ASSESSMENT AND EXTRACTION OF HYDROLOGICAL PARAMETERS OF MUNDA DAM WATERSHED – A GEOSPATIAL APPROACH

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ABSTRACT**:** *Fast urbanization and climate change have made proper water resource management very tricky. Therefore, appropriate water resource management is needed to forestall the deficiency of water in future. GIS & RS has emerged as a precise and efficient tool for hydrological analysis of watershed compared to other existing techniques. The present study is carried out to assess the hydrological parameters for Munda Dam watershed using DEM (Digital Elevation Model). The study area (Munda Dam watershed) is geographically located about 37 km near Charsaddah in Mohmand Agency, Federally Administrative Tribal Areas, of Pakistan. The hydrological analysis comprises the analysis of topography, land use pattern and drainage pattern for the water resource management. Hydrological Module of ArcGIS software was employed for watershed analysis. The stream order of watershed is 1st to 5th order, depicts dendritic type drainage pattern. The bifurcation ratio ranges from 2 to 8.5 and the average bifurcation ratio of the basin is 3.42 which specifies that this region is homogeneous in lithology and tectonically stable. The elongation ratio is 0.9, designating that the catchment area is of oval shaped geometry. The oval shape geometry of catchment area causes high flood peaks for shorter duration. Aspect map of Munda Dam watershed reveals the slope direction from East to Southeast. Topographic and slope maps show that this area is comprised of high to low topped peaks and lonely hills, having moderate to steep slope. The maximum height of peak is 8960 feet in this region.*

Keywords: Remote sensing, GIS, Watershed management, Morphometric analysis, Pakistan

1. INTRODUCTION

Presently unusual resident's expansion, fast development and environmental changes have made suitable water resource management very difficult. Therefore, it is prerequisite to evaluate water resources in detail [1]. Water resource management and construction of dams have become essential now a days to avert from deficiency of water in future. Thus appropriate watershed analysis is vital to surmount this problem [2].Watershed analysis using Remote Sensing (RS) and Geographic Information System (GIS) is very precise and proficient tool as compare to other manual watershed analysis. RS data is very effective and self-assured to analyze spatial changes in the specified area [3]. Digital Elevation Models (DEMs) are employed to reckon different geomorphological and morphometric parameters of watershed [4,5].

Quantitative morphometric analysis of drainage basin can give us statistics about the hydrological behavior of the rocks, discovered in the drainage basin. Watershed analysis requires detail information of topography, drainage pattern, morphometric parameters, and geological setting of the study area [6]. Morphometric analysis is important to select water recharge site, watershed analysis, runoff modeling, drainage basin delineation, groundwater mapping and geotechnical investigation [7].

In addition, the low intensity and erratic monsoons cause shortage of supply of surface water and groundwater levels [8]. Over exploitation of groundwater has steered to the drying up of aquifers in several regions of the country. Consequently, the groundwater recharge management demand is a necessity of time [9]. It is therefore important to take precautionary measurements to recharge the aquifer by implementing proper water management program in watershed [10].

The analysis of the drainage network is performed to understand the geological variations, topography and geomorphology of the watershed [11]. Remote Sensing and GIS based watershed analysis was carried out by many researchers in different fields [12]. Previously, morphometric parameters of drainage were calculated from the topographic maps and field surveys [13]. Extraction of morphometric parameters by means of DEM is more prevalent for last two decades [14].

The main purpose of this work is to examine and categorize various drainage parameters to analyze the geometry of the Munda Dam watershed for appropriate water resource management. The analysis carried out in the present work can be utilized as scientific data base for detailed hydrological analysis. The observed results can be utilized to overwhelm the problems in water resource management through the construction of suitable structures such as recharge shaft, check dam, storage tanks.Pakistan has an alarming rate of deforestation. The report published in 2009 by the United Nation (UN).

2. MATERIAL AND METHODS

2.1 Study Area

Munda Dam watershed lies between geographic Latitude 34⁰ 21' 12" N to 35⁰ 15' 21''N and Longitude 71⁰ 31' 58.71" E to 72⁰ 10' 31'' E about 37 km north of Peshawar near Charsaddah in Mohmand Agency, Federally Administrative Tribal Area (FATA). The area is comprised of low topped hills and barren slopes. The streams are flowing from East to Southeast. Munda dam watershed (the study area) drains into Swat River.

