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GIS-based Evaluation of Micro-watersheds to Ascertain Site Suitability for Water Conservation Structures

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Keywords Peak runoff · Runoff · Automated watershed delineation · Spatial analysis · Site suitability · Morphologic parameters · Rainfall intensity · Multi-criteria analysis · Composite erosion index

Abstract The planning of conservation measures to conserve water and soil resources taking hydrological planning unit as micro-watershed is considered to be effective. The automated watershed delineation technique using the spline interpolated filled digital elevation model (DEM) is effective in converging slopes of the area in which the stream patterns match with the manually digitized stream patterns of the topographical map. The various vector spatial layers like the slope/aspect, land-use/land-cover, runoff potential, soil erosion potential and the associated attribute information governing the criteria for different conservation structures can act as input layers in integrated spatial analysis module in GIS environment to evolve derived layers indicating the locations of conservation sites meeting the requisite criteria. The reliability of suitable conservation sites suggested out of integrated spatial GIS analysis could be ascertained using the multi criteria analysis incorporating the various factors controlling soil erosion process in the micro-watershed groups. The details of the above work are discussed in the paper.

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Introduction

The watershed based approach for planning of conservation measures to conserve water and soil resources is considered to be effective since the excess rainfall or runoff from the watershed will be drained to a common outlet and the run-off in the watershed will be controlled by various morphological parameters related to size, shape and relief of the watershed. Different conservation measures in a watershed can be carried out for conserving the water and soil resources in arable and non-arable land. Apart from which, there are gully erosion controlling structures that reduce the slope length leading to a reduced runoff due to reduction in the velocity of flow. The Remote Sensing and GIS techniques can be utilized for identifying suitable sites for soil and water conservation measures in the micro-watersheds after formulating different criteria norms (Ravindran *et al.*, 1992). The integration of Remote Sensing and GIS techniques has emerged as a powerful tool for micro-watershed based conservation measures by suitably identifying sites for conservation structures (Durbude and Venkatesh, 2004).

The automated micro-watershed delineation using raster DEM can delineate appropriate sized micro-watersheds based on the given threshold value. The DEM can be made suitable for micro-watershed delineation by using the fill depression removal algorithm (Martz and Garbrecht, 1992). The D8 automated watershed delineation algorithm creates flow path layer that gives good results in zones of convergent flows and along well defined valleys (Freeman, 1991). The D8 method tends to produce flow in parallel lines along principal directions (Moore, 2000) and will not give accurate outputs to represent adequately divergent flows over convex slopes and ridges (Freeman, 1991). The micro-watersheds of suitable sizes can be delineated by recoding the flow accumulation raster as per the required threshold and overlaying with flow path raster and is suited in hilly area (Liang and Mackay, 2000).

The DEM can also be utilized for generating slope map in raster and vector domain. The watershed management activities would be more effective when carried out on a larger micro-watershed group of area not exceeding 8.0 km^2 and formed by clubbing two to six smaller automatically delineated micro-watersheds in which the water flow leads to a common outlet.

The Soil Conservation Services (SCS) runoff model is useful for evolving the runoff potential for every feature utilizing different antecedent moisture condition (AMC) to obtain runoff potential layer and for computing the peak runoff rate. The peak runoff rate can be utilized to calibrate the conventional rational formula. The hydrological evaluation of micro-watersheds necessarily involves relating the runoff with watershed morphological parameters and quantifying the peak runoff parameter with estimation of annual average soil loss from the micro-watershed (Saxena *et al*., 2000). The conservation structures are designed for rainfall duration ‘t’ in hours and for a return period ‘T’ for the rainfall in years, the value of ‘t’ and ‘T’ will depend upon the importance of the hydraulic structure that needs to be designed. Extensive investigations have already been carried out by researchers using remote sensing techniques for suggesting suitable sites for soil and water conservation measures in various water sheds of India (Singh *et al*., 1990). Studies for suggesting suitable sites for various water harvesting structures have also been carried out (Behera and Mohapatra, 1996). Therefore, the integration of Remote Sensing and GIS techniques has emerged as a powerful tool for watershed-based conservation measures by suitably identifying sites for conservation structures. The sites for soil and water conservation measures not only depend on annual rainfall but also on other terrain factors like slope, aspect, ground undulations, soil permeability and land use variation in space and time (Chandrashekar and Rao, 1999). The integrated resources study at watershed level using remotely sensed data and field survey data provides knowledge on the potential and limitations in resources planning and utilization (Ravindran *et al*., 1992).

