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"Morphometric and Land Resource Analysis Using Remote Sensing and Geographic Information System- a Case Study in Agargaon Watershed near Nagpur, Maharashtra"

Ramprasad Kundu
Research Scholar, Vidyasagar University, Medinipur, West Bengal, India
E-mail: ramrsgis@gmail.com

Abstract:

The present investigation has been carried out in Agargaon watershed of Wardha and Nagpur district of Maharashtra to characterize and to prioritize it for conservation and management using remote sensing and GIS techniques. The watershed has been prioritized by adopting two methods viz. compound morphometric parameters and sediment yield index model. The study of morphometric parameters viz. circularity and elongation ratios show that all the sub-watersheds have close to circular shape. The highest bifurcation ratio 9.0 in ws6 suggesting a strong structural control on the drainage. Based on compound morphometric parameter values sub-watersheds have been grouped into four priority class. The highest priority is given to the sub-watersheds ws3 and ws4 where as the sub-watersheds ws1 and ws7 receive lowest priority with compound parameter values 4.75 and 5.63 respectively. Various thematic maps are generated by using IRS– P6 LISS-IV data and SOI Toposheet and those maps are intersected under GIS environment to prepare Erosion Intensity Unit (EIU) map required for to calculate sediment yield indices. The watersheds have been grouped in four priority class based on SYI values. The sub-watersheds ws6 and ws7 receive lowest priority class where as ws3 receives the highest priority for conservation.
Keywords: Morphometric Parameter, Sediment Yield Index, Remote Sensing and GIS, Erosion Intensity Unit, Prioritization.

1. Introduction:

A watershed is an ideal unit for management of natural resources like land, water to mitigate the impact of degradation. The input parameters required for planning and management of a watershed are its landform or physiography, land use, slope and soil. Remote Sensing and Geographical information system helps in creation of these database and interaction of the thematic maps. Mani et al. (2000) carried out soil erosion studies of part of the world's largest river island, Majuli River – Island, using remote sensing data and ILWIS software. Nautiyal (1994), Chaudhary and Sharma (1998) studied the relationship between cumulative stream length, and stream order and also bifurcation ratio, drainage density, texture ratio for assessing the level of soil erosion. There is a need to prioritized the watershed for its development. Several workers (Chakraborty 1991, Biswas et.al. 1999 and Nookaratnam et al. 2005) have prioritized the watershed based on morphometric analysis and sediment yield index model.

2. Objectives:

Keeping this in view the present study has been planned to characterize the seven sub-watershed of Agargaon watershed located between Wardha and Nagpur district in Maharashtra using remote sensing and GIS techniques with the following objectives:

(i) To carry out drainage morphometric analysis of the Agargaon watershed.
(ii) To prepare Erosion Intensity Units map under GIS environment.
(iii) To prioritize the sub-watersheds of Agargaon watershed based on morphometric parameters.
(iv) To prioritize the sub-watersheds of Agargaon watershed based on Sedimentary Yield Index.

3. Study Area:

Agargaon watershed lies in between 21^{0}6'41.7" to 21^{0}9'24.6"N latitude and 78^{0}31'23.7" to 78^{0}34'47.4"E longitude in Wardha and Nagpur districts of Maharashtra State. The total area of the watershed is 2112.65 ha. The main river of Agargaon watershed flows into the Kal river. Landform of the area has been developed over basaltic flows by aggregation and denudation process. This area is mainly represented by Deccan trap formation known as basaltic flows with varying thickness. The recent alluvium occurs along the river channels. Agargaon watershed exhibits dendritic to sub-dendritic drainage pattern with coarse drainage texture. Climatic condition of the study area is basically subtropical sub-humid type. The average annual rainfall ranges from 900mm-1200mm with annual mean temperature of 26.9°c. The natural vegetation comprises of dry deciduous trees.

