Morphometric Parameter Based, Watershed Prioritization Analysis – A Geospatial Study of Umrynjah Watershed, Meghalaya, India

Fedalene Jyrwa, R. Annadurai, Sachikanta Nanda

Abstract: ***The goal of this study is to identify areas that are best suitable for micro-watershed development by using Morphometric analysis based on Remote Sensing and GIS. Umrynjah River which flows from the Umiam basin situated in the East Khasi Hills district of Meghalaya has been divided into six micro-watersheds. The morphometric parameters used for this purpose are based on the basic, linear and shape aspect of the watershed. The morphometric parameters were analyzed and are further considered for the prioritization analysis. Based upon this, prioritization for each micro-watershed is done by computing the compound factor. The compound factor with the lowest value was considered for higher priority which will require strategies of restoration and response for land management. The two micro-watersheds MWS3 and MWS4 covering an area of 37.66% are given high priority. MWS3 and MWS4 are therefore subjected to maximum erodability and require the need for measures of soil conservation.***

***Keywords*: GIS, Micro-watershed, Morphometric Parameters, Prioritization.**

I. INTRODUCTION

Meghalaya experience problems like irregular topography, soil erosion, jhuming practices but has favorable conditions like plenty of rainfall, high moisture content of soil and good agricultural practices. However though most of the areas receive plenty of rainfall during the monsoons, there is acute shortage of water during the dry seasons. The Government of India has setup watershed program in vulnerable and high risk environment. Morphometric analysis performs an extensive part in evaluating the hydrogeological response of the drainage and revealing the geomorphology and structural background of the catchment. The characterization of a drainage basin is an essential aspect for the measurable study of drainage system [7]. It may be considered as the logical physical unit for planning optimum development of soil and water [1]. According to watershed categorization, the National Remote Sensing Centre (NRSC) (1995), watersheds are classified into sub-watershed with 30–50 km^2, mini-watershed with 10–30 km^2 and 5–10 km^2 as micro-watershed [3].

Morphometric analysis emphasizes an essential role on mathematical analysis on all aspects of the drainage basin that is successively useful in understanding the hydrological aspects, sedimentation and change of landscapes in a drainage basin. It checks the basic, linear, shape and geometry of the drainage system. It needs assessment of the linear features, slopes of the drainage basin and gradient of streams [4]. The characteristics of morphometry of the drainage basin might hold necessary knowledge concerning its development and structure for a watershed [6]. By using these conventional methods the characteristics of drainage for numerous drainage basins have been considered in all parts of the world [7, 5, 11]. The need of generating Digital Elevation Models (DEM) is a comparatively smooth process especially for watershed delineation. DEM contributes useful description of the topography, where the watersheds can be derived directly by using GIS technology. Remote sensing and GIS techniques serve as a powerful tool and a flexible environment for handling and analyzing of spatial information and are used for evaluating and understanding morphometric parameters of the drainage basins [2].

Concerning the above, various morphometric parameters are determine to find out the landscape development, its character and behaviour of hydrologic responses of Umrynjah micro-watershed and to prioritize the micro-watershed based on the morphometric analysis.

II. STUDY AREA

Umrynjah village is located within the Mylliem Community of East Khasi Hills district in Meghalaya, India and is

