GEOSPATIAL MODELING FOR WATERSHED PRIORITIZATION IN DAHI BLOCK, DHAR DISTRICT, MADHYA PRADESH.

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Abstract

Watershed prioritization and management requires scientific knowledge of resource information, expected sediment yield and priority class of watersheds for conservation planning. Satellite data is ideally suited to derive spatial and temporal information of watershed cover types which can be inputs to sediment yield models and watershed prioritization schemes. Prediction of surface run off and sediment yield from any catchment is a complex phenomenon which affected by various factors, e.g. Climate of catchment, its morphometry, soil properties, land use/land cover, irrigation and management practices affect the sediment yield from catchment. In this case study of Dahi Block, Dhar district soil erosion due to the runoff is most important cause of land degradation. An endeavor is made here to prioritise Dahi block, Dhar district (M.P.) based on geospatial data and by using surface run off and sediment yield models so that conservation measures can be planned and executed.

Introduction:

The established procedure for watershed development planning in India is a top down approach by way of schemes to address specific problems and opportunities. These schemes are mandated by state and central government, and implemented by the sectorial institutions in a district. Existing decision methods are traditional, manual and biased in identifying the watershed sites for different schemes. Generally, base unit for these schemes is watershed, being a complete hydrological/topographical unit. Each scheme has a set of policies that are defined by legislation. Under these watershed management schemes, planners at district/sub-district level need to identify the priority watershed/ sub watersheds for preferential treatment/ land use plans. Run off is that portion of rainfall which moves down to the stream, channel, river or ocean as surface or subsurface flow. “If the farmer can intelligently harvest the runoff from his field, store in a pond and recycle it for life saving or supplementary irrigation to crops, it will be possible to boost up his crop production and thus obtain good returns (Dhruva Narayana, 1993)”.

There are many reasons to develop a non-point source pollution prioritization system to determine which watershed requires the most attention. Once priority problems watersheds have been determined, an approach for directing specific actions is needed, i.e., targeting the specific areas of greatest potential erosion which can contribute to water quality degradation. Once targeted areas are identified, an optimizing management system can be used to examine trade – offs of the potential impacts from the implementation of various best management options. The BMP’s could be selected to minimize off – farm degradation of water quality and the farmers economic criteria.

Objective:

The primary aim of the this study is to carry out watershed prioritization based on surface run off and sediment yield models in Dahi Block, Dhar district (M.P.).

Study Area:

The study area, Dahi block of Kukshi taluka is located in south-west part of Dhar district, Madhya Pradesh. It lies between 22° 00' and 22°15' N Latitude and 74°30' and 74°45' E Longitude. The south and western boundaries of study area are marked by rivers Narmada and Hatni respectively. Total geographic area of this watershed is 470.46 sq. km. The major part of the study area is covered by Deccan traps of Lower Eocene to Upper Cretaceous Era. The study area is spread over two major geomorphic divisions, namely Vindhyachal range and Narmada valley. Physiographically Dahi block is characterized with High hills, inter hill uplands, Interfluves, Valleys and River terraces. The mean annual precipitation of the area is 395.86 mm with high degree of annual variability. The drainage density is moderate with predominantly dendritic to subdendritic drainage pattern