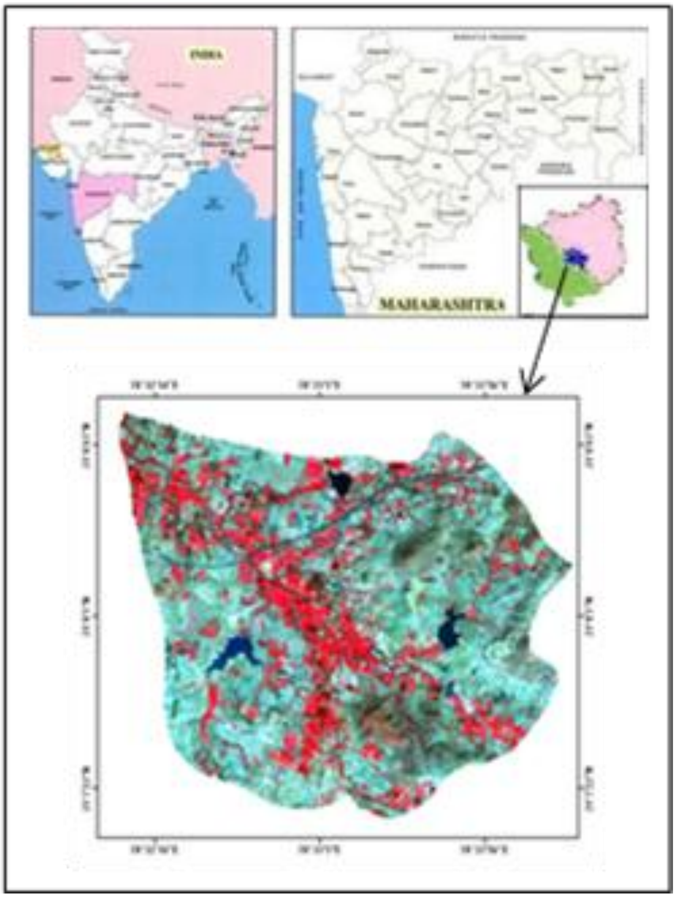

Fig. 1: Location Map of the Study Area

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4. Materials and Methods:

4.1 *Materials used:*

Digital data of IRS-P6 LISS-IV (5.8m) data has been used for deriving the information of various parameters of the watershed. The IKONOS (1.0 mt.) data from GOOGLE EARTH has also been consulted for identification of orchard. The Survey of India (SOI) topographical maps 55 K/12 (1:50,000) is also used for geo-referencing the satellite data and preparation of different thematic maps. The secondary information i.e. collateral data about the watershed has been collected from published Journals has been used characterization of the watershed.

4.2 Laboratory work:

4.2.1 Satellite data interpretation:

The methodology followed for the interpretation of satellite data is essentially the standard visual interpretation technique based on tone, texture, pattern, size, shape, etc. The collateral data such as Toposheet and other available information in the form of map etc. are used for identification and mapping of land use/land cover, physiography, and drainage morphology.

4.2.2 Morphometric analysis of the watershed:

Morphometric analysis of the watershed has been carried out using Remote sensing data & SOI toposheet on 1:50,000 scale. The using morphometric analysis methods are given in the following table:

Table 1: Methods Adopted for Computation of Morphometric Analysis

Stream Order	Hierarchial rank	Strahler (1964)
Stream Length (Lu)	Length of the stream	Horton (1945)
Mean Stream Length (Lsm)	Lsm = Lu/Nu Where, Lsm = Mean Stream Length Lu = Total stream length of order 'u' Nu= Total no. of stream segments of order 'u'	Strahler (1964)
Stream Length Ratio (RL)	RL= Lu/Lu-1 Where, RL = Stream Length Ratio Lu = The total stream length of order 'u' Lu-l= The total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb = Nu/Nu+ 1 Where, Rb = Bifucation Ratio Nu = Total no. of stream segments of order 'u' Nu+l= Number of segments of the next higher order	Schumm(1956)
Mean bifurcatin ratio (Rbm)	Rbm = Average of bifurcation ratios of all orders	Strahler (1957)
Relief Ratio (Rh)	Rh = H/Lb Where, Rh=Relief Ratio H=Total relief (Relative relief) of the basin in Kilometer Lb= Basin length	Schumm(1956)