The reliability aspects of the sites chosen for these soil and water conservation structures through use of remote sensing and GIS spatial analysis can

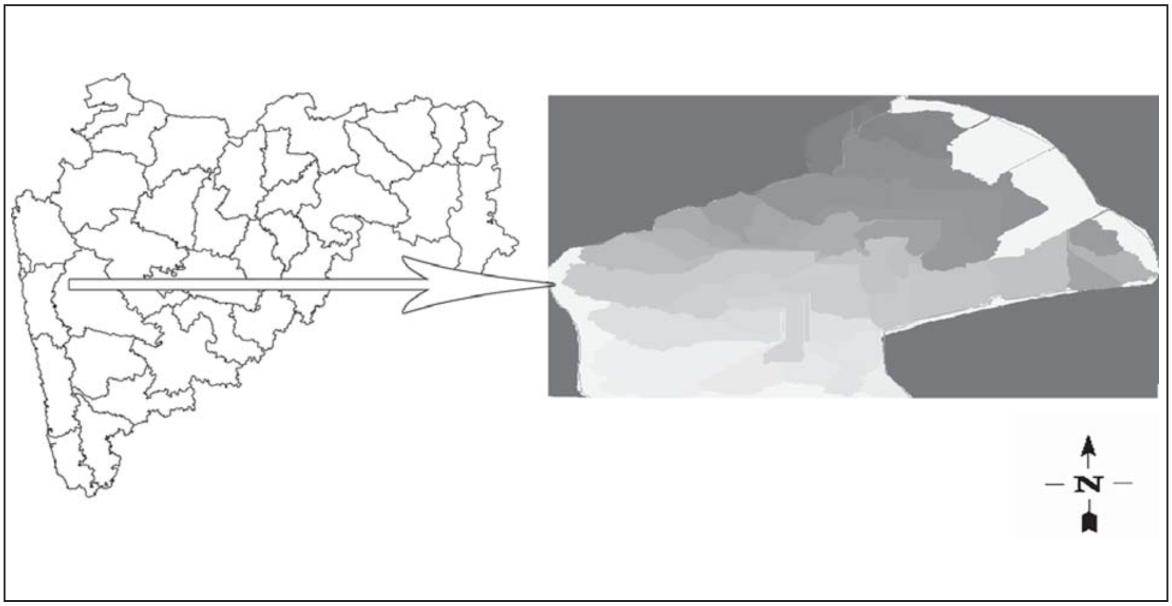

Fig. 1a Maharashtra State map with district boundaries showing study area in Pune district and automatically delineated watersheds (Not to scale)

be ascertained by multi-criteria analysis of different parameters like land cover changes, slope, soil texture, runoff variation and morphological parameters. The Analytical Hierarchy Process (AHP) multi-criteria modeling for determining the reliability of the chosen sites for soil conservation uses pair wise comparison of the erosion controlling parameters considered in the analysis to obtain a rating based on the pair wise comparison scale used for numerical rating given by Saaty (1977).

The multi-criteria analysis assigns suitable weights to each of the parameters controlling the soil erosion and then computer the composite erosion index value for the micro-watershed groups. If the composite erosion index value is more, then greater is the susceptibility of the micro-watershed group to soil erosion process. The composite erosion index values can be computed at any point of time for the micro-watershed groups based on the multi-criteria parameter values governing the micro-watersheds at that particular instant of time that is before and after conservation practices for the micro-watershed groups. The value of composite erosion index could be an indicator about the reliability of the action plan chosen after performing integrated spatial GIS analysis.