Precipitation is scarce and mostly happens in the winter season. The typical weather of this region ranges from sub-humid to semi-arid and moderate. Geomorphology of the area has a principal effect on the local climate. Precipitation happens because of the monsoons and westerly winds. The average rainfall ranges from 30 cm to 100 cm. the precipitation is more frequent in winter than that of summer.

The mean annual temperature is between $18^{0}C$ to $23^{0}C$. Frost occurs just for a few days in the months of December, January and February.

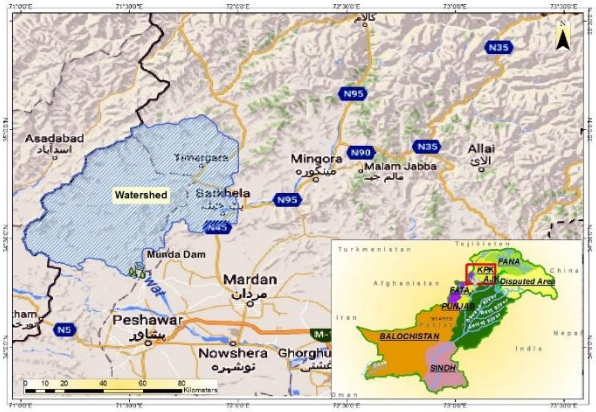

Figure 1: Location Map of Munda Dam watershed

2.2 Methodology

Assessments of drainage pattern and morphometric analysis provide information about the hydrological condition and nature of the outcrops within the watershed. Morphometric analysis of the watershed tells us about the permeability, storage capacity and the yield of the rocks within the drainage basin.

In this paper, a multispectral satellite data, DEMs (digital elevation models), topographic maps, slope and aspect maps, and land use/ land cover data are employed for the preparation of database and computation of numerous morphometric parameters. The following procedure was followed for watershed analysis:

a) Digital Elevation Model (DEM) of 30m resolution is acquired from Shuttle Radar Topographic Mission (SRTM) to carry out this research. The SRTM DEM was employed to generate topographic map, aspect and slope map, and catchment area delineation using ArcGIS 10.2.
b) Downloaded SRTM DEMs were clipped and mosaic. Topographic map was generated and analyzed using ArcGIS software.
c) Catchment area of the Munda Dam watershed is computed from DEM (Digital Elevation Model) using Hydrology tool in ArcGIS.
d) In this research, the recently available satellite data of Land sat 4-5 TM was obtained to carry out supervised classification scheme in ArcGIS 10.2 software. A maximum likelihood classification method was utilized to assess the land use/ land cover pattern of basin. Doubtful classes were verified by performing GPS surveys.
e) All the extracted parameters from satellite images and SRTM DEM such as topographic map, slope map, aspect map and morphometric parameters were calculated using ArcGIS software.
f) Quantitative morphometric analysis has been utilized to assess the drainage characteristics of Munda Dam watershed. Important areal, linear and relief parameters were computed such as perimeter, basin area, basin length , drainage density (Dd), stream frequency (Fs), elongation ratios (Re), bifurcation ratio (Rb), circulatory ratio (Rc) etc. The details of different morphometric parameters and laws used to carry out this research are given in Table 1.

