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Prioritization of Jiya Dhol Basin Using GIS

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Abstract: ***Prioritization of a river basin is utmost important for soil conservation and also it helps in identifying the critical soil loss areas of the basin. Prioritization of the basin can be done with the help of morphometric analysis. In the present study the main watershed of Jiya Dhol basin is divided into 11 sub-watersheds and morphometric analysis is carried out in each of the sub-basins using Arc GIS 10.1 tool to identify the sub-watershed which is most vulnerable to soil erosion. The prioritization of this sub- watershed has been carried out on the basis of morphometric analysis for land reclamation and soil erosion prevention. The maximum and minimum values of drainage density (Dd) are found to be 1.058 and 0.581 km/km² for sub-watershed SWS10 and SWS5 and low drainage density values of sub-watershed SWS5 indicates that it has highly resistant, impermeable subsoil material with dense vegetative cover and low relief. The elongation ratio for the sub-watershed varies from 0.368 to 0.422 which indicates gentle slope and low relief. For prioritization of the sub-watersheds, the compound parameter values are calculated and the sub-watershed with the lowest compound parameter is given the highest priority. The sub-watershed SWS8 has a minimum compound parameter value of 3.9 and SWS 5 has a maximum compound parameter 7.9. Hence SWS8 has come under the high risk for soil erosion and need to give a high priority for land conservation practices.***

Keywords: Prioritization, Morphometic Analysis, Compound parameter, Arc GIS, Sub-watershed

1. Introduction

Watershed prioritization is the ranking of different sub watersheds of a watershed according to the order in which they have to be taken for treatment and soil conservation measures. Morphometric analysis could be used for prioritization of micro-watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps (Biswas et al., 1999).

The linear parameters have a direct association with erodibility, hence for prioritization of sub-watersheds, the highest value of linear parameters have been assigned 1st rank, second highest value given 2nd and so on. It seems that higher the value of linear parameters, more susceptibility of soil erosion. The areal aspect such as form factor, elongation ratio and circulatory ratio has an inverse connection with erodibility (Nooka et al, 2005). It means lower the value more the erodibility and vice versa, hence the lowest value of areal parameters has assigned 1st rank, next lower value 2nd and so on. After the ranking of all linear and areal parameters in all sub-watersheds the values of watersheds are summing up in order to obtain compound value and its average. Based on the average value the priority criteria have decided i.e. High Priority, Medium Priority and Low Priority. The sub-watershed having highest average weight age belong to High Priority and the watershed having the lowest average weight age concerned to Low Priority.

Watershed prioritization based on morphometric characteristics carried out aids in the mapping of high flood potential and erosion prone zones.

2. Study Area

The Jiya Dhol River is one of the north bank sub- tributaries of the Brahmaputra River. This river originates from the lower Himalayan belt and cut crosses twice the easterly oriented Siwalik ranges and has been carrying very high sediment load which are deposited on the Brahmaputra plains after debouching from the hills. After passing through a narrow gorge in Arunachal Pradesh, the river enters the plains of Assam in Dhemaji district where it flows in braided channels. The river is known as 'Kumotiya' from the Railway line to the Gogamukh – Ghilamara P.W.D. road wherefrom it is known as the river 'Sampara'. The river finally debouches into the river Brahmaputra near Selamukh. The river finally debouches into the river Brahmaputra near Selamukh. The Jiya Dhal river formed a fan deposit and exhibit extensive shifting of its channels. Basin of the Jiya Dhol basin extends from 27˚25′45´´ N to 27˚44′15" N latitudes and 94˚15′ E to 94˚37′30´´ E longitudes, covering an area of 437 sq km, of which 18% (79 sq km) lies in Arunachal Pradesh and 82% (357 sq km) in Assam. The upper hilly part of the basin falls in the Outer Himalaya and the Siwaliks comprising of the Tertiary formations. While the middle part of the lies in the piedmont zone characterized by the presence of sand with admixture of cobbles and boulders, where as the lower