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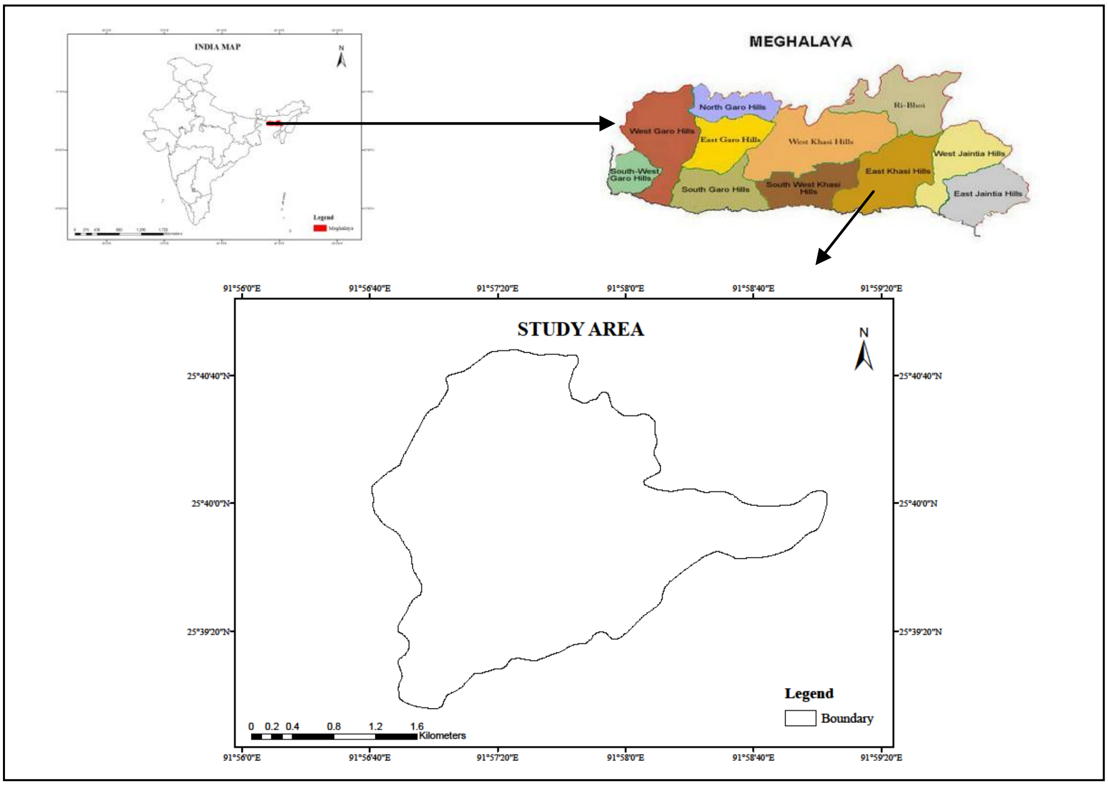

Fig-1 Location index of Umrynjah

located 20 kms away from district headquarters, Shillong. The geographical extend around the study area covers about 154.76 km^2. The Umrynjah area along the Umiam basin consist of two tributaries that is Umpling and Umphrew which covers a total area of 6.79 km^2 is taken up for the study. The Umrynjah catchment extends between the latitude of 25°45'3.01"N and 25°39'5.05"N and the longitude of 91°57'29.00"E and 91°56'51.72"E. The catchment lies within the Survey of India (SOI) topographical sheet of 78 $^{o}/_{14}$ NE (scale 1:50,000). The study area is shown in Figure-1.

Meghalaya represents the Plateau remnant of the north-eastern extension of the Indian Peninsular Shield; block uplifted at a current height of about 600-1800 meters above Mean Sea Level (MSL). This composite Plateau remnant is termed herein "Shillong Massif". Geomorphologically the area is underlain by structural origin, stream channels, micro-scrap and terracettes [13, 12]. The study area dominantly comprises of huge sequence of sedimentary rocks such as clastics, mainly sandstone, siltstone, shale, pebbles, clay and conglomerate. There are a few metamorphic rocks such as quartzite, phyllite and carbonaceous phyllite.

The climate in Umrynjah is temperate and warm. The average annual temperature in around Umrynjah is 20.2 °C. The most precipitation falls in June with an average of 973 mm. The soil ranges between sandy to sandy clayey loams, red loamy soil and black soil.

III. MATERIALS AND METHODOLOGY

The toposheet of the study area was obtained from the Survey of India (SOI) sheet no. 78 $^{o}/_{14}$ NE of a scale 1:50,000. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) with Global Digital Elevation Model Version-2 (GDEM V2) are used and date of acquisition of the data is on 2011/10/17 with spatial resolution of 30 m. The result of subtle data contributes to a more refine resolution; increased of accuracy on both horizontal and vertical direction, and water body detection and coverage. Non-spatial data such as population data and rainfall data were used for this study. ENVI 4.5 and Arc GIS 9.3 are the software's used for processing and analyzing various maps in this study.