Table 1: Methodology implemented for computation of morphometric parameters

Sr. No.	Parameters	Formulae	References
Drainage Network Analysis			
1	Stream order (U)	Hierarchical rank	[15]
2	Stream length (Lu)	Length of the stream	[16]
3	Mean stream length (Lsm)	$Lsm = Lu/Nu$	[15]
4	Stream length ratio (RL)	$RL = Lu/(Lu 1)$	[16]
5	Bifurcation ration (Rb)	$(Rb) = Nu/Nu + 1$	[17]
6	Mean bifurcation ratio (Rbm)	Rbm = average of bifurcation ratios of all order	[18]
Basin Geometry Analyis			
7	Basin Area	Using GIS Software	[17]
8	Basin Perimeter	Using GIS Software	[17]
9	Basin Length	Using GIS Software	[17]
10	Elongation ratio (Re)	$Re = D/L$	[17]
11	Circularity ratio (Rc)	$Rc = 4pA/P2$	[15]
12	Form factor (Ff)	$Ff = A/L2$	[16]
13	Drainage texture (T)	$T = Dd \cdot Fs$	[19]
Drainage Texture Analysis			
14	Drainage density (Dd)	$Dd = Lu/A$	[16]
15	Stream frequency (Fs)	$Fs = Nu/A$	[16]
Relief Characteristics			
16	Relief	$R = Hh$	[20]
17	Relief ratio	$Rr = R/L$	[21]

3. RESULTS AND DISCUSSIONS

The DEM (Digital Elevation Model) of 30m resolution was acquired to carry out watershed analysis. The drainage system depends on the precipitation, geology and tectonic setting of the area. Linear aspects, areal aspects and relief characteristics were computed using ArcGIS software to carry out hydrological analysis of Munda Dam watershed.

3.1 Topography of Study Area

Topographic map (figure 2) of the research area indicates that watershed encompasses low to high topped hills, having rugged topography. This area is hillier towards southeast where the altitude upsurges to 8960 ft. the elevation is between 2250 and 4838 ft. in the northwestern part of this region. The elevation of plains varies from 2100- 3100 ft. in the watershed.

3.2 Aspect Map

Aspect map displays the direction of faces of mountain slope. It is a significant parameter to analyze the impact of sun on local climate. West facing slopes have to face hottest time of the day. Generally, Western slopes are warmer than Eastern slopes. Because western slopes encounters maximum sun rays due to this reason these slopes have lower moisture content than that of eastern slopes. The east facing slopes have higher vegetation than that of west facing slopes because of higher moisture content in eastern slopes. The aspect map generated from DEM as shown in figure 3, reveals that the direction of slope faces is from East to Southeast.

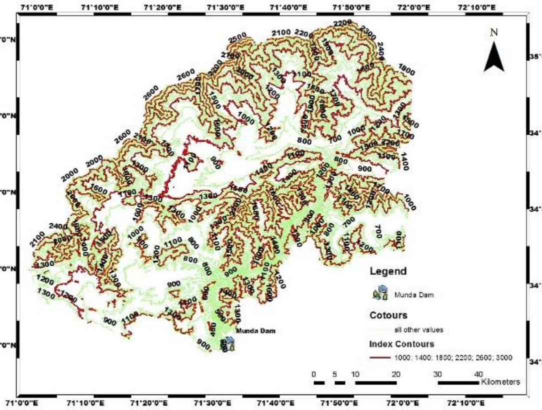

Figure 2: Topographic Map of Munda dam watershed

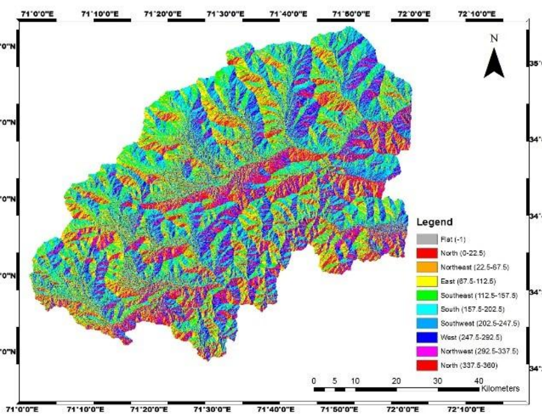

Figure 3: Aspect Map of Munda dam watershed

3.3 Slope Map

The slope map of the research area is generated from digital elevation model using ArcGIS 10.2 software. The detail analysis of slope map shows that most of the study area (figure 4) comes under moderate to steep slope. Mild to moderate slope is suitable to implement a plan for aquifer recharge because of lower runoff and higher infiltration. The steep slope is good for construction of dam due to high surface runoff. Therefore slope is an important parameter in water resource management.