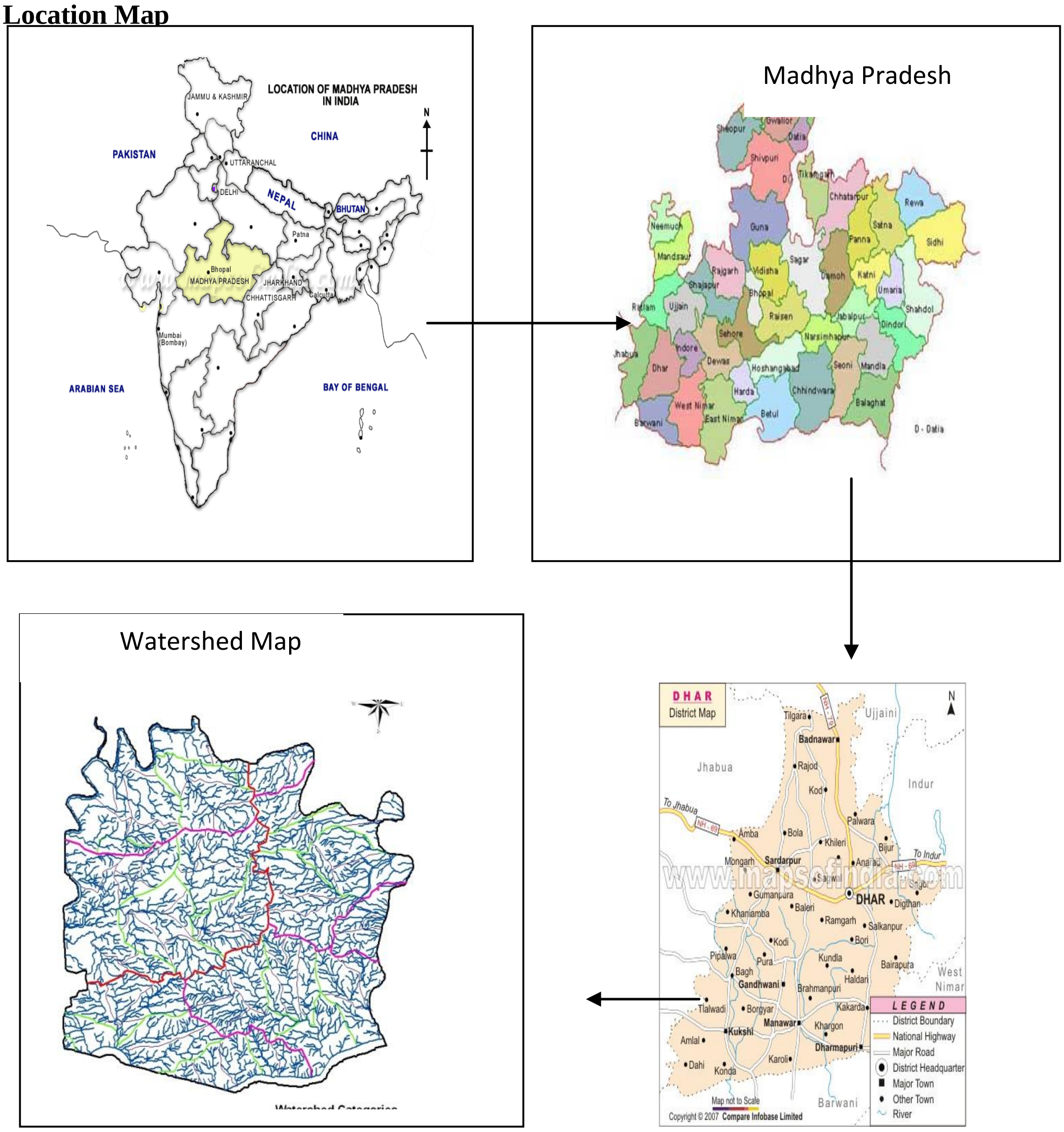
Data Used

IRS 1D multi-date satellite data, ancillary information and collateral data have been used for preparing thematic maps to be used for prioritizing watersheds in Dahi Block Dhar district (M.P.) as given in Table 1.

Table 1. Data Used

	Satellite-ID	Sensor	Date of Acquisition
Satellite Data	IRS-P6	LISS-III	24.10.2007
	IRS-P6	LISS-III	28.01.2008
	IRS-P6	LISS-III	09.05.2007
Ancillary Information	46 J/12 Toposheet (1:50,000 scale)		
Collateral Data	Daily Rainfall Data of Dahi Block Soil Texture and Soil Depth Maps, Cadastral Map		

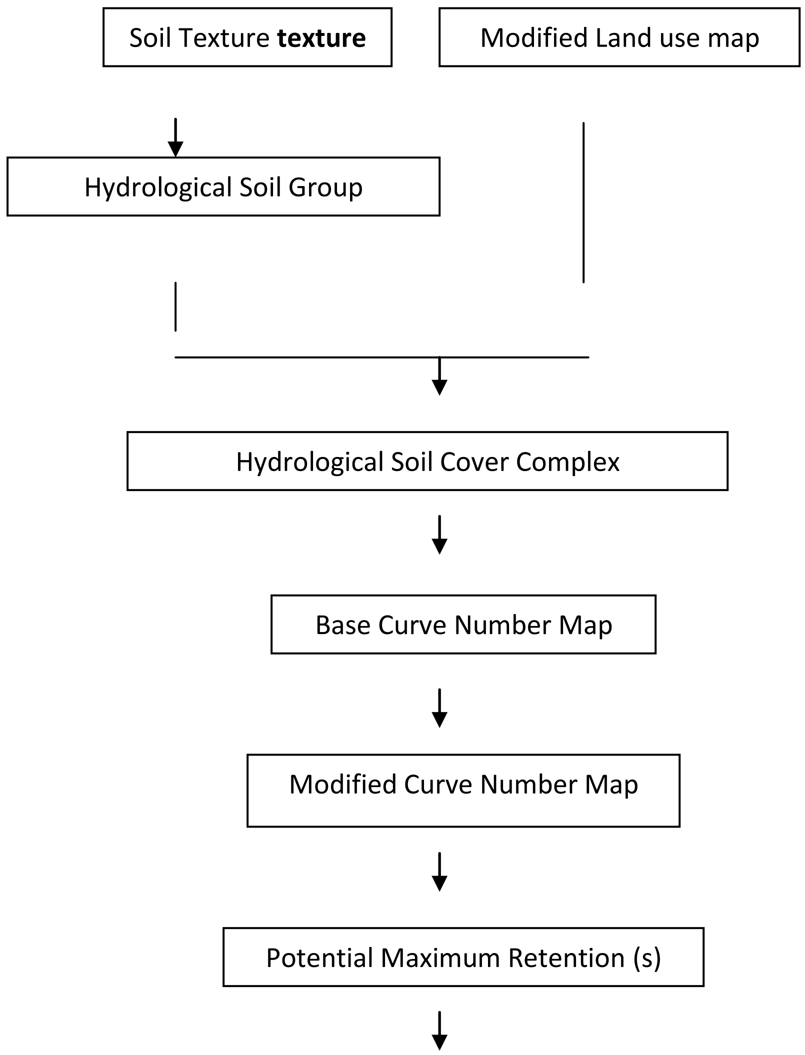
Fig. 1 Location Map



Methodology:

Various thematic maps, e.g. Land use/ cover, ground water prospect and slope were prepared through the use of multidate satellite data, ancillary information and collateral data as referred in Table 1. Later on, spatial database is created for these themes in GIS environment and subsequently this coverage's are unionized and integrated in GIS environment for creating special themes for calculation of run off and estimation of soil loss. For run off estimation, Land use/ land cover and soil maps were integrated and final run off was predicted by using SCS model as shown in Fig.1. Run off was calculated per micro-watershed wise. For soil loss calculation, Land use/ land cover, soil, slope and hydro geomorphology maps were integrated and soil loss was predicted by using Sediment Yield Index Model as shown in Fig. 2. Seasonal and month wise Run off of the study area was calculated for the year 2007.

1. Curve Number Method



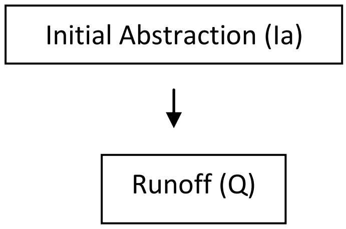


Fig. 2 Flow Chart of Runoff Estimation

Procedure adopted for estimation of direct runoff

1. Generation of NDVI (Normalized Difference Vegetation Index) map.
2. Calculating poor, fair and good condition for crop and forest.
3. Modification of Land Use map in giving poor, fair and good categories.
4. Preparation of hydrological soil group (HSG) map using soil texture.
5. Preparation of hydrological soil cover complex (HSCC) map combining HSG map and modified Land Use map.
6. Preparation of the base Curve Number (CN) map.
7. Preparation of daily rainfall maps using rainfall depth data.
8. Preparation of Antecedent Moisture Condition map using rainfall maps.
9. Modification of base curve number map for AMC I and AMC III condition.
10. Preparation of modified Curve Number (CN) map.
11. Calculation of maximum retention
12. Calculation of initial abstraction (Ia)
13. Calculation of daily runoff.

Final rainfall-runoff relation used in the SCS method of estimating direct runoff from storm rainfall is,

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

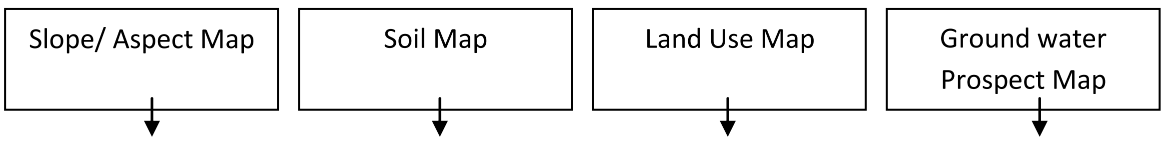
Where,

Q = Runoff in mm

P = Precipitation in mm (P > Q)

S = Potential maximum retention in (mm)

2. Integration of thematic maps and Sediment Yield Model (SYI)



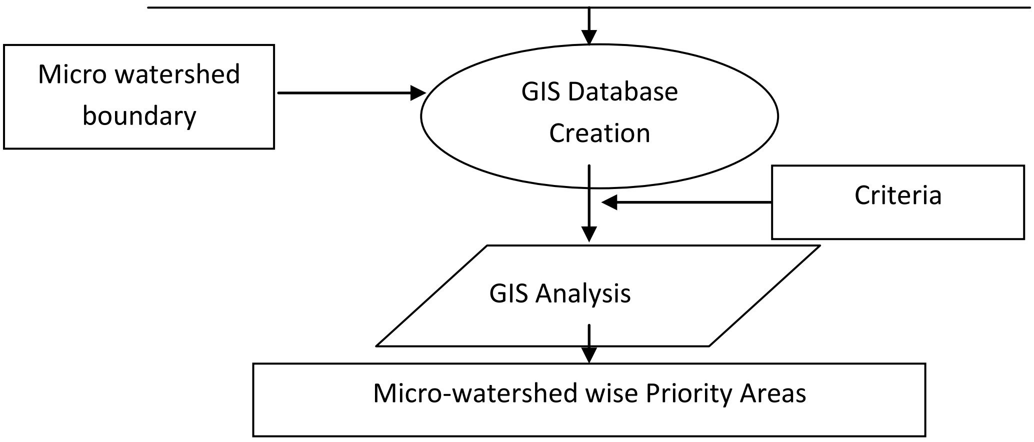


Fig. 3 Flow Chart for Micro-watershed Prioritization

HLP (Homogenous Land Parcel Unit) is homogeneous at specific level of details and is obtained by integration of the above characteristics i.e. HLP is derived from integration of slope, soil, land use and ground water prospect maps.