Using Arc GIS 9.3 software, the toposheet for the study area are georeferenced. The image is downloaded from USGS and is used for the study. ASTER DEM was downloaded from USGS and is used to generate contour and slope maps. Basemap is prepared from toposheet by digitization in Arc GIS platform. The study area extends about 154.76 km^2. It has been observed that a total of 53 streams are present in the watershed (Fig-3). The micro-watershed of Umrynjah is divided into six micro-watersheds, as shown in Figure-4, which are digitized from the topographic map and were designated as micro-watershed (MWS) MWS1, MWS2, MWS3, MWS4, MWS5 and MWS6.

The various morphometric parameters are then computed and analyzed and different thematic maps are created. The contour map was generated from ASTER DEM and finally slope map is obtained. The relief parameters are generated using data management tool and by using raster calculator the dissection index was derived in GIS environment.

After computing all these parameters a compound factor was analyzed. This was done by adding all the linear

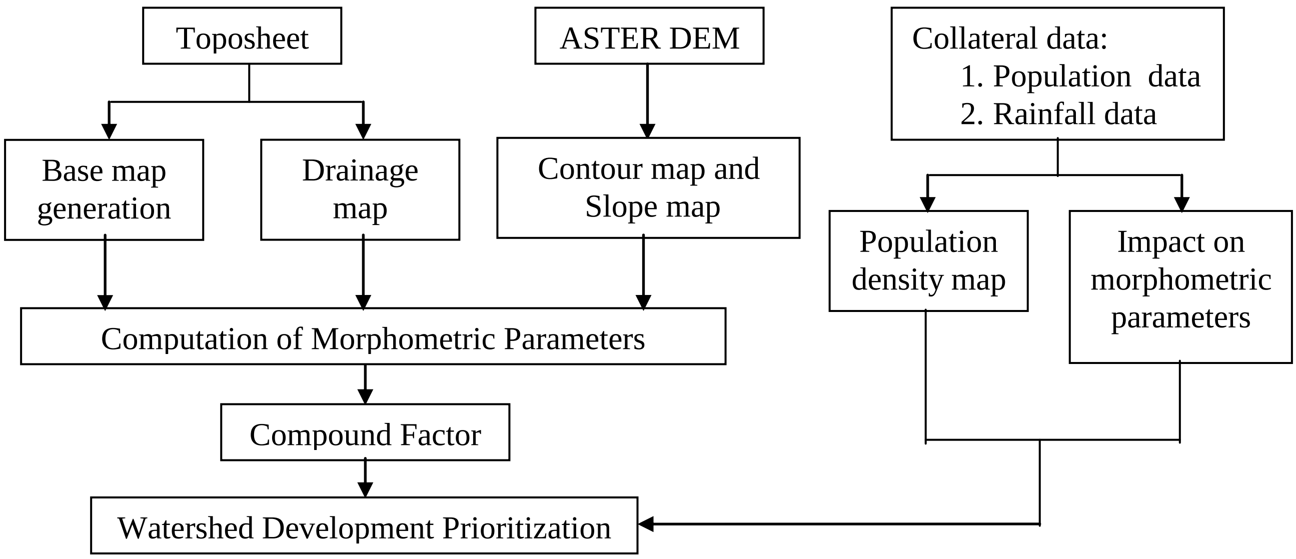

Fig-2 Flowchart of the methodology adopted

parameters and shape parameters, and dividing it by the total number of the parameters to that weightage are assigned to each of the compound factor and the lowest compound factor is taken as high priority which will need methods of rehabilitation and remedial strategies for soil conservation. The methodology adopted is shown in a flow chart (Fig-2).