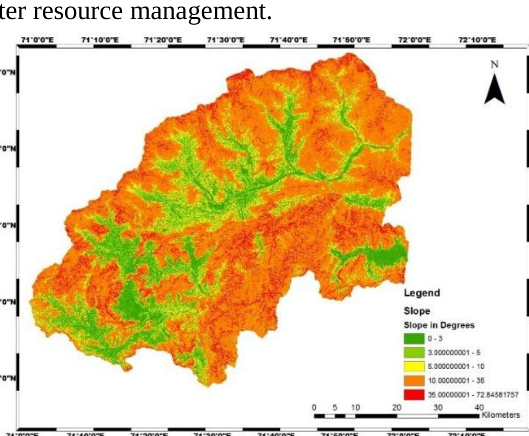

Figure 4: Slope map of Munda dam watershed

3.4 Land Use and Land Cover Mapping

Land use pattern is an essential parameter to ascertain the health of watershed. This parameter is use to govern the water demand for agricultural and domestic purposes. Land cover map tells us the surface condition and groundwater condition of the particular area. This information play a key role in watershed analysis. The detail analysis of land cover map categorize the land into barren and vegetative land. There are also some water bodies but most of the areas comes under barren land. This analysis support the watershed development and management.

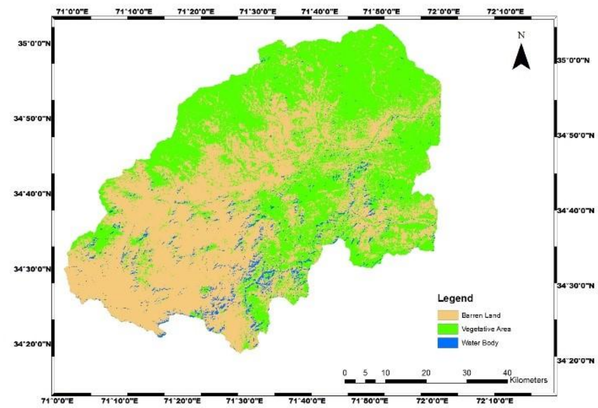

Figure 5: Land use land cover map of Munda watershed

3.5. Linear Aspects of Munda Watershed

3.5.1. Stream Number (Nu) and Stream Order (Su)

The watershed is included of dendritic type drainage pattern which is an indication of homogeneity in subsurface lithology. Drainage pattern analysis is carried out from DEM using the proposed method [15]. The analysis of this area reveals the tectonic stability of the area. The number of streams are directly proportional to stream order. The drainage pattern of the research area is shown (fig. 6). 1st to 5th order streams are found in this region. The stream order in this drainage basin is computed by the method proposed by Horton [16]. Total length of streams is maximum in first order stream. As the stream order increases, the total stream length in respective order decreases. This change in stream order indicates that streams are flowing from higher to lower elevation. The total steam length in this watershed is about 845.15 kilometers.

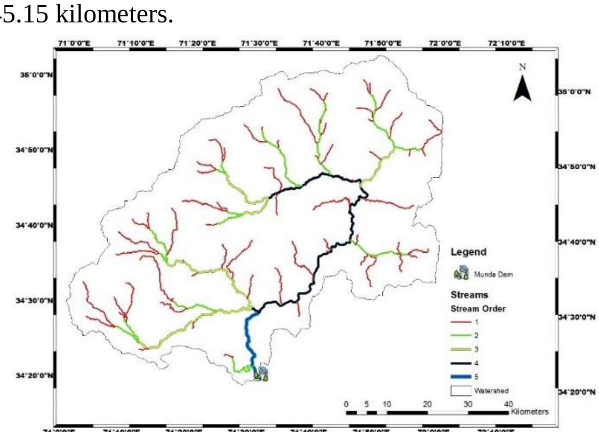

Figure 6: Stream Networking Map

The mean stream length and respected ratios are also calculated by ArcGIS 10.2. Drainage texture analysis indicates dendritic type drainage basin which shows homogeneous subsurface lithology. These are generally categorized by a treelike branching, which specifies the homogeneity and uniformity in the lithology of the region.