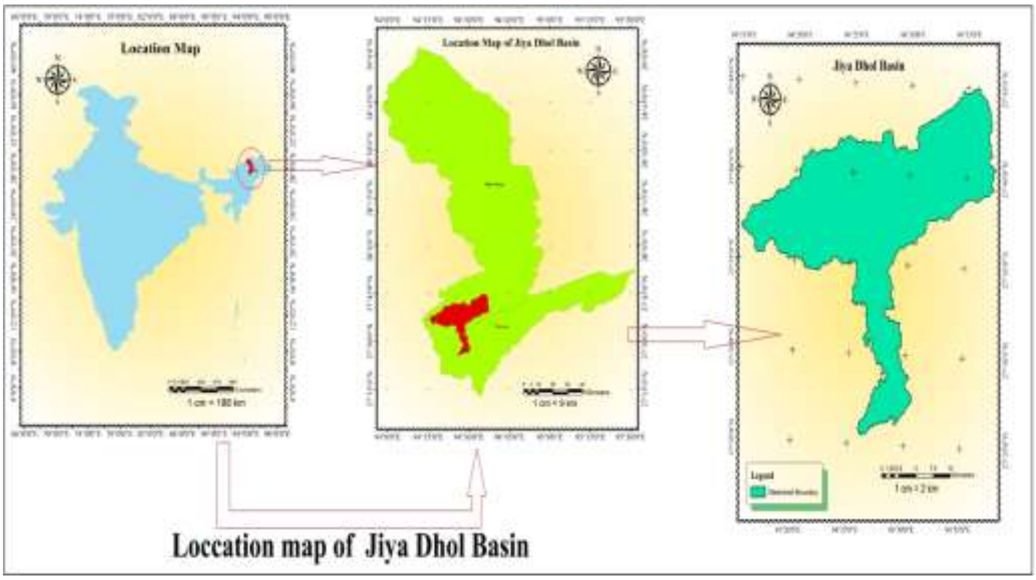

Figure 1: Jiya Dhol River Basin location map

reaches are characterized by alluvium. Climate of the basin is typically characterized by hot and humid conditions, representing oppressive climate, which is found all along the foothills and piedmont zone, i.e., junction between the Brahmaputra plains and the Himalaya Mountain. Summer rains occur in the pre- monsoon and monsoon seasons, while the winters are dry. The River used to meet the Brahmaputra at a place near Selamukh (27.08°N, 94.31°E) before abandoning of the Kherkutiya Suti by Brahmaputra. Three rivers namely Siri, Sido and Sika meet at a place called Trimukh (27 °37´56´´N, 94°25´15´´E) in Arunachal Pradesh and the downstream part from this location is called Jiya dhal. The river enters Assam at a place called Jia dhal Mukh (27.58°N, 94.45°E). Hence, the three tributaries contribute most of the runoff and sediment to the Jiya Dhol river. The name Jiya dhal derived from the words “Jiya” and “Dhal” meaning “alive” and “flash flood” respectively, as the river has great tendency of generating flash-flood during monsoonal rain. After crossing a gorge near Jiyadholmukh, it debouches on to the Brahmaputra plains, where the course of the river becomes very broad. In the plains, the river is divided in to several branches which rejoin again downstream. The most important anabranches of the Jiya Dhol, which are well known for causing floods, are Kumatia and Samorajan. At present, a considerable amount of the runoff of Jiya Dhol is carried by the Samorajan river, while the Kumatia receives water from the Jiya Dhol during the monsoon. only. Along the southern slope of the foothill many small streams combine together and flow further south in the name of No Noi or Dihingia River. It empties into Smarajan and it is the most important tributary of Jiya Dhol in the plains of Assam. The Kumatia branch of the river meets other small tributaries. On the other hand, Samarajan on entering Ghilamara is called as Sampara. After flowing further down Sampara rejoins the Kumatia branch and retain the name Sampara. Ultimately, it meets Charikoria after crossing many swamps and wetlands.