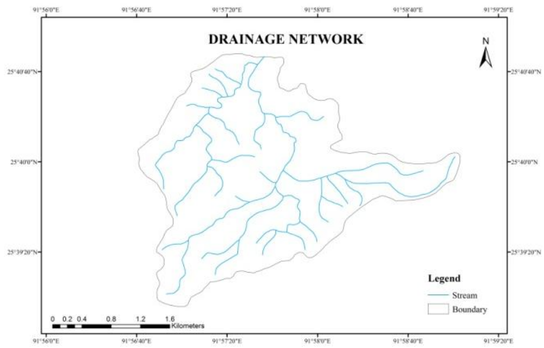

Fig-3 Drainage map of Umrynjah

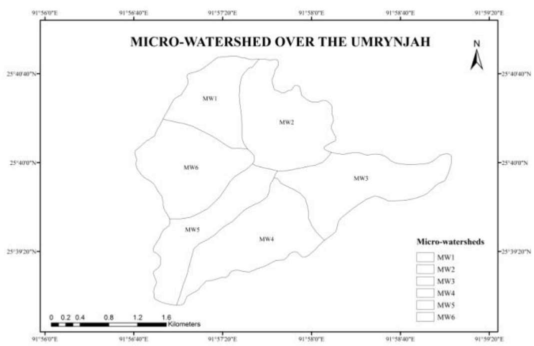

Fig-4 Micro-watershed of Umrynjah

for ASTER DEM shows high elevation at 1143 m, moderate at 1016 m and a low at 897 m.

Contour maps were generated in order to illustrate the contour line which shows the low lands and high lands, and the hilly or moderate slopes. The contour interval is 20 m. In Figure-6 the contour generated from ASTER DEM show an utmost height of 1120 m and the least height of 900 m.

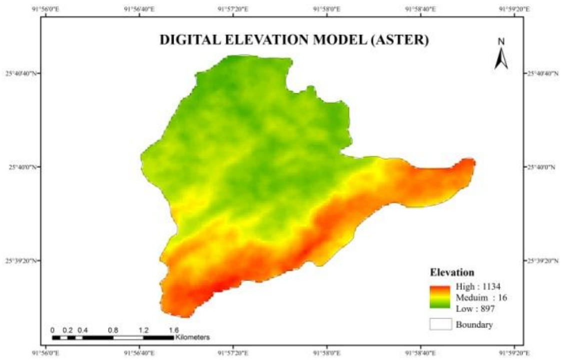

Fig-5 Digital Elevation Model (DEM) of Umrynjah

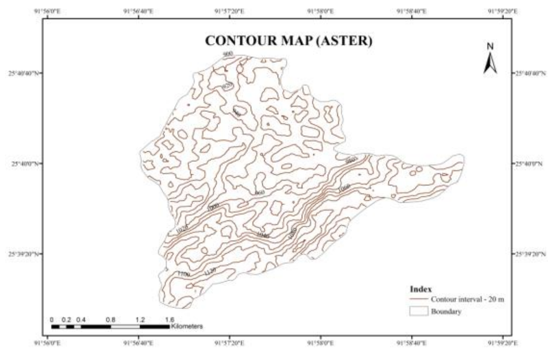

Fig-6 Contour map of Umrynjah

IV. RESULTS AND DISCUSSIONS

The elevation map from ASTER DEM is generated and represented in Figure-5 in order to represent the terrain and ground topography. The elevation maps are categorized as high, moderate and low. The Digital Elevation Model (DEM)

Relative relief which is characterized as the relative magnitude of the drainage from the highest point to the perimeter was also taken up in this study.

The relative relief in each square grid was calculated based on the maximum and minimum elevations. Absolute altitude which indicates the general nature of the topography of initial relief conditions was also generated. The relative relief and absolute relief map of the micro-watershed is represented in Figure-7 and Figure-8 respectively.