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Drainage Density (D)	D-Lu/A Where, D=Drainage Density Lu=Total stream length of all orders A= Area of the Basin (km ^{2})	Horton (1932)
Stream Frequency (Fs)	Fs=Nu/A Where, Fs=Stream Frequency Nu=Total no. of streams of all orders A= Area of the Basin (km ^{2})	Horton (1932)
Drainage Texture (Rt)	Rt=Nu/P Where, Rt = Drainage Texture Nu=Total no. of streams of all orders P=Perimeter (km)	Horton (1945)
Form Factor (CRt)	$Rg=A/Lb^2$ Where, Rf=Form Factor A=Area of the Basin (km ^{2}) Lb^2=Square of Basin length	Horton (1932)
Circularity Ratio (Re)	$Re=4\ \pi A/P^{\ 2}$ Where, Re=Circularity Ratio $\pi = 3.14$ A=Area of the Basin (km ^{2}) P = Perimeter (km)	Miller (1953)
Elongation Ratio (Re)	$Re=(2/Lb)*(A/3.14)^{0.5}$ Where, Re=Elongation Ratio A=Area of the Basin (km ^{2}) Lb=Basin length	Schumm (1956)
Compactness Constant(Cc)	$Cc = 0.2821\ P/A^{0.5}$ Where, Cc = Compactness Ratio A = Area of the basin (km^2)	Schumm (1956)

4.2.3 Sediment yield index analysis of the watershed:

Erosion Intensity Unit map (EIU) has been prepared by integrating land use/land cover map, slope map, physiography-soil and sub-watershed map under GIS environment to calculate sediment yield indices(SYI) of each EIU. The value of SYI was computed as:

$$SYI = \sum (Ei\ Aie\ D) / \sum AW \times 100$$

Where, SYI = Sediment Yield Index, Ei = Weighting value of erosion intensity unit, Aie = Area of the erosion intensity unit in a basin, D = Delivery ratio and AW = Total area of the basin.

4.2.4 Prioritization of watershed:

4.2.4.1 Based on drainage morphometric analysis:

The compound values of morphometric parameters are calculated by summing up the values of these parameters and by dividing it by the number of the parameters considered and based on the compound values of the morphometric parameters prioritization have been done where the least value received the highest priority class and highest value received the lowest priority.

4.2.4.2 Based on Sediment Yield Index (SYI):

Sediment yield index model (SYI) as described by All India soil and land use survey has been used for

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prioritization of watershed. The adopted methodology is given in fig. 2.

4.3 Field work:

The thematic maps i.e. slope, land use/land cover and physiography, prepared based on image interpretation, has been verified in the field. Physiography-soil relationship has been established based on the ground truth.