Study area

The present study area has been carried out in Bavdhan micro-watersheds surrounding Pune city located in Pune district of western Maharashtra and occupies the eastern part of Mula river basin, the micro-watersheds of the study area is located between 18º30′8.74″- 18º33′58.49″ N latitude and 73º44′50.74″ - 73º49′8.3″E longitude (Figs. 1a, b). The hilly region has altitude varying from 400m to about

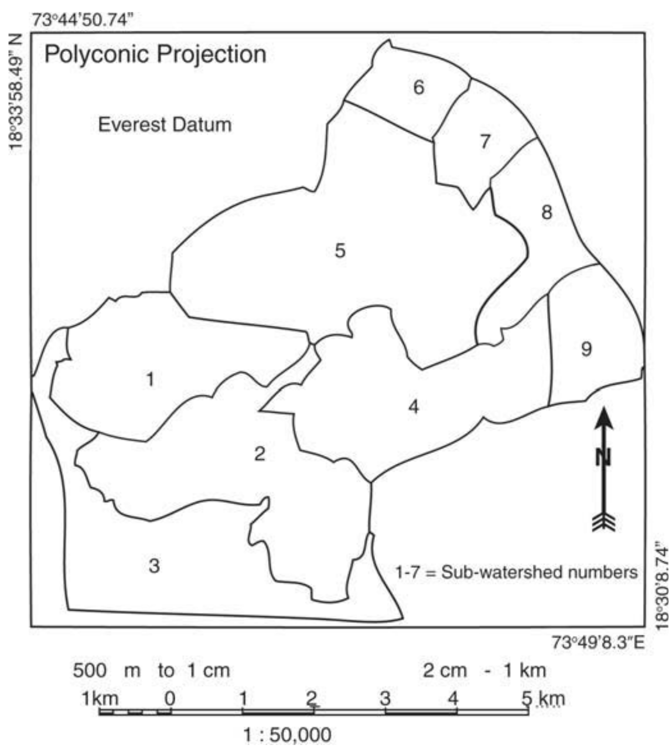

Fig. 1b Vector Micro-watershed group of Study Area

900 m. The total area covered by automatically delineated micro-watershed groups is 25.7 km^2 of this 30.5% alone is arable area while 42.1% is forest area. The satellite data for the study is standard False Colour Composite (FCC) of LISS-III remotely sensed satellite data of 23.5 m spatial resolution obtained on 03 January 2001, covering the study area and topographical map 47 F/14 of 1:50,000 scale in polyconic projection system.

Methodology

In the present study the micro-watersheds were delineated from DEM generated using digitized contour data obtained from topographical map. The digitized contours were converted into raster with elevation values attributed into it. The delineation of micro-watersheds was carried out by utilizing a threshold value of 3185 pixels to the flow accumulation layer for recoding and segmentation. Nine groups of suitable sized micro-watersheds of area not exceeding 8km^2 were earmarked for evaluation, each group comprising two to six automatically delineated micro-watersheds. Image classification of remote sensing data was done after reducing the correlation in spectral bands using principal component analysis (PCA). The minimum distance to mean classification on principal component composite suited the requirements of reliable land-use/land-cover output. The weighted curve number used in the Soil Conservation Services (SCS) runoff model for every feature was obtained for different antecedent moisture condition (AMC) and the runoff values in cm depth for rainfall values obtained in cm depth was computed using the SCS model. Slope-map, runoff potential map and other criteria for different water conservation structures were integrated by crossing in the spatial analysis tool of GIS to arrive at suitable sites for water conservation. Geomedia Professional 6.0 raster and vector modules were used.

For the present study USDA SCS curve number technique (USDA, 1972) was used for runoff computation. Image classification of 23.5 m data gave a reliable level-I detail of the landscapes suitable to obtain weighted curve numbers for different periods representing different antecedent moisture condition and hydrological soil groups.

The SCS runoff expressed in unit depth spread over the entire micro-watershed is given by

Runoff Q = (P-0.2S)(P-0.2S)/(P+0.8S)
P = Rainfall in unit depth spread over the entire watershed.
CN = 2540/ (25.4+S)
CN = Curve number.
S = Potential maximum water retention of the watershed.