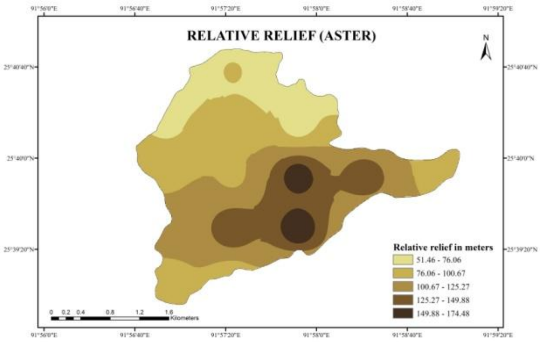

Fig-7 Relative relief map of Umrynjah

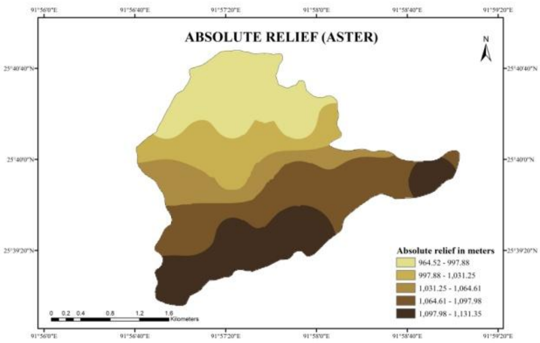

Fig-8 Absolute relief map pf Umrynjah

In the study area, the slope map is categorized into gentle slopes, moderate slopes, moderately steep slopes, steep slopes and extremely steep slopes. Slope map from ASTER data are generated. In Figure-9, 0.00° to 8.20° represents gentle slopes whereas 32.81° to 41.02° represents extremely steep slopes from ASTER.

The slope direction map in the study area is interpreted and is found that the slopes is along all directions and converge to a watershed. Figure-10 represents the slope direction map, where 25.422% of the area is facing north, 22.339% of the area is facing east, 29.494% of the area is facing south and 22.718% is facing west.

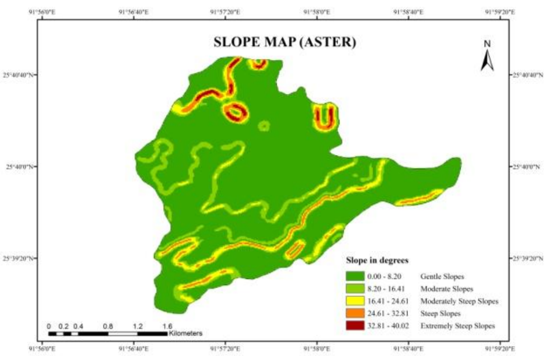

Fig-9 Slope map of Umrynjah

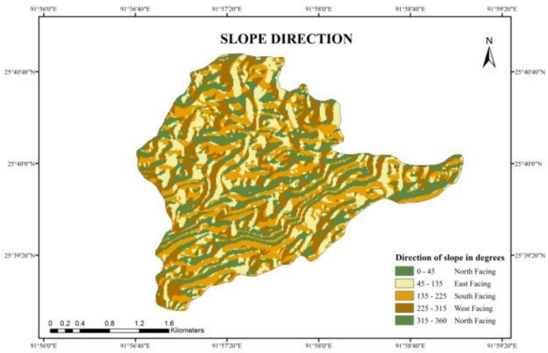

Fig-10 Slope direction map of Umrynjah

Dissection index was used in this study as it helps in indicating the degree of terrain dissection [8]. The map shows three levels of dissection that is high, moderate and low. The maximum area of 49.109% lies at 0.08-0.11 m which is moderately dissected whereas a minimum of 23.495% of the area which is low in dissection lies at 0.05-0.08 m. The dissection index map is represented in Figure-11.

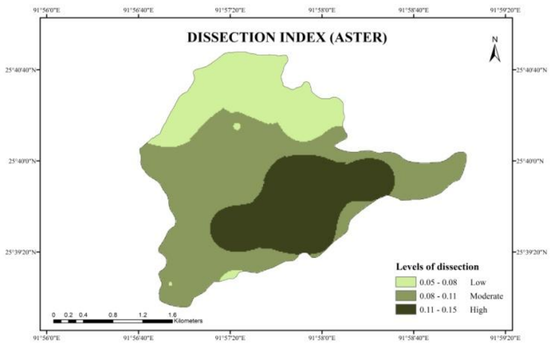

Fig-11 Dissection Index of Umrynjah

The morphometric parameters that are carried out were divided into three aspects: basic, linear and shape parameters of the drainage basin. Using basic formulas the morphometric analysis were carried out.