To derive HLP following inputs were used.

i) Elevation contour – from SOI topographical map with contour interval 20m at 1:50,000 scale

ii) Soil – Soil map prepared by giving soil depth attributes to the cadastral map of selected study area.

iii) Ground water prospect map derived from prepared hydrogeomorphological map of selected study area.

iii) Land use map at level-III using remote sensing data of the selected study area.

Results and Discussion

Various thematic maps, e.g. Land use/ cover, ground water prospect, slope and soil depth were prepared through the use of multidate satellite data, ancillary information and collateral data. Later on, spatial database is created for these themes in GIS environment and subsequently these coverages are unionized and integrated in GIS environment for creating special themes for calculation of run off and estimation of soil loss. Runoff Calculated using SCS CN method. For soil loss calculation, Land use/ land cover, soil, slope and hydro geomorphology maps were integrated and soil loss was predicted by using Sediment Yield Index Model.

Several studies have been carried out to develop methodology for prioritizing watershed using remotely sensed data and through GIS. "Advances have been made in the development of discrete input output models of the rainfall run off processes (Guang Te Wang and Yuan, 1990)". Many models, Rational Method, Cook Method, Khosla's Model and Curve Number Methods of run off estimation have been attempted by various authorities for watershed prioritization. For the present case study, Curve Number Method has been attempted. A number of sediment yield models, both empirical and conceptual, are in practice to address wide ranging soil and water management problems. Many models, Douglas Sediment Yield Equation, Musgrave Equation, Sediment Yield Predictive Equation, Universal Soil Loss Equation and sediment Yield Index Equation of soil loss estimation have been attempted by various authorities for watershed prioritization. "The watershed that contains the largest amount of impervious area has the largest amount of storm runoff (Brown, 1988)". Most conservation planning for erosion control, however use empirical models to estimate average annual soil loss. "The accelerated soil erosion in the catchments of multipurpose dam reservoirs and transport of eroded material through the drainage network give rise to series of problems (Karale et al, 1989)". "Investigation into such empirical models reveals that most of these models require input parameter in terms of spatial information of land use, soils, slope, drainage density, besides run off and rainfall intensity (Chakraborti, 1991)". The sediment Yield Equation model developed by All India Soil and Land Use Survey, Government of India, New Delhi (1977) for estimation of soil loss has been used in this study. The run off estimation has been done by Curve Number Method. The details for Curve Number Method are as follows-

Estimation of runoff

Curve Number Method

Curve Number Method was developed by Ogrosky and Mockus (1957) for determining peak rate of run off for small watersheds by synthesizing information about characteristics, physiographic factors and soil cover data. "Runoff is the water in a river or stream that is derived from precipitation (Barry et. Al, 1988)". In the present study, the model Soil Conservation Service (SCS), established by United States of Agriculture is used to study the hydrologic response of the watershed to precipitation in order to prioritize watershed for adopting suitable water conservation measures. This method is used to estimate direct runoff volume from the rainfall depths. This method takes into account the parameters characterizing a watershed such as land use, hydrological soil cover and antecedent moisture condition for predicting yield from the watershed. The Land Use/ Land Cover map that was generated based on IRS-P6 LISS III images was used as one of the inputs. There are 15 categories in Land Use/ Land Cover ,i.e., Built up - Villages(Rural), Agriculture - Kharif, Rabi, Double crop and Fallow, Wasteland – Land with scrub, Land with out scrub, Barren Rocky / Stony Waste, Mining(Industrial waste), Forest – Dense forest, open forest, scrub forest, forest blank, crop land in forest and water bodies. All these land use/ land cover classes have been modified into three classes of poor, fair and good based on good crop, good canopy of forest/ Land with scrub given in a modified land use/ land cover map. A NDVI map was prepared for the images using NIR-R/ NIR+R band. NDVI images for forest and agriculture were prepared. Then by using mean and standard deviation values under agriculture and forest poor, fair and good conditions were calculated as follows:

NDVI	>=	μ + 6		Good Condition
μ + 6	>	NDVI	> μ - 6	Fair Condition
NDVI	<=	μ - 6		Poor Condition
Where, μ	=	Mean		
6	=	Standard deviation		

Table 2. Modified land use/land cover classification system.

Sl. No.	Level II	Level III	Hydrological crop condition
1.	Built-up	Village (Rural)	
2.	Agriculture	a. Kharif	Poor Agriculture
		b. Double crop	Fair Agriculture
		c. Cropland in forest	Good Agriculture

3.	Fallow	a. Rabi	Fallow
		b. Fallow land	
4.	Forest	a. Dense Forest	Good Forest
		b. Open Forest	Poor Forest
		c. Scrub Forest	Fair Forest
		d. Forest Blank	
5.	Wasteland	a. Land with scrub	Good Wasteland
		b. Land without scrub	Fair Wasteland
		c. Barren rocky/stony waste	Poor Wasteland
		d. Mining outcrop	
6.	Water bodies	Streams/Reservoirs	

Antecedent soil moisture is known to have significant effect on both volume and rate of runoff. This factor is duly considered by classifying moisture content in the soil into 3 antecedent moisture conditions. Antecedent moisture condition is five days moisture or wetness condition of the soil before occurrence of storm and hence, this is determined by the total in the 5 day period preceding a storm. To calculate AMC of a particular day, the cumulative rainfall values of the prior five days is calculated and decided with the help of table 3.