3.5.2. Stream length (Lu), mean stream length (Lsm) and stream length ratio (RL)

The stream length, mean stream length and stream length ratio were calculated for Munda Dam watershed using ArcGIS on the basis of the law proposed by Horton [16]. Generally, the total stream length has an inverse relation with stream order. These parameters are significantly important to analyze the hydrological characteristics of the watershed, as these are signs of the permeability of subsurface rocks in basin. This analysis describes the hydrological nature of the subsurface rocks [22]. The relation between stream length ratio and bifurcation ratio confirms geological, geomorphological and hydrogeological nature of the research area. The linear aspects of the watershed are computed using ArcGIS 10.2 (Table 2).

3.5.3. Bifurcation Ratio (Rb)

The bifurcation ratio is a ratio of the number of streams (Nu) in the specified order to the very next higher order (Nu + 1) number of streams. It is a degree of index of relief [16]. It is shown that the bifurcation ratio designates very small deviation in different areas, until the principal geological control overwhelms [18]. Bifurcation ratio shows different values various stream orders due to geology and lithological variations of in the watershed [18]. The bifurcation ratio is a dimensionless property and it is usually from 3.0 to 5.0. The smaller the bifurcation ratio, the more will be tectonic stability [18]. The higher value of bifurcation ratio is described as structurally disturbed area. The present research proves smaller value of bifurcation ratio (Table 2) up to 3rd order stream. While 4th order stream specifies highly disturbed area due to bifurcation ratio of 8.5.

3.5.4. Weighted Mean Bifurcation Ratio (Rbwm)

To acquire a more representative bifurcation number, weighted mean bifurcation ratio is attained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams included in the ratio and taking the mean of the sum of these values [23]. The weighted mean bifurcation ratio of Munda dam watershed (Table 2) is 2.68.

3.6. Areal Aspects of Munda Dam Watershed

3.6.1. Basin Area (A)

The basin area is very essential parameter like the stream length in drainage basin. A fascinating relationship was proven between the total length of streams and the total basin areas, which was supported by the contributing regions [17]. The basin area (Table 3) is computed 4515 Sq. Km using ArcGIS-10.2.

3.6.2. Basin Perimeter (P)

The perimeter of the drainage basin is the exterior boundary of the basin with respect adjoining area. It describes the shape and size of the basin. The perimeter of the watershed is 371.3 km (Table 3), which is computed using ArcGIS software.

Table 2: Linear Aspects of the Munda Dam Watershed

Sr. No.	Parameters	Stream Order (Su)					Total	Mean
1	No. of Stream (Nu)	I	II	III	IV	V		
		72	36	16	17	2	143	
2	Total Length of Stream (Km)	449.36	169.85	115.49	90.12	20.3	845.15	
3	Mean Stream Length (Lsm)	6.24	4.71	7.21	5.3	10.15		
4	Bifurcation Ratio	2	2.25	0.94	8.5		13.69	3.42
5	Stream Length Ratio (Lur)		0.75	1.53	0.73	1.91	4.92	1.23
6	Weighted Mean Bifurcation Ratio (Rbwm)	2.68						
8	Weighted Mean Stream Length Ratio (Luwm)	1.49						

3.6.3. Length of the Basin

Many a researcher defined basin length accordance with their own research. Length of basin is the lengthiest aspect of the watershed along the main stream [17]. It is the length of the basin along the main river of the basin. (Gregory and Walling, 1968). The length of the basin is the length of line from a mouth of the drainage basin to a point on the perimeter from the mouth of the drainage basin to either direction round the perimeter. The author has measured the length of drainage basin [17], which is 93.78 km (Table 3).

3.6.4. Form Factor

Form Factor (Ff) is termed as the ratio of the area of the drainage basin to square of the length of the basin. It is the amount of flow in the watershed for a specified area. The value of form factor must always be less than 0.7854 [24].

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The Higher value of the form factor indicates that geometry of the basin is circular. The circular geometry of the basin shows high surface runoff for shorter duration. The form factor measured for this watershed is 0.64 (Table 3). This value of form factor suggests the oval shape geometry of drainage basin. The elongated geometry of the basin signifies flat peak flows for a longer period.