Basic Parameter

Basic parameters such as stream order, stream number, stream length, mean stream length, stream length ratio and basin length were determined and the results are shown in Table-1.

Stream Order (U)

The stream ordering systems have been used to rank the streams [7] of the Umrynjah watershed. The Umrynjah watershed is divided into six micro-watersheds out of which MWS1 to MWS6 are of the 1st and 2nd and MWS3, MWS4 and MWS5 also contributes to 3rd order. Therefore the drainage is categorized to three stream orders.

Stream Number (Nu)

This parameter is characterized by arranging the stream segments in a specific form. MWS4 consist of stream number 13 and less stream number of 6 found in MWS2 and MWS6 respectively. The details of the overall range of streams segments in every order for the Umrynjah micro-watershed is represented in Table-1.

Stream Length (Lu)

Usually, length of the stream decreases as the order of the stream increases. In this study, it is observed that MW3 shows a slight deviation which can indicate the flow from high altitude, change in rock type or and uplift across the basin. Also MWS3 has the longest length in comparison to other orders in the micro-watershed with 5.749 km. Table-1 shows the length of different stream orders in each micro-watershed.

Mean Stream Length

Generally, the mean of the stream length increases if the order of the stream increases. From the table, it is seen that there is some deviation in MWS1, MWS3, MWS4, MWS5 and MW6. This is due to the variation of topography and slope. Table-1 represents the mean stream length of each micro-watershed.

Stream Length Ratio (R_L)

This parameter has a valuable relation with the discharge of surface flow and the level of erosion in the basin. In this study the stream length ratio ranges from 0.182 to 1.354. Table-4 shows the change in R_L in the micro-watershed.

Basin Length (L_b)

As the basin length increases, the peak discharge decreases. The basin length values ranges from 1.172 km to 1.514 km for micro-watershed MWS1 to MWS6. Table-1 shows the basin length values for each micro-watershed.

Linear Parameters

Linear parameters have a direct relationship with soil erosion. The linear parameters such as bifurcation ratio, drainage density, stream frequency, drainage texture ratio and length of overland flow were calibrated and the results are shown in Table-2.

Bifurcation ratio (R_b)

Bifurcation ratio is a useful in measuring the proneness of flooding in the drainage basin. In Table-2, the mean bifurcation ratio of the six micro-watersheds in the study area ranges from 0.5 to 2.83.

Mean bifurcation ratio (R_{bm})

The average bifurcation ratio of all orders can be obtained by computing the average of the bifurcation ratios [9]. In Table-2, the total mean bifurcation ratio is 1.346.

Drainage density (D_d)

The drainage density is very essential as it can be identified as the cause of temporal movement of water [10]. Drainage density is beneficial in mathematical analysis of land dissection and run off[7]. From Table-2, the overall drainage density of the Umrynjah micro-watersheds is 3.526 km/ km^2 which are classified as coarse.

Stream frequency (F_s)

Frequency of higher stream is favored in regions of impermeable subsoil and steep gradients. In this study the stream frequency of the micro-watersheds ranges from 4.746 to 14.616 as shown in Table-2.

Drainage texture ratio (R_t)

Horton identified the texture ratio which is influence by the infiltration capacity and studied that both drainage density and drainage frequency should include in drainage texture. The higher amount of rainfall more is the drainage texture. In this study, the highest texture ratio is 2.834 in MWS1 whereas the lowest texture value is 1.178 in MWS2. The drainage texture values for the entire micro-watershed lie between 1.178 to 2.834 which is classified under coarse texture. Table-2 shows the texture ratio for each micro-watershed.

Length of overland flow (L_g)

This parameter accounts to the inverse of moderate slope of the drainage and it is entirely similar to high degree of length of flow. In this parameter the micro-watershed ranges from 1.291 to 2.258. In Table-2, it is observed that high drainage values indicate low length of overland flow.

Shape Parameters

Shape parameters such as form factor, shape factor, elongation ratio, circulatory ratio and compactness coefficient are derived and the results are shown in Table-3.