Table 3. Classification of antecedent moisture classes (AMC) for the SCS method of rainfall abstractions.

AMC Group	Total 5 – day Antecedent Moisture Condition (Rainfall in mm)	
	Dormant Season	Growing Season
I	Less than 12.5	Less than 35

II	12.5 – 27.5	35 -52.5
III	Over 27.5	Over 52.5

Example: If the cumulative rainfall for the prior five days calculated is 50 mm in the growing season then it is grouped into the AMC group-II.

Soil properties influences the generation of runoff from rainfall and they must be considered in the method of runoff estimation. The properties of the soil which influences the runoff are effective depth, clay in the surface layer, average clay in the profile, infiltration, permeability, soil texture etc. Soil map was prepared using soil texture information. Soil classification system developed by Soil Conservation Service (SCS) has been followed while classifying soil into different hydrological soil group, i.e., moderately low run off, moderately high run off and high run off. Hydrological soil group map was integrated with modified Land Use/ Land Cover to get Hydrological Soil Cover Complex Map (HSCC). Run off numbers were assigned to the Hydrological Soil Cover Complex Map considering average antecedent moisture condition. For assigning of curve numbers for different combinations of HSCC table was used as given in table 4 and shown in Fig.4.

The average curve number i.e. normal antecedent moisture condition (AMC-II) values of the selected study area was redesigned to the actual antecedent moisture condition i.e. dry conditions (AMC I) or wet conditions(AMC III) with the help of base curve number map. The following two equations used for CN (I) and CN (III) with respect to (AMC I) and (AMC III) respectively.

$$CN(I) = \frac{4.2 * CN(II)}{10 - 0.058CN(II)}$$

$$CN(III) = \frac{23 * CN(III)}{10 + 0.13CN(II)}$$

Potential maximum retention (s) was calculated for all the three antecedent moisture conditions using ARC/INFO GIS. The formula used for the calculation of potential maximum retention is as follows.

$$S = (25400/CN) - 254$$

Initial abstraction is calculated for the study area depending upon the antecedent moisture conditions using ARC/INFO GIS. Vanderspan, Bali J.S. and Yadav Y.P. (1990) suggested "various initial abstractions (Ia) to be used in the SCS rainfall runoff relationship". The formula used for the calculation of the initial abstraction (Ia) for Indian condition is as follows.

Black soil region AMC II and AMC III, $Ia = 0.1S$

Black soil region AMC I, $Ia = 0.3S$

All other regions $Ia = 0.3S$

Where 'S' is the potential maximum retention, 'Ia' is the initial abstraction. Study area comes under the category 'All other regions'. So the following formula was used.

$$Ia = 0.3S$$

Calculation of runoff on daily basis

The values of the s and Ia have been put into the following equation to get the runoff values on daily basis. For the selected study area, the runoff was calculated in mm since precipitation was given in mm.

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)}$$

Ia = 03S Then formula becomes

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)}$$

After calculating runoff on daily basis it was calculated event wise. Fig. 4 shows Total run off for the year 2007.

Table 4. Run off Curve Number for Hydrological Soil Cover Complex

Land use cover	Treatment of Practice	Hydrological condition	Hydrological soil groups			
			A	**B**	**C**	**D**
Fallow	Straight Row	Poor	77	86	91	94
Row crop	Straight Row	Poor	72	81	88	91
	Straight Row	Fair	67	78	85	89
	Straight Row	Good	65	76	84	88
Pasture or Range or waste land		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
Woodlands (farm wood lots or forest)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads			59	74	82	86
Roads (dirt)			72	82	87	89
(settlement)			74	84	90	92

Soil Loss Estimation

The sediment yield equation was used for estimating soil loss from each micro - watershed. To derive HLP map from the above four inputs fig (layouts) criterion analysis was carried out. The criteria used in this case were areas less than 1.5 sq. km., after union were deleted/dissolved and some categorical generalization was done considering the location and extent of units/polygons and the scale of mapping. As a first step, Slope and Soil coverages were intersected. Secondly, Land use was intersected with derived layer of slope soil map. In the final step, the ground water prospect map was intersected with slop soil land use map to derive HLP map. Later on weightages were assigned to HLP combinations as specified in Table 5 and shown in Fig. 6. Soil erosion takes place at all the places but the intensity of erosion is different at different places. It is not possible to take measures for minimizing soil erosion at all the places at the same time due to constraints of money and technical man power. Hence, areas which are eroding more in time and space are to be conserved first. In this study, an effort is made to identify priority areas for soil conservation by using empirical formula developed by All India Soil and Land Use Survey organization, Government of India, New Delhi. The following sediment yield equation has been used for estimation of Soil loss.

$$SYI = \frac{Aei * Wei * D * 100}{Aw}$$

Where	SYI	=	Sediment Yield Index
	Aei	=	Area of homogeneous land parcel unit
	Aw	=	Area of micro-watershed
	Wei	=	Weightage of erosion intensity, and
	D	=	Delivery ratio

On the basis of SYI, the watersheds are categorized into very high, high, medium, low priorities for taking up soil conservation measures. In Dahi block 2715 ha of area in under low category, 855 ha. under moderate category, 2769 ha. under high category and 1379 ha. Under very high priority category as given in Table 6 and shown in Fig. 5

Table 5. Following table delineate different combinations of HLP and their weightages.