Table 3: Basin geometry

Sr. No.	Parameters	Results	
1	Basin length (Km)	83.79	
2	Basin area	4515	
3	Basin Perimeter	371.3	
4	Form Factor (Ff)	0.64	
5	Elongation Ratio (Re)	0.9	Oval shape basin
6	Circulatory Ratio (Rc)	0.4	
7	Drainage Texture (Dt)	2.59	Coarse (2-4)
8	Compactness Coefficient	1.55	

3.6.5. Elongation Ratio (Re)

Elongation ratio (Re) is the ratio between the circular diameter of the same area of the basin and the maximum length of the basin [17]. Its value generally ranges from 0.6 to 0.8 because of variations in geological and climatic conditions. The higher value of elongation ratio signifies low relief and vice versa [15]. These are generally classified as; circular (> 0.9), oval (0.9-0.8) and elongated (<0.7). The elongation ratio of this basin computed using ArcGIS is 0.9. This value of elongation ratio is an indication of low to moderate relief and oval shape geometry (Table 3).

3.6.6. Circulatory Ratio (Rc)

Circularity ratio (Rc) is a ratio of the basin area to the circular area of the basin having the same perimeter as the drainage basin. It is influenced by the length and frequency of rivers, geological structures, land cover, climate, topography and slope of the drainage basin. Circulatory ratio value is 0.40, which is an indication of homogeneous geological materials, permeable subsurface rocks and oval shape geometry. The circularity ratio is 0.4 which is calculated using ArcGIS 10.2 software (Table 3).

3.6.7. Drainage Texture (Dt)

The drainage texture of the basin is a very important parameter which gives us an idea about the geomorphology of the basin. It states subsurface lithology and infiltration capacity of the watershed. Drainage texture is a proportion of the total number of streams of all orders in the basin to the perimeter of the basin [16]. Smith [19] classified drainage texture in several textures such as very fine (>8), fine (6-8), moderate (4-6), coarse (2-4). Very coarse (<2). In the present research, the drainage texture of the watershed is determined 2.59 which specifies the coarse drainage texture (Table 3).

3.6.8. Compactness Coefficient

Compactness coefficient of the drainage basin is a proportion of perimeter of basin to the circumference of circular area which is equal to the area of drainage basin. The compactness coefficient is autonomous size of the drainage basin and only on dependent upon the relief. The researcher has calculated the compactness coefficient of Munda basin which is 1.55 (Table 3).

3.7. Drainage Texture Analysis

3.7.1. Stream Frequency

Stream frequency (Fs) is the total number of streams in drainage basin per unit area [24]. Stream frequency directs a positive relation with drainage density of the watershed proposing high stream population happens with respect to rise in the drainage density. Stream frequency is 0.3 of the drainage basin which designates a positive correlation with the drainage density of the study area representing an incline in stream population with respect to rise in drainage density (Table 4).

3.7.2. Drainage Density

It is a ratio of stream length per unit area in drainage basin which is another parameter of drainage texture analysis. Drainage density is a superior quantitative parameter to analyze the structure of landform. On the other hand geology, climate, slope, relief and topography are also very essential parameters for watershed analysis. The author has computed the drainage density by using ArcGIS-10.2 which is 0.18 Km/KM2 (Table 4).

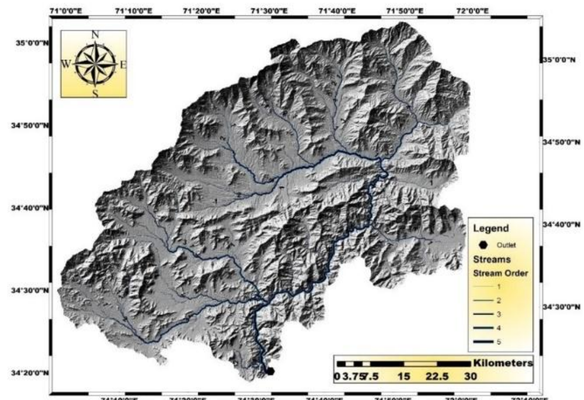

Figure 7: Stream Networking Map with hillshade View

3.7.3. Constant of Channel Maintenance (I/D)

It is a reciprocal of drainage density. It describes the geomorphology of the watershed [17]. This constant displays the number of Km^2 of drainage basin surface needed to progress a channel of 1 Km long. This parameter describe the relative size of landforms in a drainage basin and has a certain inherited implication [18]. Channel maintenance constant is calculated 5.55 Km2/Km using ArcGIS (Table 4).