Form factor (R_f)

For a perfect circular basin, this parameter should be less than 0.785. Table-3 shows the form factor values for each micro-watershed where the value ranges from 0.561 to 0.597 which signify that the shape of drainage basin is moderately circular in shape.

Shape factor (B_s)

This factor is inversely proportional with form factor (R_f). Table-3 shows the shape of the micro-watershed ranging from 1.673 to 1.781 where MWS1 shows the lowest value whereas MWS4 shows a higher value.

Elongation ratio (R_e)

In this parameter, values which are close to 1.0 are areas of low relief, however steep ground slope and maximum relief consist of values which varies from 0.6 to 0.8 [7]. Table-3 shows the values of elongation ratio which ranges from 0.845 to 0.872 which represents steep slope and moderately high relief in the micro-watershed.

Circulatory ratio (R_c)

This ratio is altered by the distance, stream frequency, and complex in geology, land pattern, climate and slope. Table-3 shows the circulatory ratio values of the micro-watershed which ranges from 0.371 to 0.783.

From the table, the circulatory value ranges from 0.371 to 0.783 which indicates that MWS5 is moderately elongated whereas MWS1, MWS2, MWS3, MWS4 and MWS6 are moderately circular in shape.

Compactness Coefficient (C_c)

For a perfect circular basin the compactness coefficient value should be equal to 1. There is a high value from 1.129 to 1.639 in the micro-watershed; which indicates that it is moderately elongated with respect to the shape of the basin. Table-3 represents the values of compactness coefficient of the micro-watershed.

Table-1 Basic parameters of the micro-watershed

Micro-watershed	Area (sq.km)	Perimeter	Number of stream			Stream length (km)				Mean stream length (km)			Stream length ratio (R_L)		Basin Length (L_b)
			1st	2nd	3rd	1st	2nd	3rd	Total stream length	1st	2nd	3rd	2nd/1st	3rd/2nd	
MWS1	0.821	4.233	6	6	0	2.109	1.432	0	3.541	0.351	0.238	0	0.678	0	1.172
MWS2	1.264	5.091	3	3	0	1.387	1.878	0	3.265	0.462	0.626	0	1.354	0	1.498
MWS3	1.273	5.860	6	4	2	4.544	0.585	0.620	5.749	0.757	0.146	0.31	0.128	1.059	1.504
MWS4	1.287	5.691	6	4	3	2.615	1.795	0.315	4.725	0.435	0.448	0.105	0.686	0.175	1.514
MWS5	0.931	5.608	4	2	2	1.694	1.356	0.247	3.297	0.423	0.678	0.123	0.800	0.182	1.259
MWS6	1.221	4.425	4	2	0	3.066	0.709	0	3.775	0.766	0.354	0	0.231	0	1.469
Total	**6.797 sq.km**	**30.908 km**							**24.352 km**						

Table-2 Linear parameters of the micro-watershed

Micro-watershed	R_b			R_{bm}	D_d	F_s	R_t	L_g
	1st	2nd	3rd					
MWS1	1	0	0	0.5	4.313	14.616	2.834	2.156
MWS2	1	0	0	0.5	2.583	4.746	1.178	1.291
MWS3	1.5	2	0	1.75	4.516	9.426	2.047	2.258
MWS4	1.5	1.33	0	2.83	3.671	10.101	2.284	1.835
MWS5	2	1	0	1.5	3.541	8.592	1.426	1.770
MWS6	2	0	0	1	3.091	4.914	1.355	1.545

Table-3 Shape parameters of the micro-watershed

Micro-watershed	R_f	B_s	R_e	R_c	C_c
MWS1	0.597	1.673	0.872	0.575	1.317
MWS2	0.563	1.775	0.847	0.612	1.277
MWS3	0.562	1.776	0.846	0.465	1.465
MWS4	0.561	1.781	0.845	0.499	1.415
MWS5	0.587	1.702	0.864	0.371	1.639
MWS6	0.565	1.767	0.848	0.783	1.129