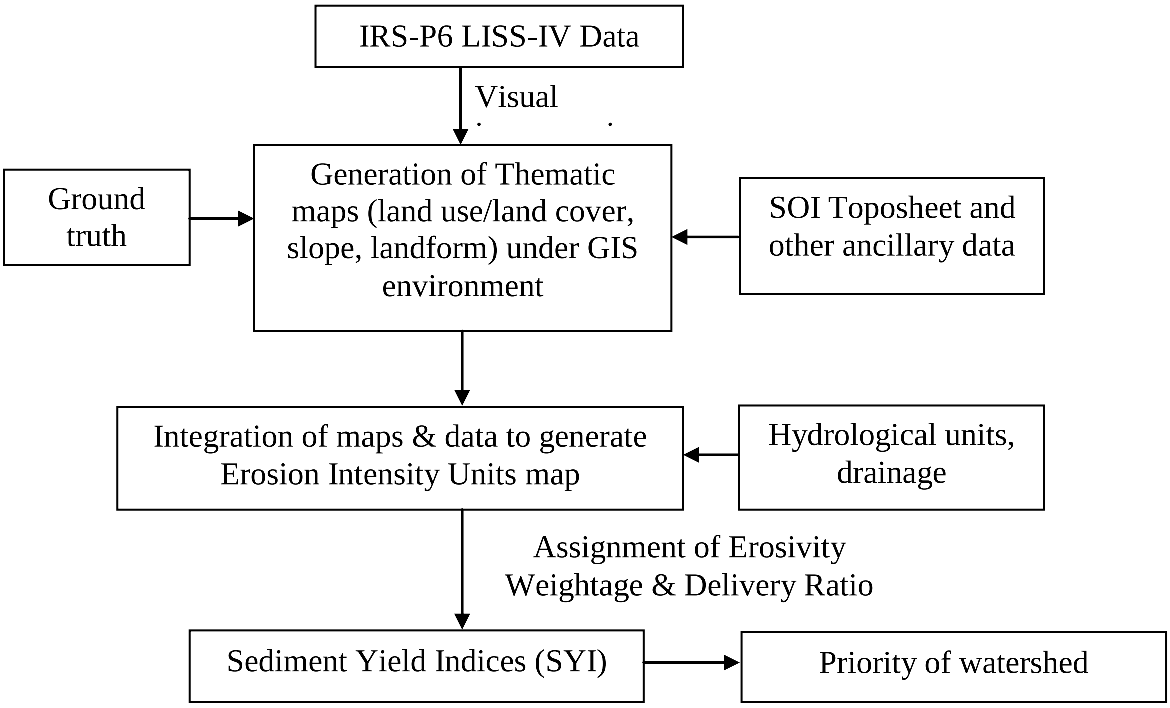

Fig. 2: Methodology Adopted for Prioritization of the Watershed Based on SYI

5.0 Results and Discussion:

The present investigation has been carried out in Agargaon watershed of Wardha and Nagpur district of Maharashtra to characterize and to prioritize it for conservation and management using remote sensing and GIS techniques.

5.1 Morphometric analysis of the watershed:

Morphometric analysis of a watershed provides a quantitative description of the drainage hence consider as an important factor of characterization of watershed. For the purpose of prioritization the Agargaon watershed, has been divided into seven sub-watersheds based on drainage and elevation. These sub-watersheds have been designated as ws 1 to ws 7 (fig. 3). The designation of stream order is the first step in morphometric analysis of a watershed and is based on the hierarchy of the streams Strahler (1964). In the watershed there are 76, 15 and 5 streams of 1st 2nd and 3rd order which link to 4th order stream. The drainage order of the watershed is given in fig. 4. The drainage order is closely governed by the topographic conditions. Higher the order of

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streams, lower is the slope value and vice versa. In the watershed smallest stream length is 301 m. and the longest is of 1.21km in 1st order drainage. It is observed that there are 76, 15, 5, 1 number of streams with stream length 36.5, 9.8, 8.9, 5.9 km of 1st to 4th order respectively.

For morphometric analysis of Agargaon watershed different types of morphometric parameters like Drainage density (Dd), Stream frequency, Texture ratio, bifurcation ratio, Circulatory ratio, Form factor, Compactness ratio, Elongation ratio etc are considered and calculated. The calculated morphometric parameters outcome result is given in the following table.

Table 2: Morphometric Parameters of Agargaon Watershed

Morphometric Parameters	Watershed No.							
	Whole WS	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Drainage Density	2.9	2.56	2.53	3.21	3.2	2.8	2.1	1.4
Stream Frequency	4.59	4.1	4.72	6.55	5.48	3.91	4.13	2.62
Texture Ratio	5.1	1.41	1.73	2.42	1.98	1.38	1.58	0.54
Bifurcation Ratio	4.36	5.00	3.00	4.13	3.67	3.25	9.00	4.00
Circularity Ratio	0.732	0.322	0.726	0.512	0.526	0.507	0.763	0.324
Form Factor	0.489	0.237	0.425	0.287	0.342	0.286	0.31	0.251
Compactness Ratio	1.168	1.762	1.189	1.397	1.378	1.404	1.144	1.755
Elongation Ratio	0.789	0.549	0.736	0.584	0.66	0.605	0.714	0.565