The value of curve number (CN) for different land-use conditions and hydrologic soil group were given in standard curve number tables. These values were applied to antecedent moisture condition AMC-II only, which is for average soil moisture condition. To get the curve number values for AMCs (i.e. I and III), the correction factors were applied or suitable models used. AMC-I, this indicates the lowest runoff potential because the soils are dry enough and AMC-III indicates highest runoff potential of the soil, which practically happens when areas of watershed are saturated from antecedent rains. The curve numbers for AMC-I and AMC-III had been obtained using the following formulae

CN for AMC-I = (23*CN-II)/(10 + 0.13*CN-II)

CN for AMC-III = (4.2 CN-II)/ (10 –0.058*CN-II)

The weighted curve number for each land-use category can be calculated from the CN multiplied by the corresponding percentage of land-use.

The peak runoff (Qp) for small watersheds was computed for micro-watershed groups using method given by Singh *et al*. (1990).

Qp = 0.0208 * Area of watershed *Q/Tp.
Tp = Time to peak in hours.
Qp = Peak runoff rate in cubic meters per second.

Area of watershed will be in hectares.
Q = SCS runoff in cm depth.

To obtain Tp
LAG = $L^{0.8}((1000/CN) - 9)^{0.7}/(1900 \times S^{0.5})$

LAG is a watershed characteristic, which depends on hydraulic length, curve number and average slope of watershed

S = Percentage average slope of the watershed obtained from topo-graphical maps and is given by, S = $(M \times N \times 100)/A$
M = Total length of contours within the watershed in meters.
N = Contour interval in meters.
LAG/0.6 = Time of concentration (Tc).
Tp = $(Tc^{1/2} + 0.6 * Tc)$.
L = Hydraulic length of watershed in ft, which is the length of watershed from the outlet to the most distant ridge.

Hence depending upon the design rainfall, return period, type of hydraulic structure, the peak runoff rate at the outlet of the micro-watersheds can be computed. The peak runoff (Qp in Cumec) obtained by SCS method is utilized to calibrate the conventional rational formula given by

Qp = (C*I*A)/360
C = Coefficient of runoff.
I = rainfall intensity in mm per hour.
A = Area of micro-watershed in hectares.
Qp = Peak runoff in Cumec.

The rainfall intensity (I) in cm/hr was computed using $(K*T^a)/(t+b)n$

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T = Return period in years.

t = Strom duration in hours.

K, a, b, n are constants and were obtained from hydrological tables pertaining to western Maharashtra region. These values are dependent on the geographical location of the watershed. For the watersheds in the area K=3.974, a =0.1647, b =0.15 and n =0.7327.

The rainfall intensity was computed for the following combinations to enable arriving at the coefficient of runoff values for these combinations in the nine micro-watershed groups (T=25 Years, t=6 hours), (T=20 Years, t=5 hours), (T=15 Years, t=4 hours) (T=10 Years, t=2 hours) and (T=5 Years, t=1 hours). The value of rainfall (P) in cms for a specified duration was obtained using P=I*t in cms for which Q and Qp had been computed.

The integrated spatial analysis on different theme layers and attributes was carried out in vector GIS environment after formulating criteria norms for various conservation structures as given in Integrated Mission for Sustainable Development (IMSD) to arrive at sites suitable for conservation in arable and non-arable lands away from built-up area and locating them on streams. For this purpose buffer polygons were drawn around the built-up area features to prevent any site falling in the built-up area jurisdiction. The sites were chosen to lie in streams to ensure availability of water. These sites were arrived by performing spatial query analysis and can be altered slightly to suit the local ground conditions. All the conservation sites, mainly the gully plug or the stream bunds, were checked by overlaying the drainage map and they were found close to the drains or on the drains.