3. Materials and Methodology

The main objective of morphometric analysis is to find out the drainage characteristic to explain the overall evaluation of the basin and prepare different thematic maps. Morphometric analysis comprises of a series of sequential steps. Toposheets for Jiya Dhol basin is not available as the area falls under restricted zone of Assam and Arunachal Pradesh. The present study is mainly concerned to evaluate morphometric characteristics of the river basin at sub watershed level in order to assess the prioritization of Jiya Dhol basin on the basis of erodibility with geospatial techniques. To do the same DEM data (30 m resolution) ASTER is used in GIS environment.

Drainage network is delineated by using the Arcmap 10.1 using the DEM of ASTER. The various morphometric parameters are evaluated for the Jiya Dhol basin. The morphometric parameters were divided in three categories: basic parameter, derived parameters and shaper parameters. Area, Perimeters, Basin Length, Stream Order, Stream Length, Maximum and Minimum Heights and slope come under first categories. Those of the second categories are Bifurcation Ratio, Stream Length Ratio, Stream Frequency, Drainage Density, Drainage Texture, Basin Relief and Relief Ratio are calculated with the help of standard formulae. The Shape parameters are Elongation Ratio, Circularity Index and Form Factor. The drainage network of the basin was analyzed as per Horton laws and the stream ordering was made after Strahler. After performing the morphometric analysis, compound parameter of the sub-watersheds is calculated and subsequently prioritization is carried out.

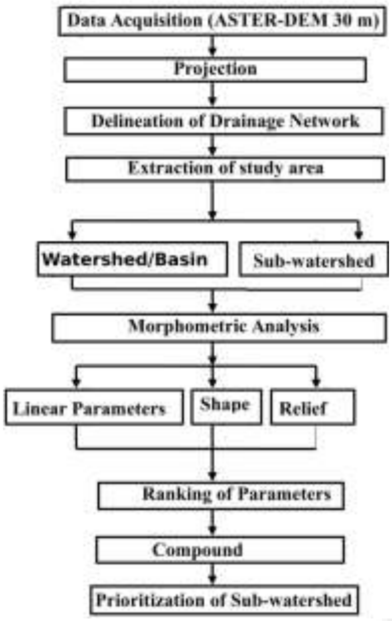

Figure 2: Flow chart prioritization of Watershed.

4. Morphometric Analysis

The study of river basin is very important in fluvial geographic characteristics. Analysis of basin morphometry is an integral part in the study of river basin. River basin or drainage basin of a river is the whole area bounded by ridge line within which every single drop of water in the form of precipitation contributes to the flow of a particular master river. A drainage basin is bounded by drainage divide. A proper study of the basin morphometry helps a lot in the better understanding of the basin characteristic and this helps in better planning and management of the basin. Morphological study provides quantitative description of the basin or sub-watershed sand fluvial geometry, structural controls, geological and geomorphic aspect of a drainage basin. The morphometric parameters can be classified as linear, shape and relief parameters. The quantitative analysis of morphometric parameters is of much significance in river basin evaluation, watershed prioritization, soil and water conservation, and natural resources management at micro level. It is of great significance in understanding the hydrologic scenario of an area, because a strong mutual relationship exists between morphological variables and hydrological characteristics. The following table depicts the mathematical formulae for deriving those parameters and the relationship that may exist between them.