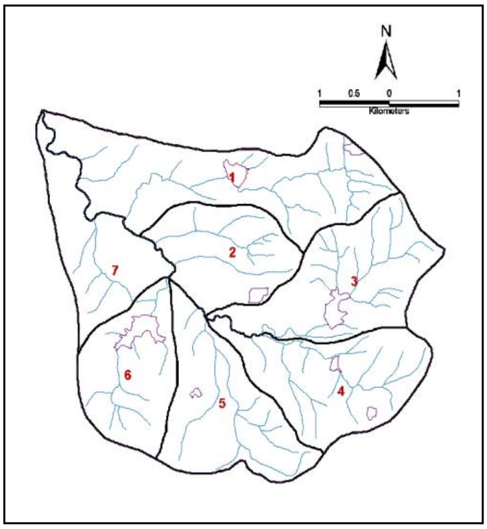

Fig. 3: Subwatersheds of Agargaon Watershed

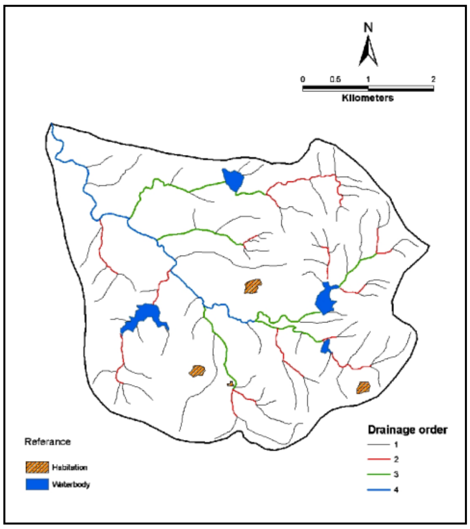

Fig. 4: Drainage Order of the Watershed

5.2 Characterization of watershed:

5.2.1 Preparation of slope map and land use land cover:

The digital elevation model (DEM) has been developed using 20 m contour interval of SOI toposheet (1:50000). Slope classes identified and based on DEM classes are Very gently sloping (1493.54 hector), gently sloping (268.46 hector) and moderately

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steeply sloping (306.91 hector). Land use/land cover is one of the important parameter of erosion intensity units based on which the sediment yield index is calculated. The visual interpretation of IRS-P6 LISS- IV FCC led to the identification and delineation of land use/ land cover categories. The study of land use pattern indicates that the 74 percent watershed under cultivation where single crop and double crop occupies 53 and 21 percent respectively.

5.2.2 Physiography-soil mapping and preparation of Erosion Intensity Unit map:

Based on interpretation of IRS P6 LISS-IV data along with toposheet and subsequent ground truth verification four major landforms units viz. Hilly terrain (H), Subdued plateau(S), Pediment (D) and Valley (V) are identified and are further subdivided based on slope. To understand the soil variability groundtruth regarding soil have been collected in different physiographic units and physiography-soil relationship has been established.

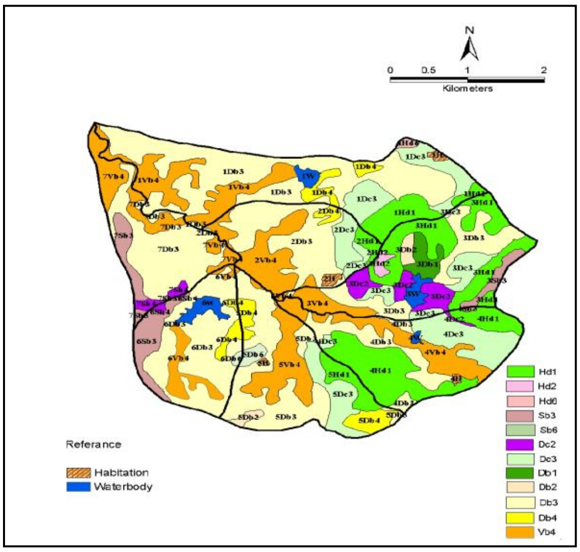

Fig. 5: Subwatershed Wise Erosion Intensity Unit Map

Above (fig. 5) Erosion Intensity Unit (EIU) map has been prepared by integrating maps of land use/land cover, slope, physiography-soil and sub-watershed under GIS environment to determine the SYI values. The map symbol of EIU and their description are given in table 3.

Table 3: Erosion Intensity Unit Symbol and Their Description

Map symbol	Description of Erosion intensity unit
Hd1	Moderately steeply sloping hilly terrain with Extremely shallow to very shallow, excessively drained, brown (7.5YR 4/4) sandy loam soils with moderate stoniness under mod. dense forest
Hd2	Moderately steeply sloping hilly terrainwith Extremely shallow to very shallow, excessively drained, brown (7.5YR 4/4) sandy loam

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	soils with moderate stoniness under degraded forest
Hd6	Moderately steeply sloping hilly terrain with Extremely shallow to very shallow, excessively drained, brown (7.5YR 4/4) sandy loam soils with moderate stoniness under waste land
Sb3	Very gently sloping Subdued plateau with Very shallow, somewhat excessively drained, dark brown (10YR 3/3) Clay loam soils under single crop
Sb6	Very gently sloping Subdued plateau with Very shallow, somewhat excessively drained, dark brown (10YR 3/3) Clay loam soils under waste land
Dc2	Gently sloping pediment with Very shallow to shallow somewhat excessively drained, dark brown (10YR 3/3) Clayey soils. under degraded forest
Dc3	Gently sloping pediment with Very shallow to shallow somewhat excessively drained, dark brown (10YR 3/3) Clayey soils under single crop
Db1	Very gently sloping pediment with Shallow, well drained, very dark grayish brown (10YR 3/2) clay loam soils under mod. dense forest
Db2	Very gently sloping pediment with Shallow, well drained , very dark grayish brown (10YR 3/2) clay loam soils under degraded forest
Db3	Very gently sloping pediment with Shallow, well drained , very dark grayish brown (10YR 3/2) clay loam soils under single crop
Db4	Very gently sloping pediment with Shallow, well drained , very dark grayish brown (10YR 3/2) clay loam soils under double crop
Vb4	Very gently sloping valley with Deep to very deep, moderately well drained, very dark grayish brown (10YR 3/2), calcareous, clayey (Black cotton) soils under double crop