The reliability of the suggested erosion control sites in the study area was carried out by studying temporal remote sensing data (LISS-III) acquired during 23 December, 1999 and 03 January, 2001 (95Path, 59row), which showed degradation of dense forests and increase in open forests, changes in landscapes from open scrub to cultivation and open forest to open scrub. The cover-1 (C1) comprises decrease of vegetation area attributed to decrease in dense forest cover and double cropped area during the period, which cause increase of soil erosion. The cover-2 (C2) of the area has undergone increase in barren land due to change in degraded forests and single cropping area that cause increase of soil erosion. Other parameters utilized in the multi-criteria analysis were

(a) Rainfall erosivity (R) as a measure of climatic influence on soil erosion.
(b) Soil texture (T) indicating particle size distribution with silt and very fine sand being the least resistant soil having particle size 0.002 to 0.7.
(c) Slope (S) as a measure controlling runoff and soil erosion. The slope in % is chosen as the criteria.
(d) Drainage density (Dd) depends upon basin characteristics like soil and rock type, vegetation cover and infiltration, which has bearing on soil erosion.
(e) Circulatory ratio (CR) is a measure of basin shape, which is related to runoff characteristics.

The range of change in area (in hectares) under Cover-1 and Cover-2 is rated for the area in 9-point weight scale appropriately as per their contribution to soil loss. The weights assigned from 1 to 9 to the area changes in cover-1 and cover-2 has been carried out according to the extent of area change for these covers during the change detection period. In the same way based on the values of other multi-criteria parameters, the weights can be assigned to them on a scale of 1 to 9.

The area index of erosion (C_k) for each criterion encompassing all the nine micro-watershed groups was obtained using

(C_k) = Ó (Weight obtained for the criteria in the j^{th} micro-watershed * Area of K^{th} criteria for j^{th} micro-watershed)/(Area of jth micro-watershed).

The Composite Erosion Index (CEI) relates to the erosion intensity of the unit area under relative contribution of given criteria and is obtained using

CEI = C1*W1 + C2*W2 + C3*W3 + C4*W4 + C5*W5 + C6*W6 + C7*W7

C1, C2, …..C7 are the area weighted erosion index for the seven criteria.

W1,W2…..W7 are the Analytical Hierarchical Process (AHP) weights obtained by performing pair wise comparisons of the seven erosion controlling parameters.

The value of CEI could suggest trends in landscape changes owing to the execution of action plan. This can help in reliability assessment of the conservation practices evolved using GIS analysis.

Results and discussion

Table 1 presents the SCS model runoff for all nine watershed groups using annual average rainfall of 1338.2mm. The runoff, peak runoff, runoff potential, form factor, circulatory ratio and ruggedness number for all nine watersheds is given in Table 2. General trend indicates an increase in runoff value associated with increased morphologic parameter values. The values of the rainfall intensity for different rainfall duration and return periods are given in Table 3. The coefficient of runoff values for utility into conventional rational peak runoff equation is given in Table 4. The attribute structure formulated for different spatial features is shown in Table 5. Table 6 presents the criteria norms governing the different conservation practices. The spatial distribution and the area extent of various conservation sites obtained through spatial analysis in GIS is shown in Fig. 2. It is also observed that the runoff potential for the built-up area is high so not suited for soil and water conservation sites and only low and moderate runoff potential zones are suitable.

Table 1 Annual average rainfall values

Year	Annual average rainfall (mm)
1997	1023.4
1998	812.1
1999	724.4
2000	509.9
2001	565
2002	424.7
2003	458.8
2004	913.2
2005	1338.2
2006	1266.9

Table 7 gives the weights assigned for the two cover types C1 and C2 based on the extent of temporal change. Table 8 gives the weights for the remaining five soil erosion controlling parameters. The AHP weights were estimated subjectively by carrying out the pair wise comparison of the matrix for the seven erosion controlling parameters given in Table 9. The Composite Erosion Index (CEI) values for each criteria and the total CEI value for the nine micro-watershed groups are given in Table 10. The CEI value for the area was 1.45 averaged for the nine micro-watersheds. So the study area can be counted as moderate to high erosion potential area. As per norms CEI value ranging from 1.6 to 1.8 indicates a moderate to high erosion area, more the magnitude of CEI, higher would be the erosion potential there by requiring suggested conservations measures. This can alter the landscapes towards improved sustainability and socio-economic criteria of the area. The multi-criteria evaluation can act as effective planning measure for controlling the parameters that are detrimental to sustainability and has high environmental impact. It can also be used to predict environmental impact due to various criteria and for suggesting remedial action plans with an objective of reducing the CEI value through alternative land