Table 1: Morphometric Parameters

Morphometric Parameter	Formulae/ Relationship	Reference
Stream order	Hierarchical rank	Strahler, 1964
Stream length (L_u)	Length of stream	Horton, 1945
Mean Stream length (L_{um})	$L_{um}= L_u/N_u$, where L_u is the total stream length of order 'u', N_u number of stream segments of order 'u'	Strahler, 1964
Stream length ratio (R)	$R= L_u/L_{u-1}$, where L_u is the total stream length of order 'u, L_{u-1} is the total stream length of its next lower order	Horton,1945
Bifurcation ratio (R)	$R_b=N_u/N_{u+1}$, where N_u is the total number of stream segment of order 'u', $N_{u+!}$ is the number of stream segments of the next higher order	Schumn, 1956
Mean bifurcation ratio (R_{bm})	R_{bm}= average of the birfurcation ratio of all the order	Strahler, 1957
Relief ratio (R_h)	$R_h= H/L_b$, where H is the total relief (relative relief) of the basin, L_b is the basin length	Schumn, 1956
Relative relief (R_r)	$R_r= H/P$, where H is the total relief (relative relief) of the basin, L_b is the basin length	Melton, 1957
Drainage density (D_d)	$D_d=L_u/A$, where L_u is the total stream length of order 'u' and 'A' is the basin area in km^2	Horton, 1932
Constant of channel maintenance (C_m)	$C_m= 1/D_d$, where D_d is the drainage density	Schumn, 1956
Length of overland flow (L_g)	$L_g= 1/(2 \times D_d)$, where D_d is the drainage density	Horton, 1945
Ruggedness number (R_n)	$R_n= D_d \times H$, where D_d is the drain age density and H is the total relief (relative relief) of the basin.	Strahler, 1958
Stream/Drainage frequency (D_f)	$D_f= N_u/A$, where N_u is the total number of stream segment of order 'u' and 'A' is the basin area in km^2	Horton, 1932
Drainage Texture (T)	$T= N_u/P$, where N_u is the total number of stream segment of order 'u' and P is the perimeter (km) of the basin	Horton, 1945
Form factor (R_f)	$R_f= A/L_b^2$, where A is the basin area in km^2 and L_b is the basin length (km)	Horton, 1932
Circulatory ratio (R_c)	$R_c= (12.57 \times A)/P^2$, where A is the area ($km^2$) and P is the perimeter (km) of the watershed	Miller, 1953

5. Results and Discussion

The main watershed of Jiya Dhol Basin is divided into 11 subwatersheds named SWS 1 to SWS 11 using Arc GIS tool. The various morphometric analysis is carried out in its of the basin to calculate different morphometric parameters. Based on the values of the parameters obtained in GIS prioritazion and other analysis is performed.

5.1 Stream Length and stream Nos

It is the total length of streams in a particular order and it is denoted as Lu. The numbers of streams of various orders in a Sub-watershed were counted and their lengths measured in GIS. Generally, the total length of stream segments decrease with stream order. Length of different drain segments have been extracted in GIS and presented in Table . Higher length of streams in sub-watersheds revealed good morphologic characteristics. For sub-watersheds total stream length value ranges from lowest 4.61 km for SWS5 and highest value 78.49 km for SWS 8.

Table 2: Physical Parameters of Sub-watersheds

Sl. No	Sub Watersheds	Area, A Km	Perimeter, P, Km	Min. Elevation, Km	Max. Elevation, Km	Total Relief, Km	Nos. of Streams Nu	Total Stream Length, Lu, Km
1	SWS1	46.18	34.73	0.207	1.185	0.978	20	40.25
2	SWS2	28.67	36.76	0.207	1.181	0.974	11	22.91
3	SWS3	49.12	42.32	0.207	1.217	1.01	16	35.29
4	SWS4	59.65	64.41	0.101	1.04	0.939	28	56.6
5	SWS5	7.93	13.57	0.207	1.032	0.825	2	4.61
6	SWS6	38.36	37.09	0.207	1.13	0.923	15	30.53
7	SWS7	46.09	37.43	0.207	1.135	0.928	17	38.24
8	SWS8	93.31	51.1	0.255	1.507	1.258	41	78.49
9	SWS9	32.99	46.41	0.094	0.898	0.804	13	29.07
10	SWS10	24.44	34.1	0.093	0.139	0.046	12	25.86
11	SWS11	10.31	19.89	0.088	0.137	0.049	4	9.02

Table 3: Orderwise Number of streams of sub-watersheds of Jiya Dhol basin.

Sl. No	Sub Watersheds	Nos of Streams			
		Order 1	Order 2	Order 3	Order 4
1	SWS1	15	3	1	1
2	SWS2	6	3	1	1
3	SWS3	12	3	1	----
4	SWS4	20	4	3	1
5	SWS5	1	1	----	----
6	SWS6	11	3	1	----
7	SWS7	13	3	1	----
8	SWS8	34	6	1	----
9	SWS9	9	3	----	1
10	SWS10	7	3	1	1
11	SWS11	2	1	----	1

Table 4: Orderwise Stream Length of sub-watersheds of Jiya Dhol Basin.