5.3 Prioritization of watershed:

5.3.1 Based on drainage morphometric analysis:

The morphometric parameters namely bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness constant are termed as a erosion risk assessment parameters and have been used for prioritization of sub-watersheds (Biswas et al.1999 and Akram et al.2009).

In the present study, the compound parameters (bifurcation ratio, drainage density, stream frequency, form factor, texture ratio, elongation ratio, circularity ratio and compactness ratio) values of all the seven sub-watersheds of Agargaon watershed have been calculated and have been grouped such as low(>4.91), medium(4.15-4.90) high (3.39-4.14), and very high (2.63-3.38) priority class. The sub-watershed ws7 receive lowest priority with compound parameter values 5.63, where as the ws 3 and ws 4 receive the highest priority with compound values 3.00 and 2.63. The highest priority indicates that the ws 3 and ws 4 have the greater degree of erosion and receive the maximum priority for conservation measures. The priority map, of the Agargaon watershed prepared based on the morphometric parameters is shown in fig 6.

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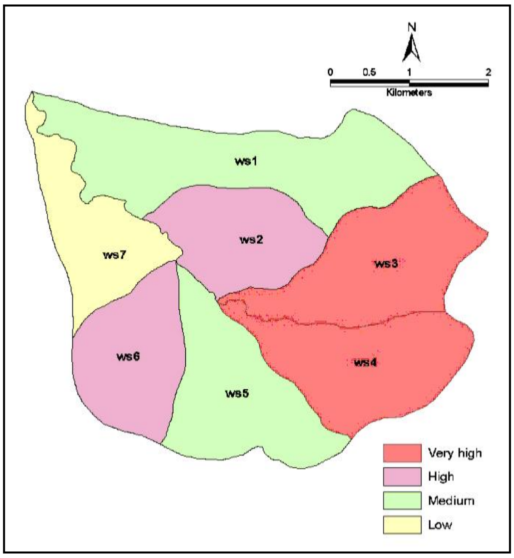

Fig. 6: Prioritized Map of Agargaon Watershed Based on Morphometric Analysis

5.3.2 Prioritization based on Sediment Yield Index (SYI):

Sediment yield index model (SYI) as described by All India soil and land use survey has been used for prioritization of watershed. The sediment yield indices are calculated using the equation as:

$$SYI = \Sigma \frac{(Ei * Aie * D)}{AW} * 100$$

Where SYI = Sediment Yield Index, Ei = Weighting value of erosion intensity unit, Aie = Area of the erosion intensity unit in a basin, D = Delivery ratio, AW = Total area of the basin.

For the purpose, erosion intensity unit are assigned relative erosivity values based on erosive determinants viz. physiography-soil, slope, land use/land cover, and existing soil conservation measures. The erosivity values assigned to the erosion intensity unit (EIU) are given in table 4.

Table 4: Assigned Values of Erosivity

Physiography	Soil	Land use	Erosivity value
Moderately steeply sloping hilly terrain	Extremely shallow to very shallow, excessively drained, brown (7.5YR 4/4) sandy loam soils with moderate stoniness	Mod. dense forest	12
		Degraded forest	17
		Waste land	17
Very gently sloping Subdued plateau	Very shallow, somewhat excessively drained, dark brown (10YR 3/3) Clay loam soils	Double crop	12
		Single crop	13
		Waste land	14

Gently sloping pediment	Very shallow to shallow somewhat excessively drained, dark brown (10YR 3/3) Clayey soils	Degraded forest	16
		Single crop	14
Very gently sloping pediment	Shallow, well drained, very dark grayish brown (10YR 3/2) clay loam soils	Mod. dense forest	11
		Degraded forest	14
		Single crop	13
		Double crop	12
Very gently sloping valley	Deep to very deep, moderately well drained, very dark grayish brown (10YR 3/2), calcareous, clayey (Black cotton) soil	Double crop	11