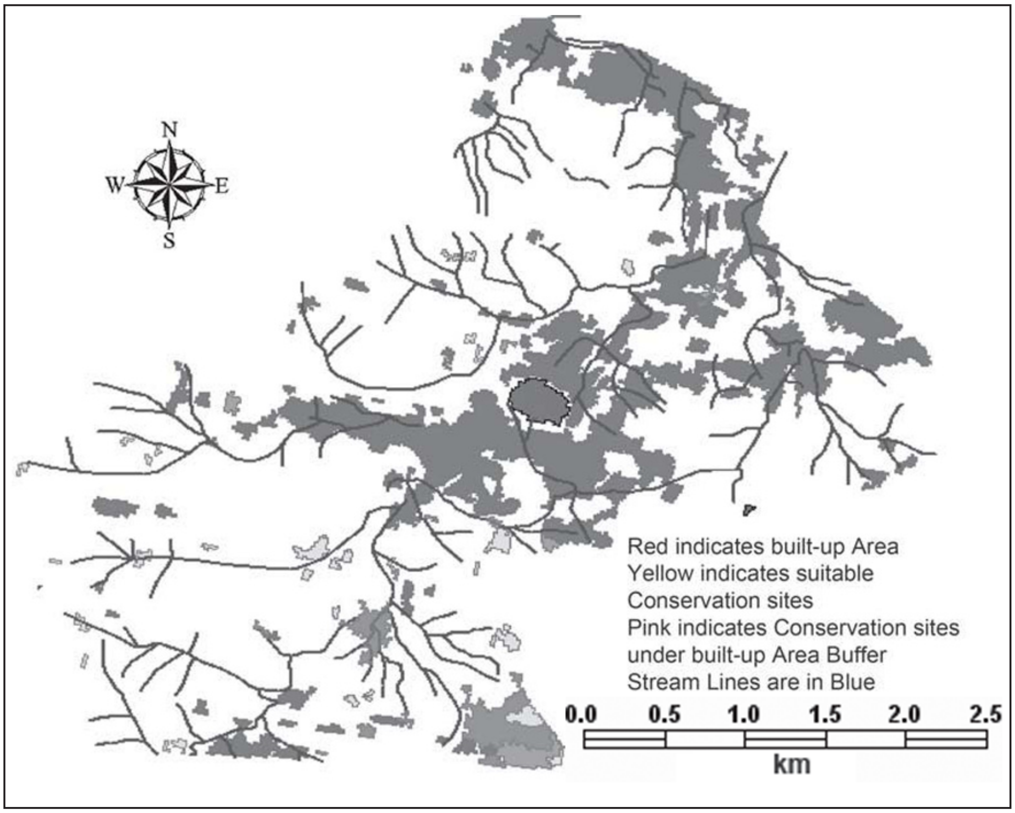

Fig. 2 Site suitability map for conservation structures.

Table 2 Runoff and Morphologic parameters

Micro-watershed group no.	Runoff (cm)	Peak runoff (cubic meter per second)	Runoff potential	Form factor	Ruggedness no.	Circulatory ratio	Stream density
No-1	119.7263	3.839303391	0.89468192	0.29	2.7	0.32	0.004
No-2	116.2795	5.269312338	0.86892448	0.45	2.8	0.29	0.003
No-3	118.5519	5.424808344	0.88590534	0.61	2.1	0.12	0.003
No-4	121.6201	4.113956135	0.90883356	0.25	1.4	0.30	0.002
No-5	119.4506	8.008094763	0.89262109	0.56	1.8	0.47	0.002
No-6	121.3337	1.732440461	0.90669362	0.62	1.6	0.62	0.002
No-7	119.3396	1.754531997	0.89179181	0.48	2	0.71	0.003
No-8	117.9481	1.979346529	0.88139344	0.24	2.2	0.41	0.003
No-9	118.3519	2.059796043	0.88441083	0.46	1.9	0.77	0.003