Sl. No	Sub Watershed	Stream Length, Km			
		Order 1	Order 2	Order 3	Order 4
1	SWS 1	25.72	4.31	7.43	2.8
2	SWS 2	9.5	10.88	1.05	1.47
3	SWS 3	17.92	11.34	6.03	---
4	SWS 4	32.92	3.47	1.93	18.29
5	SWS 5	2.36	2.24	---	---
6	SWS 6	16.51	9.79	4.24	---
7	SWS 7	24.06	5.51	8.67	---
8	SWS 8	42.49	17.82	18.18	---
9	SWS 9	18.09	3.2	---	7.78
10	SWS 10	13.82	3.53	2.02	6.49
11	SWS 11	4.31	1.2	4.65	---

Table 5: Morphometric Parameters of sub-watershed

Sl No	Morphometric parameters	SWS 1	SWS 2	SWS 3	SWS 4	SWS 5	SWS 6	SWS 7	SWS 8	SWS 9	SWS 10	SWS 11
1	Area (A) (SqKm)	46.180	28.670	49.120	59.650	7.930	38.360	46.090	93.310	32.990	24.440	10.310
2	Basin Perimeter (P)(Km)	34.730	36.760	42.320	64.410	13.570	37.090	37.430	51.100	46.410	34.100	19.890
3	Basin Length (Lb) (Km)	11.570	8.826	11.983	13.381	4.253	10.413	11.557	17.253	9.558	8.061	4.937
4	Total no of Streams (Nu) (Nos)	20	11	16	28	2	15	17	41	13	12	4
5	Total stream length (Lu) (Km)	40.25	22.91	35.29	56.6	4.61	30.53	38.24	78.49	29.07	25.86	9.02
6	Drainage Density (Dd) (Km/SqKm)	0.872	0.799	0.718	0.949	0.581	0.796	0.830	0.841	0.881	1.058	0.875
7	Constant of Channel maintenance (Cm)	1.147	1.251	1.392	1.054	1.720	1.256	1.205	1.189	1.135	0.945	1.143
8	Total Relief (H) (Km)	0.978	0.974	1.010	0.939	0.825	0.923	0.928	1.258	0.804	0.046	0.049
9	Length of Overland Flow (Lo) (Km)	0.574	0.626	0.696	0.527	0.860	0.628	0.603	0.594	0.567	0.473	0.572
10	Drainage Frequency(Df)	0.433	0.384	0.326	0.469	0.252	0.391	0.369	0.439	0.394	0.491	0.388
11	Drainage Texture (T) (unit/Km)	0.576	0.299	0.378	0.435	0.147	0.404	0.454	0.802	0.280	0.352	0.201
12	Form Factor (Rf)	0.345	0.368	0.342	0.333	0.438	0.354	0.345	0.313	0.361	0.376	0.423
13	Bifurcation Ratio (Rb)	3.000	2.000	3.500	3.110	1.000	3.450	3.665	5.835	3.000	2.110	1.000
14	Stream Length Ratio (R)	0.7583	0.8823	).5823	3.380	0.950	0.5130	0.9015	0.720	1.3035	1.3467	2.0800
15	Elongation Ratio (Re)	0.374	0.386	0.372	0.368	0.422	0.379	0.374	0.357	0.383	0.391	0.414
16	Circulatory Ratio (Rc)	0.481	0.266	0.344	0.181	0.541	0.350	0.413	0.449	0.192	0.264	0.327
17	Relief Ratio (Rh)	0.085	0.110	0.084	0.070	0.194	0.089	0.080	0.073	0.084	0.006	0.010
18	Relative Relief (Rr)	0.028	0.026	0.024	0.015	0.061	0.025	0.025	0.025	0.017	0.001	0.002
19	RuggednessNumber(Rn)	0.852	0.778	0.726	0.891	0.480	0.735	0.770	1.058	0.708	0.049	0.043
20	Shape Factor (Sf)	2.899	2.717	2.923	3.002	2.281	2.827	2.898	3.190	2.769	2.659	2.364
21	Compactness Coefficient (Cc)	0.036	0.060	0.037	0.038	0.131	0.045	0.037	0.022	0.058	0.067	0.122