Sl. No	HLP Combinations	SYI Calcode	Weightagess
1	Gentle slope categories and Deep soil categories and whole agriculture from Land use.	10	1
2	Gentle slope categories and Shallow soils and whole agriculture from Land use.	20	3
3	Gentle slope categories and Shallow soils and open forest, scrub forest and land with scrub	30	5
4	Steep slope categories and deep soil and whole agriculture	40	5
5	Steep slope categories and deep soil and open forest, scrub forest and land with scrub	50	4
6	Steep slope categories and deep soil and forest blank	60	4
7	Steep slope categories and shallow soil and whole agriculture	70	8
8	Steep slope categories and shallow soil and open forest, scrub forest and land with scrub	80	8
9	Steep slope categories and shallow soil and forest blank	90	8
10	Gentle slope categories and deep soil and open forest, scrub forest and land with scrub	100	2
11	Gentle slope categories and deep soil and forest blank and land without scrub	110	2
12	Gentle slope categories and shallow	120	5

	soil and land without scrub		
13	Steep slope categories and whole soil categories and land without scrub	130	5
14	Gentle slope categories and shallow soil and forest blank	140	5
15	Water body in land use	99	0
16	Dense forest	77	1
17	Barren rocky/stony waste	88	2
18	Gentle slope categories and mining outcrop	661	4
19	Steep slope categories and mining outcrop	662	9
20	Village (rural)	55	0

Table 6. Priority areas soil conservation

Priority Class	Area (ha)
Low	27151.21
Moderate	855.8062
High	2769.017
Very High	1379.374