Table 3 Rainfall intensity, duration and return period

Return period (years)	Rainfall duration (hrs)	Rainfall intensity (I) in mm per hour $I = (K*T^a)/(t + b)n$
25	6	17.84267
20	5	19.58693
15	4	21.88196
10	2	33.13982
5	1	46.76004

Table 4 Coefficient of runoff values

Micro-watershed group No	Area (hectare)	T=25Yrs t =6hours I=17.84mm/hr C=(Qp*360)/I*A	T=20Yrs t =5hours I=19.58mm/hr C=(Qp*360)/I*A	T=15Yrs t =4hours I=21.88mm/hr C=(Qp*360)/I*A	T=10Yrs t =2hours I=33.13mm/hr C=(Qp*360)/I*A	T=05Yrs t =1hour I=46.76mm/hr C=(Qp*360)/I*A
No-1	316.32	0.24	0.22	0.20	0.13	0.098
No-2	481.25	0.22	0.20	0.18	0.11	0.08
No-3	446.96	0.24	0.22	0.20	0.13	0.09
No-4	404.60	0.20	0.18	0.16	0.11	0.07
No-5	760.14	0.21	0.19	0.17	0.11	0.08
No-6	106.70	0.32	0.29	0.26	0.17	0.12
No-7	110.93	0.31	0.29	0.26	0.17	0.12
No-8	158.44	0.25	0.23	0.20	0.13	0.09
No-9	147.61	0.28	0.25	0.23	0.15	0.10

Table 5 Attribute structure for spatial GIS Analysis

Sl No	Features	Attribute schema
1	Stream	Perennial or Non Perennial, Stream length, Cross section, Longitudinal slope as shallow, moderate, steep.
2	Barren land	Soil type, Soil Texture, Infiltration, Slope and aspect, Type of Barren land
3	Built-up area	Type, existing drainage, rainwater accumulation in the area with reasons
4	Water feature	Area
5	Vegetation/Grassland	Type, condition, impervious or pervious

use/management activities and practices (LUMAPs). This can have bearing on farm income, soil erosion and surface water quality at the watershed scale.

Conclusion

The study area can be considered as hydrologic moderate water potential area in the region. The major land use identified in the area is sparse vegetation or open vegetated area. This is suited for gully plugs or stream bunds. Accurate computation of runoff is mainly dependent on the watershed characteristics. The soil conservation services model (SCS) described in the paper can be utilized for estimating the peak runoff rate of watersheds to design hydraulic or conservation structures. The SCS method is based on potential maximum retention of water at different antecedent moisture conditions

Table 6 Criteria rules for locating sites for conservation structures

Sl No	Type of conservation structure	Criteria to be followed
1	Contour bunding	Slope: Level to Medium Soil Texture: Low Small to Medium Watershed area Runoff potential is medium
2	Gully plug	Level to medium ground and very low soil texture
3	Percolation tank	Large watershed more than 40 hectares, level to medium slope, medium to high soil texture with low runoff potential
4	Nala bund	Medium watershed, level to gentle slope, medium soil texture, medium runoff potential
5	Farm pond	Watershed area more than 2 hectares with level to gentle slope and low percolation and low to medium runoff

Table 7 Temporal land cover change of cover types and assigned weights in brackets

	Cover-1			Cover-2		
Micro-watershed	Area in 2001 (ha)	Area in 1999 (ha)	Area reduction (ha) and weight indicated in brackets	Area in 2001 (ha)	Area in 1999 (ha)	Area increase(ha) and weight indicated in brackets
1	158.16	171.16	13(8)	63.26	43.16	20.10(7)
2	72.18	83.18	11(6)	385	355.05	29.95(9)
3	268.5	283.18	15(9)	134.09	111.59	22.50(7)
4	222.53	236.53	14(8)	40.46	22.46	18.0(5)
5	114.02	130.02	16(9)	380.07	350.02	30.05(9)
6	26.67	29.67	3.0(2)	21.34	6.84	14.50(1)
7	22.18	24.35	2.17(1)	44.37	26.07	18.30(5)
8	23.76	26.10	2.34(2)	95.06	75.99	19.07(6)
9	36.90	39.86	2.96(2)	73.80	55.03	18.77(5)