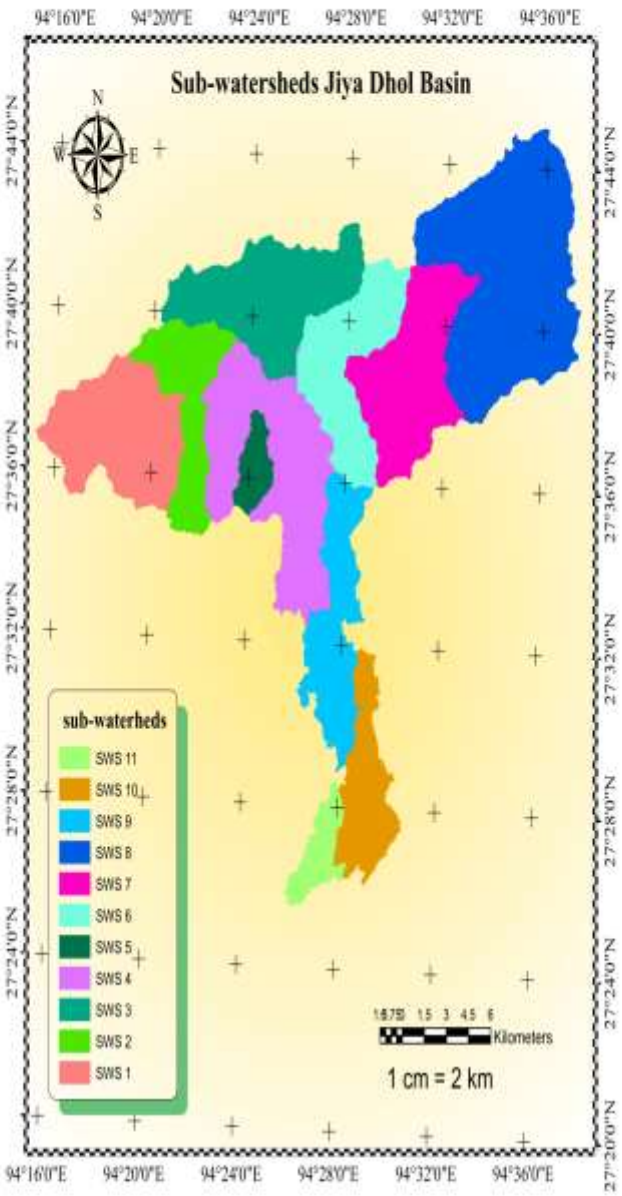

Figure 2: Subwtersheds of Jiya dhol Basin

5.2 Prioritization of Sub-Watersheds

Watershed prioritization is the scientific process of watershed delineation and monitoring. The prioritization is based on Morphometric parameters using GIS techniques. The study emphasizes the prioritization of the sub-watersheds on the basis of morphometric analysis. Morphometric analysis flow(Lo), drainage density (D_d), elongation ratio (R_e), Form factor(Ff) etc are termed as erosion risk assessment parameters and have been used for prioritization of sub watersheds (Biswas et al, 1999).

The linear parameters have a direct association with erodibility, hence for prioritization of sub watersheds, the highest value of linear parameters have assigned Ist rank, second highest value given IInd and so on, the lowest value. It seems that higher the value of linear parameters, more susceptibility of soil erosion. The areal aspects such as form factor, elongation ratio and circulatory ratio have an inverse connection with erodibility (Nooka et al, 2005), it means lower the value more the erodibility and vice versa.

