	--
g. Runoff								
Very High (516.33- 958.89mm)	5.28	3.40	4.46	4.30	6.51	10.90	7.90	10.64
High (354.15-516.32 mm)	31.65	43.89	39.96	36.57	32.77	15.19	22.62	29.31
Moderate (199.16 - 354.14 mm)	18.57	21.96	32.21	32.31	22.09	15.14	29.06	25.89
Low (84.59- 199.15 mm)	4.40	20.60	19.15	23.72	29.41	55.27	16.17	31.56
Very low (36.87- 84.58 mm)	40.10	10.16	4.22	3.09	9.22	3.50	24.26	2.61

Table 2 Pair wise comparison matrix for the AHP process

Layer	Drainage density	Geology	Landform classification	Slope	Landuse / landcover	Rainfall	Runoff
Drainage density	1.00	0.50	0.20	0.50	2.00	0.50	0.50
Geology	2.00	1.00	2.00	0.50	0.33	0.50	2.00
Geomorphology	5.00	0.50	1.00	0.33	0.50	0.50	0.50
Slope	2.00	2.00	3.00	1.00	3.00	0.33	2.00
Landuse / landcover	0.50	3.03	2.00	0.33	1.00	0.33	2.00
Rainfall	2.00	2.00	2.00	3.00	3.00	1.00	2.00
Runoff	2.00	0.50	2.00	0.50	0.50	0.50	1.00
Total	14.50	9.53	12.20	6.17	10.33	3.67	10.00

Table 3 Normalized Score Table

Layer	Drainage density	Geology	Landform classification	Slope	Landuse / landcover	Rainfall	Runoff	Weightage	Average weight
Drainage density	0.069	0.052	0.016	0.081	0.194	0.136	0.050	0.60	**0.60/7** = 0.09
Geology	0.138	0.105	0.164	0.081	0.032	0.136	0.200	0.86	0.12
Landform classification	0.345	0.052	0.082	0.054	0.048	0.136	0.050	0.77	0.11
Slope	0.138	0.210	0.246	0.162	0.290	0.091	0.200	1.34	0.19
Landuse / landcover	0.034	0.318	0.164	0.054	0.097	0.091	0.200	0.96	0.14
Rainfall	0.138	0.210	0.164	0.486	0.290	0.273	0.200	1.76	0.25
Runoff	0.138	0.052	0.164	0.081	0.048	0.136	0.100	0.72	0.10
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	7.00	1.000

Table 4 Random index values.

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Table 5 Final weights calculated using AHP for influencing parameters

Parameter	AHP Weightage ***W***	Categories	Rank	Percentage Relative weight ***i***	Final Weight = ***W*i***
Drainage density	0.09	Very High (>2.46 km/km^2)	5	**(5/15)*100=** 33.3	3.00
		High (1.84 - 2.46 km/km^2)	4	26.67	2.40
		Moderate (1.24-1.84 km/km^2)	3	20.00	1.80
		Low (0.47-1.24 km/km^2)	2	13.33	1.20
		Very low (0- 0.47 km/km^2)	1	6.67	0.60
Geology	0.12	Diveghat formation		55	6.60
		Purandargarh formation		45	5.40
Slope	0.19	Very steep (>35%)	7	25.00	4.75
		Mod. Steep (15–35%)	6	21.43	4.07
		Strong (10–15%)	5	17.86	3.39
		Mod. Strong (5–10%)	4	14.29	2.72
		Gentle (3–5%)	3	10.71	2.03
		Very gentle (1–3%)	2	7.14	1.36
		Nearly level (0–1%)	1	3.57	0.68
Landform classification	0.11	Plateau surface remnants	4	40.00	4.40
		Plateau fringe surface	3	30.00	3.30
		Buried Pediment	2	20.00	2.20
		Rolling Piedmont Plain	1	10.00	1.10
Landuse/landcover	0.14	Waste land	5	33.33	4.67
		Forest/vegetation	4	26.67	3.73
		Agriculture land	3	20.00	2.80
		Water bodies	2	13.33	1.87
		Built-up land	1	6.67	0.93
Rainfall	0.25	< 900mm	5	33.33	8.33
		900mm-975mm	4	26.67	6.67
		975mm- 1050mm	3	20.00	5.00
		1050mm-1100mm	2	13.33	3.33
		>1100mm	1	6.67	1.67
Runoff	0.10	VeryHigh(516.33- 958.89mm)	5	33.33	3.33
		High (354.15-516.32 mm)	4	26.67	2.67
		Moderate(199.16-354.14 mm)	3	20.00	2.00
		Low (84.59- 199.15 mm)	2	13.33	1.33
		Very low (36.87- 84.58 mm)	1	6.67	0.67

Table 6 DGSLR index value and cumulative ranking of sub-watersheds

Layer	Sub watershed							
	1	2	3	4	5	6	7	8
Drainage density	2.83	2.74	2.80	2.73	2.75	2.61	2.80	2.74
Geology	5.98	6.22	5.96	6.25	6.38	6.59	6.34	6.53
Slope	3.46	3.45	3.44	3.02	3.29	2.75	3.25	2.53
Landform classification	3.22	2.90	3.15	2.79	2.99	2.19	3.34	2.55
Landuse / landcover	3.97	4.00	3.79	3.85	3.76	3.44	3.85	3.78
Rainfall	4.78	4.59	5.14	5.15	4.73	5.17	5.83	6.76
Runoff	4.89	5.16	5.36	5.25	4.57	4.58	4.56	5.23
DGSLR Index value	29.13	29.06	29.64	29.04	28.47	27.32	29.97	30.12
Priority rankings	Fourth	Fifth	Third	Sixth	Seven	Eight	Second	first

Table 7 Prioritization of sub-watersheds

Priority type	Sub-watershed	DGSLR Index range	Percentage area
Very high	SW7, SW8, SW3	30.11 - 29.42	33.12
High	SW1, SW2, SW4	29.42 – 28.72	43.06
Moderate	SW5	28.72 – 28.02	15.82
Low	SW6	28.02 – 27.32	8.00