Table 8 Weights for soil erosion controlling parameters

Micro-watersheds	R	wt	S (%) Av	wt	T	wt	Dd	wt	Rc	wt	ws area (ha)
1	30.04	3	8	9	14	3	0.004	8	0.3	5	316.32
2	30.04	3	7	7	16	3	0.003	5	0.3	4	481.25
3	30.04	3	6.5	6	10	2	0.003	5	0.1	2	446.96
4	30.04	3	4.6	3	17	4	0.002	2	0.3	5	404.60
5	30.04	3	5.6	5	20	4	0.002	2	0.5	6	760.14
6	30.04	3	5.1	4	12	2	0.002	2	0.6	8	106.70
7	30.04	3	6.9	6	12	3	0.003	5	0.7	9	110.93
8	30.04	3	7	7	11	2	0.003	5	0.4	6	158.44
9	30.04	3	6	5	10	2	0.003	5	0.8	9	147.61
										Total	2933

Table 9 AHP Weights derived from Pair-wise normalized comparison matrix

Criteria	C1	C2	R	S	T	Dd	CR	Wt (w)
C1	0.38	0.35	0.43	0.3	0.4	0.36	0.39	0.38
C2	0.38	0.35	0.43	0.4	0.2	0.28	0.3	0.33
R	0.05	0.04	0.05	0.1	0.2	0.08	0.09	0.09
S	0.05	0.04	0.02	0	0.2	0.12	0.09	0.08
T	0.05	0.12	0.02	0	0.1	0.08	0.04	0.05
Dd	0.04	0.05	0.03	0	0	0.04	0.04	0.03
CR	0.04	0.05	0.03	0	0.1	0.04	0.04	0.04
Sum	1	1	1	1	1	1	1	

based on its importance can be computed by calibrating the rational peak runoff formula based on the time of concentration applicable for the area. The automated watershed delineation would be more effective with dense contours and low contour interval. The reliability of site suitability analysis could be carried out at any time using the multi-criteria analysis using temporal remote sensing data and quantification of composite erosion index value used as a measure to ascertain the extent of erosion in the micro-watersheds caused by different erosion controlling parameters.

Table 10 CEI for micro-watersheds

WS	c2/CEI	c1/CEI	S/CEI	T/CEI	Dd/CEI	RC/CEI	R/CEI	Total/CEI	Priority
1	0.1467819	0.1249342	0.72	0.15	0.24	0.2	0.27	1.8517161	high
2	0.1848317	0.0521136	0.56	0.15	0.15	0.16	0.27	1.5269453	moderate
3	0.1162836	0.1147734	0.48	0.1	0.15	0.08	0.27	1.3110571	moderate
4	0.0734043	0.105188	0.24	0.2	0.06	0.2	0.27	1.1485923	Average
5	0.1174101	0.0719864	0.4	0.2	0.06	0.24	0.27	1.3593965	moderate
6	0.0448424	0.0213669	0.32	0.1	0.06	0.32	0.27	1.1362093	Average
7	0.2721914	0.0074333	0.48	0.15	0.15	0.36	0.27	1.6896248	moderate
8	0.2383075	0.0112241	0.56	0.1	0.15	0.24	0.27	1.5695316	moderate
9	0.2098122	0.0152401	0.4	0.1	0.15	0.36	0.27	1.5050523	moderate
Average	0.155985	0.0582511	0.462	0.14	0.13	0.24	0.27	1.4553473	moderate

and study of land cover types of watershed. This method is effectively applicable for runoff estimation using better resolution remotely sensed data for smaller watersheds (Area not exceding 8 km^2) because in a smaller watershed there would be smaller land cover areas that is sensitive to intense rainfall and not suppressed by streams. The peak runoff rate for various rainfall duration and return periods used in the design of hydraulic structures

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