Hence the lowest value of aerial parameters has assigned as Ist rank, next lower value as IInd and so on. After the ranking of all linear and aerial parameters in all sub watersheds the values of each watershed are summing up in order to obtain compound value and its average. Based on the average value the priority criteria have decided i.e. High Priority, Medium priority and low priority. The sub watershed having lowest average weitage belongs to High priority and the watershed having highest average weightage concerned to low priority. Based on Morphometric of 11 sub-watersheds have been priorities for conservation and management of water resources. The sub-watersheds has been categorized into five classes as highest (≤ 3.9), high (3.9-5.2), moderate (5.2-5.7), Low (5.7-7.1), Lowest (≥7.8) priority. On the basis of C_p value, the highest erosion prone SWS 8 and lowest being SWS 5 . Highest priority indicates the greater degree of erosion in the particular sub-watershed and it becomes potential area for applying soil conservative measures. Sub-watershed SWS 8 with a compound parameter value of 3.9 receives the highest priority (one) with next in the priority list is sub-watersheds SWS 4, SWS 1 and SWS 7 having the compound parameter value of 4.1, 5.1, 5.2 possess high priority followed by sub-watersheds SWS 3,SWS 6,SWS 9,SWS 10 having the Cp value of 5.4, 5.5 and 5.7 fall under moderate priority. Then sub-watersheds SWS 2 and SWS 11 having a compound parameter value of 6.5 and 7.1 possess low priority and the least priority is the sub-watershed SWS 5 with a value of 7.8.

Involves a set of parameters like; Aerial aspects, linear aspects, relief aspects. The morphometric parameters i.e. stream order (U), Stream frequency (Fs), length of overland

Table 6: Compound Parameters and erodibility

Compound Parameter	Erodibility
≤ 3.9	Highest
3.9-5.2	High
5.2-5.7	Moderate
5.7-7.1	Low
≥7.8	Lowest

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Table 7: Assignment of ranks and compond parameter of eleven sub-watersheds of Jiya Dhol Basin

Sub Watersheds	Linear parameters					Shape Parameter					
	Drainage density (Dd)	Drainage frequency (Df)	Bifurcation Ratio (Rb)	Drainage Texture (T)	Length of Overland Flow (Lo)	Form factor (Rf)	Shape Factor (Bs)	Compactness Coefficent (Cc)	Elongation Ratio (Re)	Circularity Ratio (Rc)	Compound Parameter (Cp)
SWS 1	5	4	6	2	7	4	7	2	4	10	5.1
SWS 2	8	8	8	8	4	7	4	7	7	4	6.5
SWS 3	10	10	3	6	2	3	8	3	3	6	5.4
SWS 4	2	2	5	4	10	2	9	4	2	1	4.1
SWS 5	11	5	8	11	1	10	1	10	10	11	7.8
SWS 6	9	6	4	5	3	5	6	5	5	7	5.5
SWS 7	7	9	2	3	5	4	7	3	4	8	5.2
SWS 8	6	3	1	1	6	1	10	1	1	9	3.9
SWS 9	3	5	6	9	9	6	5	6	6	2	5.7
SWS 10	1	1	7	7	11	8	3	8	8	3	5.7
SWS 11	4	7	8	10	8	9	2	9	9	5	7.1

Table 8: Classification of sub-watersheds on the basis of erodibility.

Sl. No	Sub-Watershed	Compound Parameter, Cp	Final Priority	Erodibility
1	SWS 1	5.1	III	High
2	SWS 2	6.5	VIII	Low
3	SWS 3	5.4	V	Moderate
4	SWS 4	4.1	II	High
5	SWS 5	7.8	X	Lowest
6	SWS 6	5.5	VI	Moderate
7	SWS 7	5.2	IV	High
8	SWS 8	3.9	I	Highest
9	SWS 9	5.7	VII	Moderate
10	SWS 10	5.7	VII	Moderate
11	SWS 11	7.1	IX	Low