A delivery ratio is governed by the soil factor as well as the morphometric characteristics of the watershed. The morphometric attributes determine the flow mechanism. The relative delivery ratio values assigned to each erosion intensity unit which varies from in different hydrological unit's i.e. sub-watersheds. After computing values of sediment yield indices, of each sub-watershed (Table 5) the sub-watershed are grouped into four priority class viz. low, medium, high and very high based on SYI values <950, 951-990. 991-1030 and >1031 respectively. On the basis of the assigned SYI values for respective priority class, the sub-watersheds ws6 and ws7 receive lowest priority class where as ws3 receives the highest priority (fig. 7) for conservation.

Table 5: Computation of Sub-Watershed Wise Sediment Yield Indices and Their Priority

EIU Unit	Aie	Ei	D	Aie x Ei x D	Total Aie x Ei x D	SYI	Priority class
Sediment Yield Indices of ws 1					4483.01	967	Medium
Hd1	44.02	12	0.79	417.31			
Hd6	3.49	16	0.8	44.672			
Dc3	59.87	14	0.79	662.162			
Db3	242.27	13	0.78	2456.62			
Db4	19.33	12	0.78	180.929			
Vb4	84.07	11	0.78	721.321			
Sediment Yield Indices of ws 2					2287.83	980	Medium
Hd1	9.84	12	0.81	95.6448			
Hd2	0.05	17	0.83	0.7055			
Dc3	31.05	14	0.81	352.107			
Db3	111.81	13	0.8	1162.82			
Db4	6.39	12	0.8	61.344			
Vb4	69.91	11	0.8	615.208			
Sediment Yield Indices of ws 3					3615.6	1076	Very high
Hd1	104	12	0.86	1073.28			
Hd2	6.07	17	0.88	90.8072			

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Sb3	14.66	13	0.85	161.993			
Dc2	36.3	16	0.87	505.296			
Dc3	35.62	14	0.86	428.865			
Db1	20.34	11	0.85	190.179			
Db2	7.74	14	0.85	92.106			
Db3	75.61	13	0.85	835.491			
Vb4	25.41	11	0.85	237.584			
Sediment Yield Indices of ws 4					3150.64	1014	High
Hd1	115.94	12	0.83	1154.76			
Sb3	1.07	13	0.82	11.4062			
Dc2	1.62	16	0.84	21.7728			
Dc3	66.42	14	0.83	771.8			
Db3	56.04	13	0.82	597.386			
Vb4	65.8	11	0.82	593.516			
Sediment Yield Indices of ws 5					2977.31	968	Medium
Hd1	24.65	12	0.78	230.724			
Sb6	7.83	14	0.77	84.4074			
Dc3	42.44	14	0.78	463.445			
Db2	5.63	14	0.77	60.6914			
Db3	132.83	13	0.77	1329.63			
Db4	29.09	12	0.77	268.792			
Vb4	63.71	11	0.77	539.624			
Sediment Yield Indices of ws 6					2199.39	909	Low
Sb3	36.8	13	0.76	363.584			
Sb4	2.71	13	0.76	26.7748			
Db3	144.5	13	0.76	1427.66			
Db4	11.3	12	0.76	103.056			
Db6	2.46	14	0.76	26.1744			
Vb4	30.16	11	0.76	252.138			
Sediment Yield Indices of ws 7					2051.45	930	Low
Sb3	25.7	13	0.75	250.575			
Sb4	9.27	12	0.75	83.43			
Db3	124.38	13	0.75	1212.71			
Vb4	61.18	11	0.75	504.735			

Where, Aie = Area of the erosion intensity unit in a basin, **Ei** = Weighting value of erosion intensity unit, **D** = Delivery ratio, SYI = Sediment yield index.