Prioritization of the micro-watershed based on morphometric analysis

Prioritizing the watershed is a major part in watershed management. In this study, Umrynjah watershed has been divided into six micro-watersheds where the watersheds have been given priority based upon the morphometric parameters. Since linear parameters have a direct relationship with soil deterioration therefore the highest value is rank as 1. On the other hand, shape parameters show an inverse relation to erodability. Thus the lowest values of shape parameters are ranked as 1. Prioritizing the micro-watershed is down by calculating the compound factor that is by taking the average of all the ranking values of the parameters for each micro-watershed. Table-4 shows the compound factor with the lowest value is assigned as the highest priority which will require strategies of restoration and response for land management. The micro-watersheds were then categorized into five classes as very high, high, moderate, low and very low. Thus, MWS3 and MWS4 were given very high priority were a maximum population of 1280 falls within these two micro-watersheds. The priority rank map, final prioritized map and population density map of the study area are shown in Figure-12, Figure-13 and Figure-14 respectively.

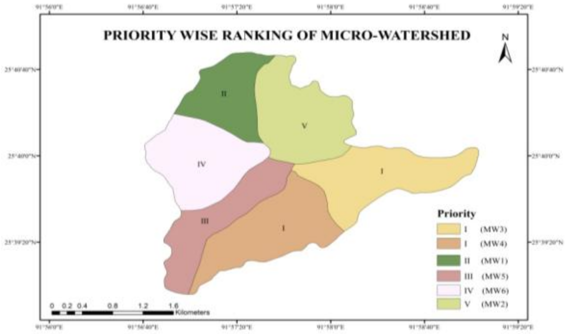

Fig-12 Prioritized rank map of Umrynjah

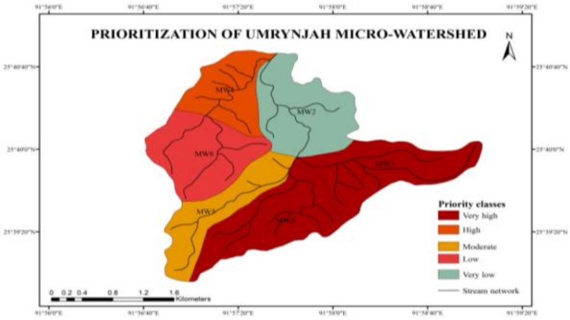

Fig-13 Micro-watershed prioritization map of Umrynjah

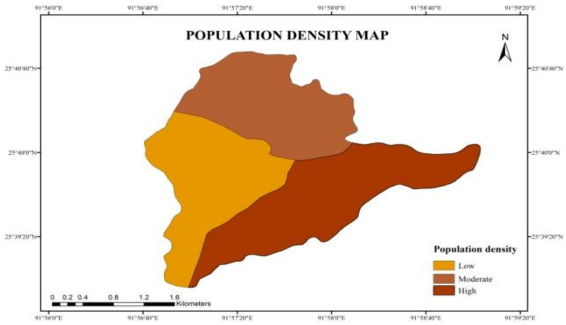

Fig-14 Population density map of Umrynjah

V.CONCLUSION

The morphometric parameters of Umrynjah watershed have been analyzed and the characteristics of the six micro-watersheds have been studied. In this study, the mean bifurcation ratio is 1.346 which indicates that the watershed is flat and moderately circular in shape. The drainage density of the study area is 3.526 km/km^2 which show a coarse texture and indicating presence of permeable sub-soil and dense vegetation. Form factor ranges from 0.561 to 0.597 which signify that the shape of the drainage basin is moderately circular. Elongation ratio values ranges from 0.845 to 0.872 which shows that the watershed have a slightly high relief and hilly slope. The compactness coefficient varies from 1.129 to 1.639 which reveals that the basin shape is extended moderately. The Umrynjah watershed has been rank and prioritized based on their susceptibility to run-off and erosion. It is found out that two micro-watersheds MWS3 and MWS4 having the least compound factor of 2.6 respectively were given highest priority as they are vulnerable to high peak flows and erosion. About 37.66% of the area with a maximum population of 1280 falls under these two micro-watershed. Therefore intermediate measures of soil conservation should be taken up in order to prevent the land from further degradation. This study demonstrates that morphometric analysis is very effective through geospatial techniques.

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