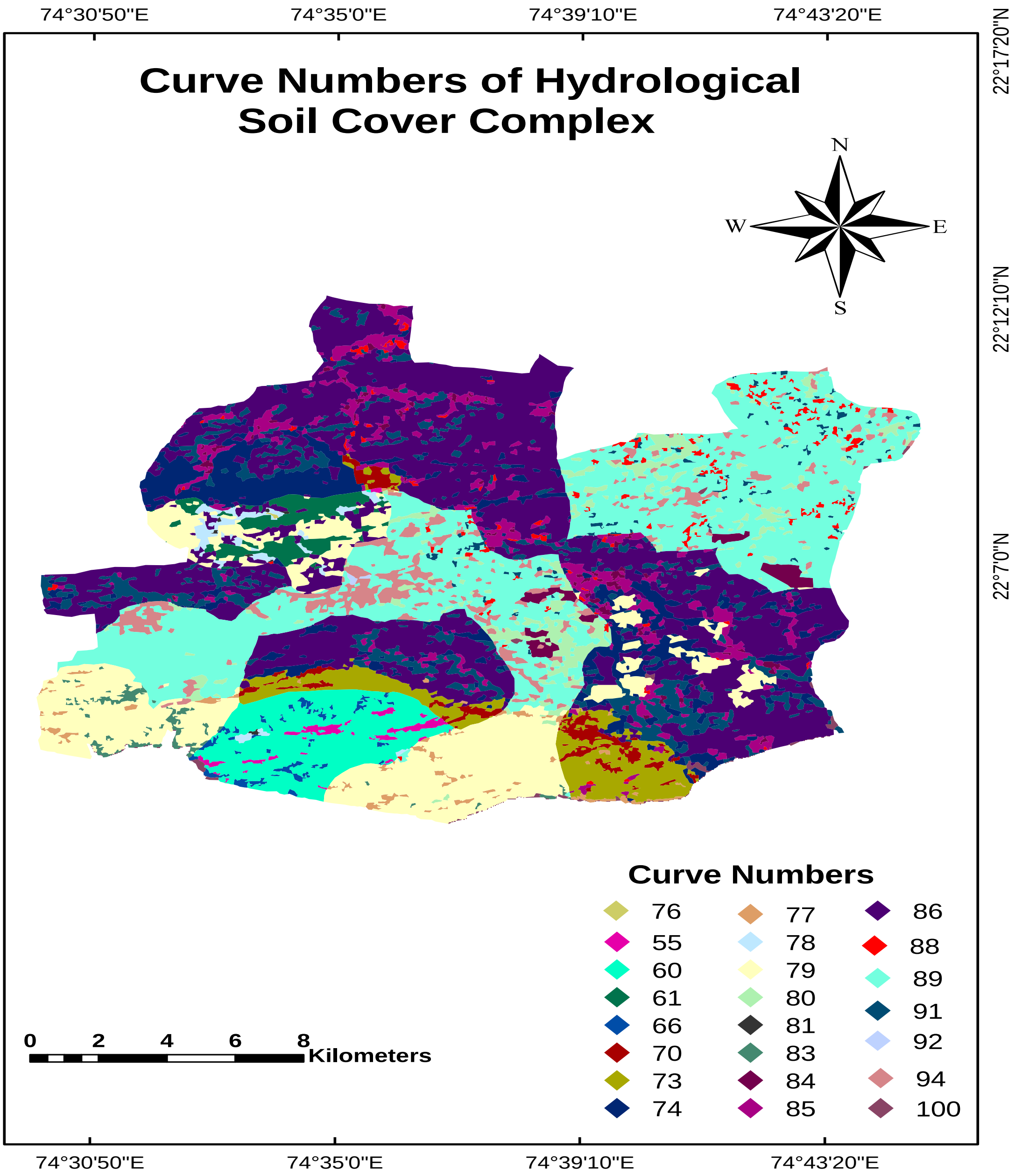


Fig. 4 Curve Number Map of Hydrological Soil Cover complex Map

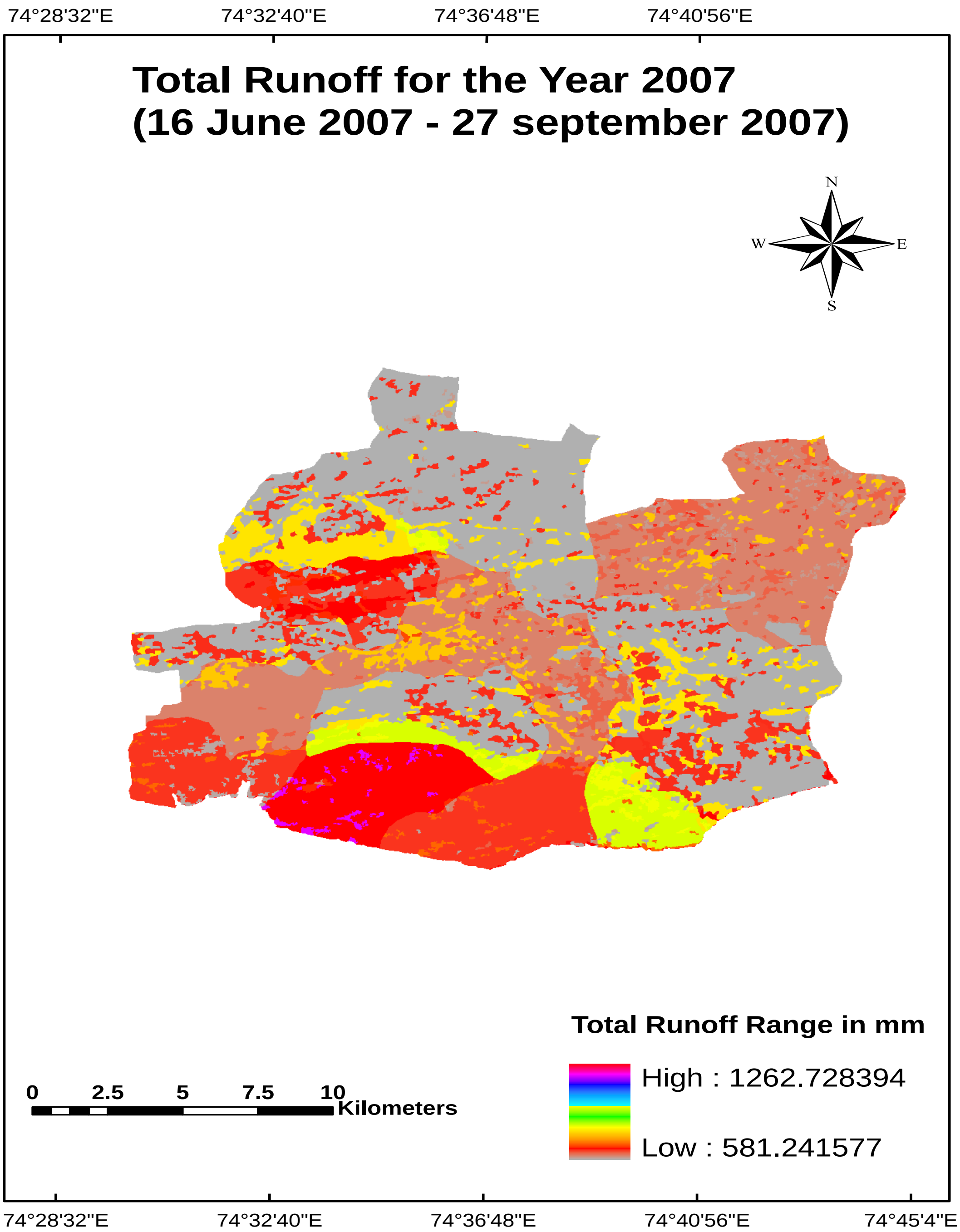


Fig. 5 Total Runoff Map for the Year 2007

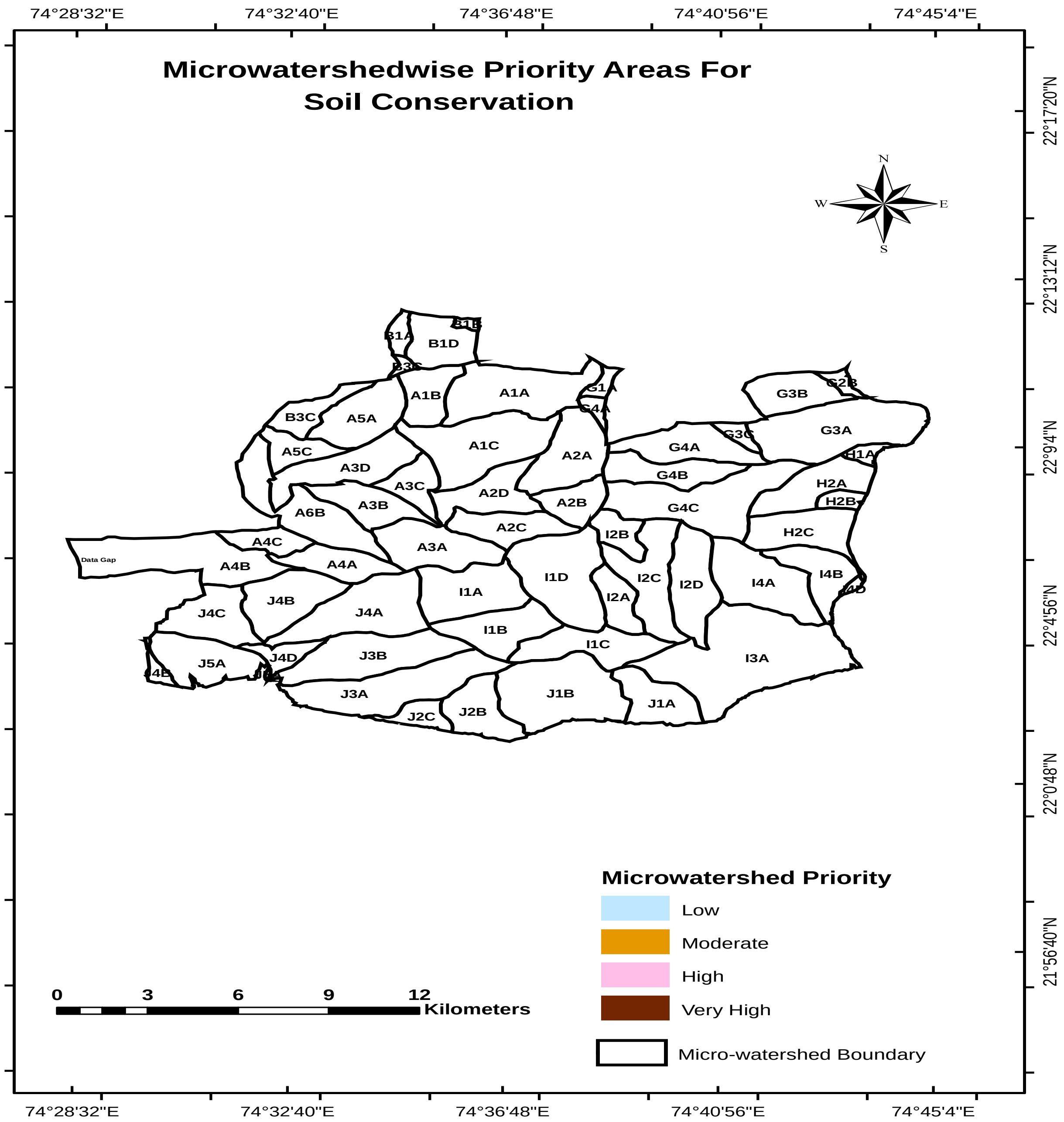


Fig. 6 Micro-watershed wise Priority areas for Soil Conservation

Conclusion

Watershed prioritization of selected study area of Dahi Block was carried out through estimating runoff and sediment yield using Soil Conservation Service model and Sediment Yield Index model.

Geographic Information System (GIS) is proved to be a useful tool in spatial data base creation, for making data compatible from one format to another and retrieval of data as per requirements. Since input data is geographic in nature, GIS found to be a potential tool while carrying out criteria based spatial analysis towards optimal management of natural resources. It is found that natural phenomenon such as hydrologic response of selected area of watershed to precipitation and its proneness to water erosion can be best simulated through GIS. SCS CN model and SYI model used for the estimation of runoff and soil loss respectively, have several advantages. They require few and easily available parameters, sensitive to changing land use condition/practices and easy to use by employing GIS techniques. Using GIS, it is possible to handle spatial and non-spatial data and it is important in run off and sediment data handling. SCS CN model is very useful for prediction of run off. Sediment Yield Index gives priority areas for soil conservation. The analysis reveals that In Dahi block 2715 ha of area in under low category, 855 ha. under moderate category, 2769 ha. under high category and 1379 ha. under very high priority category of prioritization.

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