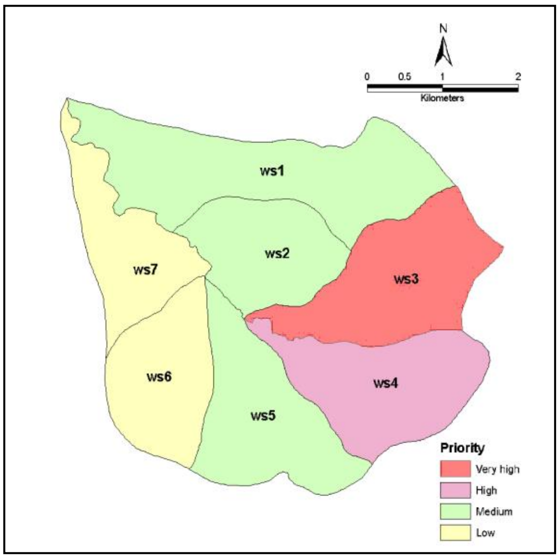

Fig. 7: Prioritized Map of Agargaon Watershed Based on Sediment Yield Index

6.0 Conclusion:

From the study it may be concluded that-

(i) The low bifurcation ratio and drainage density values indicate that the drainage of the Agargaon watershed is not affected by structural disturbances and has permeable sub-soil material and medium relief.

(ii) The computed values of form factor and circulatory ratio suggest that the shape of watershed basin is nearly circular shape hence has high pick flow of shorter distance.

(iii) The spatial information on land use/land cover, slope, physiography-soil are base material for computing sediment yield indices and based on these indices the priority of the watershed is decided. These spatial informations can be gathered cost and time effectively using remote sensing and GIS techniques.

(iv) The sub-watershed ws 3 of the Agargaon watershed received the maximum priority based on morphometric analysis as well as based on SYI model hence maybe taken up conservation on the top priority.

Reference:

Akram, J., Mohd Y.K. and Ahmed, R. (2009): “Prioritization of sub-watersheds based on Morphometric and Land Use Analysis using Remote Sensing and GIS Techniques”, Journal of the Indian Society of Remote Sensing, **37**, 261-274.

Biswas, S., Sudhakar, S. and Desai, V.R. (1999): **“**Prioritization of subwatersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach”, Journal of the Indian Society of Remote Sensing, **27(3)**, 155-166.

Neo Geographia (ISSN-2319 – 5118) Vol. III, Issue. III, July 2014

Chakraborty, A.K. (1991): **“**Sediment yield prediction & prioritisation of watershed using Remote Sensing data”, Presented at the 12th Asian Conference on Remote Sensing, Singapore, October 30 – November 5.

Chaudhary, R.S. and Sharma, P.D. (1998): “Erosion hazard assessment and treatment prioritization of Giri river catchment, North western Himalayas”, Ind. J. Soil Cons., **26**, 611.

Horton, R.E. (1932): “Drainage basin characteristics”, Trans. Am. Geophys. Union, **13**, 350-361.

Horton, R. E. (1945): “Erosional development of streams and their drainage basins: Hydrological approach to quantitative morphology”, Geological Society of American Bulletin, **56**, 275-370.

Mani, P. and Patwary, B.C. (2000): “Erosion trends using remote sensing digital data: a case study at Majuli Island”, Proc. Brain Storming Session on Water Resources Problems of North Eastern Region, held at NIH, Guwahati on May 20, 2000, 29-35.

Miller, V. C. (1953): “A quantitative geomorphic study of drainage basin characteristics in the clinch mountain area: Technical report”, Department of Geology, Columbia University.

Nag, S. K. (1998): “Morphometric analysis using remote sensing techniques in the Chaka subbasin, Purulia district, West Bengal”, Journal of Indian Society of Remote Sensing, **26(12)**, 69-76.

Nautiyal, M.D. (1994): “Morphometric analysis of drainage basin, district Dehradun, Uttar Pradessh”, Journal of Indian Society of Remote Sensing, **22(4)**, 252-262.

Nookaratnam, K., Srivastava, Y. K., Rao, V. V. and Murthy, K. S. R. (2005): “Check Dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis – remote sensing and GIS perspective”, Journal of the Indian Society of Remote Sensing, **33(1)**, 25-38.

Schumm, S. A. (1956): “Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey”, Geological Society of America, Bulletin, **67**, 597-646.

Strahler, A. N. (1957): “Quantitative analysis of watershed geomorphology”, Trans. Am. Geophys. Union, **38**, 913-920.

Strahler, A. N. (1964): “Quantitative geomorphology of drainage basins and channel networks, section 4II. In: V.T. Chow”, Handbook of Applied Hydrology (pp.439), McGraw-Hill.