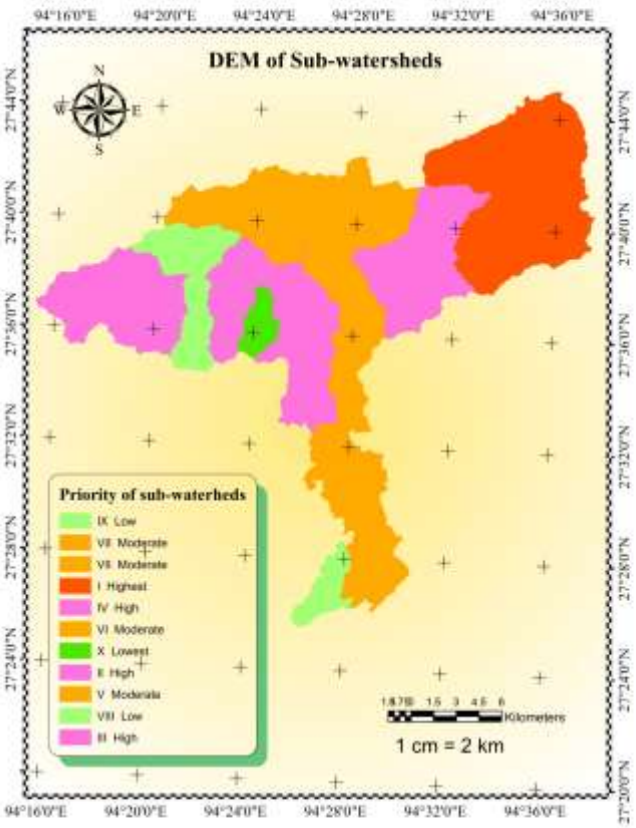

Figure 3: Prioratization of Sub-Watersheds

6. Methods of Soil Conservation

Based on the morphometric analysis, we have prioritized the sub-watershed SWS 8 as the most susceptible to erosion. Different control measures should be adopted to protect the soil resources against erosion. The concept of soil conservation cannot be materialized without conserving and efficient use of water resources. It is therefore pre-requisite that soil conservation practices should be adopted. Some of the soil conservation techniques are briefly discussed below. There are two types of soil conservation techniques that may be used in a watershed.
1) Mechanical measures
2) Biological measures

6.1 Mechanical Measures

These are the series of mechanical barriers constructed across the slope to reduce or break the length of slope only and/ or both the land and degree of slope. Since soil loss is proportional to square root of the length of the slope, doubling the length of the slope increases the erosion by 1.4 times. It means that only the degree of slope, but also the length of slope is equally important. If length of the slope is not broken at suitable intervals, surface runoff would pick up erosive velocity. Thus, reducing the length of slope, considerable amount of erosion can be checked.

Some of the common Mechanical measures that are used to conserve soil in watershed are

- Contour Bunding
- Graded Bunding
- Bench Terracing
- Contour Terrace Wall
- Conservation Ditching

Mechanical measures such as contour bunding and graded bunding only reduce the length of the slope as they do not change the slope in the inter bunded areas, whereas bench terracing reduces both length and degree of the slope on steep lands by modifying the land surface.

6.2 Biological Measures

Biological measures or vegetative measures of resource conservation have gained momentum recently due to many inherent advantages over mechanical measures. These measures are normally adopted on lands having milder slope without any disturbance / movement of surface soil or modification of land surface. They can be adopted singly or/ and in combination with mechanical measures depending upon the intensity of soil erosion problem.

Some of the Biological measures are

- Vegetative barriers
- Alley Cropping
- Ley Cropping
- Strip Cropping
- Contour Farming
- Land Configuration
- Tillage, Mulching and Residue Management

7. Conclusion

Prioritization of sub-watersheds is essential for basins as it helps to identify the critical soil loss areas of the basins so that some sort of soil conservative measures can be taken in those areas for arresting of soil loss. In the present study the main watershed of Jiya Dhol basin is divided into 11 sub-basins namely SWS 1 to SWS 11. After performing morphometric analysis and assigning ranks to various sub-basins, SWS 8 falls under highest priority and SWS 5 falls under lowest priority. The present study is valuable for erosion control, watershed management, land and water resouces planning and future prospective related to runoff study. The study of morphometric analysis using GIS helps to analysis the drainage basin easily & accurately which have various watershed problems like drought area, soil erosion, and change of land use land cover, watershed evaluation, flooding, groundwater potential zones & its scarcity. Therefore the researcher and concern stakeholders should carry out such kind of research in those basins which are much vulnerable to erosion so that some kind of soil conservation techniques can be applied to those basins to arrest soil loss.

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