3.7.4. Infiltration Number (If)

The infiltration number of the basin is a product of drainage density and stream frequency. It describes the infiltration properties of the drainage basin. The infiltration value has an inverse relation with runoff. Infiltration number of the basin is 0.24 (Table 4).

3.7.5. Length of Overland Flow

This terminology is stated as the extent of flow of precipitation on the ground before it is channelized into specific stream [16]. It is half of the distance between stream channels calculated by [16]. For the sake of easiness, it is taken half of the drainage density. In the present research, the length of overland flow is determined 2.77 Km (Table 4) which is an indication of high surface runoff of the watershed.

Table 4: Drainage Texture Analysis

Sr. No.	Parameters	Results
1	Stream Frequency (Fs)	0.3
2	Drainage Density (Dd)	0.18 km/km2
3	Constant of Channel Maintenance (I/D)	5.55
4	Infiltration Number (If)	0.24
5	Length of Overland Flow(Lg)	2.77 Km

3.8. Relief Characteristics of Munda Watershed

Total relief of the watershed is calculated by subtracting highest point of altitude from the lowest point of altitude in the drainage basin. It is a ratio of total relief of the drainage basin to the total length of basin determined along the principal drainage line [17]. Relief ratio and hydrological parameters of the watershed have an important relationship [17]. Sediments in bulk per unit area is closely associated with relief ratio. The value of the relief ratio determined 0.33 using ArcGIS 10.2 (Table 5). It is assessed that this region is having low to moderate relief. Low value of relief is a principal clue of resistant and homogeneous subsurface lithology.

Table 5: Relief Characteristics

Height of Basin Mouth z (m)	Maximum Height of the Basin z (m)	Total Basin Relief H (m)	Relief Ratio
400	3200	2800	0.33

3.9. Hydrological inferences from morphometric parameters

The morphometric analysis carried out using remote sensing and GIS, is vital for proper water resource management. This study indirectly gives us a clue about the health of drainage basin. Quantitative morphometric analysis has been found very efficient tool in soil analysis, water resource management and watershed management. The morphometric analysis of Munda dam watershed reveals that this region is having low to moderate relief and oval shape geometry. Topographic and slope analysis are utilized to ascertain the appropriate sites for artificial recharge in watershed management. GIS and RS is very precise tool in this regard. Permeability of subsurface rocks is assessed by drainage texture analysis of the basin. This analysis is used for further hydrological analysis of the watershed.

Morphometric analysis confirms that drainage basin has dendritic type drainage pattern due to homogeneous subsurface lithology. These parameters also confirms that research area is tectonically stable and having permeable subsurface rocks. Slope is inversely proportional to infiltration. Topography and slope of the research area shows that this is good for suitable water resource management and construction of dam.

4. CONCLUSIONS AND LIMITATIONS

4.1 Conclusions

In this research, three decades land cover change and the hydrological analysis carried out for the Munda dam watershed. This analysis confirms that the research area is 4515 Km^2, having an oval shape geometry. Dendritic type drainages pattern in the watershed governs that this area is homogeneous in lithology and tectonically stable. It helps to comprehend several terrain parameters i.e., infiltration capacity, nature of the bedrock and runoff etc. very low value of stream frequency (0.3) and drainage density (0.18 km/km2) indicates high permeability rate of the subsurface rocks. Conversely, low to moderate relief and high slope reveals rugged topography which is appropriate for the construction of dam. These parameters show that recharge related measures and water storage plans can be analyzed for accurate water resource management. GIS and remote sensing is very precise and effective tool for watershed management to analyze terrain parameters, i.e., drainage pattern, nature of bedrock and etc., which helps to understand the health of landform and water resource planning and management.

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