

# Morphometric Analysis of Mhadei River Basin using SRTM Data and GIS

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**Abstract**—An attempt has been made to study drainage morphometry and its influence on hydrology of mhadei watershed, Goa. For detailed study used Shuttle Radar Topographic Mission (SRTM) data for preparing Digital Elevation Model (DEM), aspect grid and slope maps, Geographical Information System (GIS) was used in evaluation of linear, aerial and relief aspects of morphometric parameters. The study reveals that the elongated shape of the basin is mainly due to the guiding effect of thrusting and faulting. The lower order streams are mostly dominating the basin. The development of stream segments in the basin area is more or less affected by rainfall. The mean Rb of the entire basin is 4.2 which indicates that the drainage pattern is not much influenced by geological structures. Relief ratio indicates that the discharge capability of these watersheds is very high and the groundwater potential is meagre. These studies are very useful for planning rainwater harvesting and watershed management.

**Keywords**—GIS; Goa; Mhadei Watershed; Morphometric Analysis; SRTM Data.

**Abbreviations**—Basin Perimeter (P); Bifurcation Ratio (Rb); Circularity Ratio (Rc); Drainage Density (Dd); Drainage Texture (T); Elongation Ratio (Re); Form Factor (Ff); Stream Frequency (Fs); Stream Length (Lu); Stream Length Ratio (RL); Stream Number (Nu); Stream Order (U).

## I. INTRODUCTION

INDIA is endowed with a rich and vast diversity of natural resources. Water being one of them. However with the growing population and exploitation of natural resources on large scale, the future of these resources looms in darkness. Water resources in this case have suffered a major brunt. With the increasing demand of water, both economically and domestically, humans today have gone against the norms of nature to fulfill their needs, putting a question mark over the sustenance of these resources in future.

There is acute water storage in many parts of the world today, with consequences being grave in India. Several interstate river water disputes have arose in parts of India, where in the states are adamant on changing the courses of naturally occurring river by building dam on it. We have Andhra Pradesh and Maharashtra fighting over Krishna River, Tamil Nadu and Karnataka fighting over Cauvery River. The most recent one being the interstate dispute going on between Goa and Karnataka over the Mhadei River.

The state of Karnataka wants to divert the headwaters of the river Mhadei and its tributaries to its Malaprabha river basin, so as to meet the need of people of Karnataka bordering the eastern part of Goa, by constructing about six dams on it.

However the state of Goa has expressed deep concern over the ill effects of the proposed projects on the ecological balance, hydrological regime and economic development in the lower reaches of the catchment. Various ill-effects such as reduction in the discharge of the river, lowering of ground water level, submergence of land and forest, sea water intrusion, threats to the biodiversity and ecological balance of the Western Ghats, effects on the fishery industry, agriculture and other small scale industries located along the river Mhadei are anticipated.

Hence the drainage basin analysis is important in any hydrological investigation like assessment of groundwater potential, groundwater management, pedology and environmental assessment. Hydrologists and geomorphologists have recognized that certain relations are most important between runoff characteristics, and geographic and geomorphic characteristics of drainage basin systems. Various important hydrological phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the contributories etc [Rastogi & Sharma, 7].

Geology, relief and climate are the primary determinants of running water ecosystems functioning at the basin scale [Mesa, 23]. Detailed morphometric analysis of a basin is a

great help in understanding the influence of drainage morphometry on landforms and their characteristics.

To prepare a comprehensive watershed development plan, it becomes necessary to understand the topography, erosion status and drainage pattern of the region. For the purpose of detailed morphometric analysis SRTM data was used for preparing DEM map, slope and aspect maps. GIS was used in evaluation of Linear, Aerial and Relief morphometric parameters.

Using SRTM data and GIS techniques (Map Maker) is speed, precision, fast and inexpensive way for calculating morphometric analysis [Farr & Kobrick, 17; Smith & Sandwell, 19; Grohmann, 20; Grohmann et al., 25]. An attempt has been made to utilize SRTM data and the interpretative techniques of GIS to find out the relationships between the morphometric parameters and hydrological parameters.

## II. STUDY AREA

The Mhadei watershed covers an area of 899.46 km<sup>2</sup> in north Goa district, Goa and a part of Maharashtra. It falls between latitudes N 15°22'14.85'' and N 15°42'8.3'' longitudes E 74°02'25.6'' and E 74°25'00'' in the toposheets No. 48 I/2, 48 I/3, 48 I/6 and 48 I/7. The area being in the tropical zone and near the Arabian Sea, experiences warm and humid climate for most of the year. The average annual rainfall is approximately 325cms, most of which falls during southwest monsoon from June to September. The month of May is the hottest, with the day temperature reaching 35°C, with short cool season which lasts between mid-December and February.

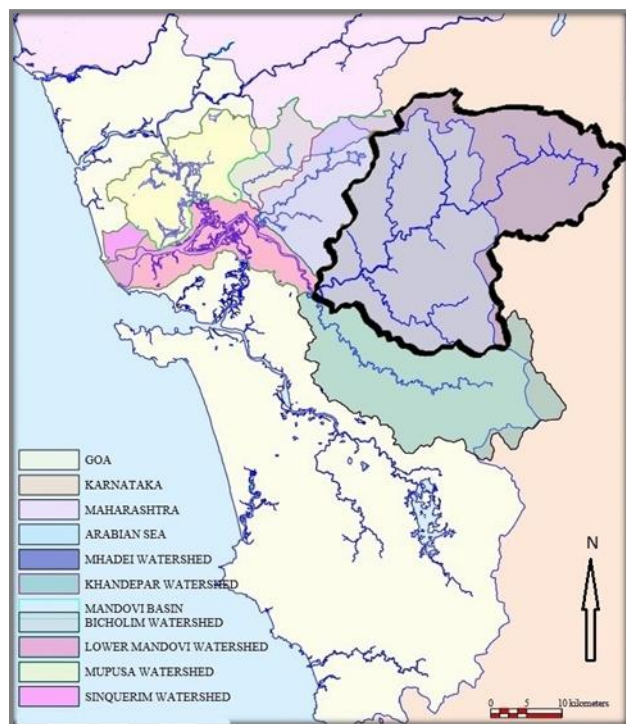


Figure 1: Location Map of Mhadei River Basin

### 2.1. Drainage

The type of drainage is dendritic, which is characterized by irregular branching of tributary streams in many directions, joining the main channel at considerably lesser than a right angle (Figure 2). The total area of the basin is 899.46 km<sup>2</sup>, and of the total 4829 streams recognized in the area, 80.92 percent area is of 1st order, 14.32 percent of the 2nd order, 3.54 percent area of the 3rd order, 0.97 percent area of the 4th order 0.16 percent area of the 5th order, 0.04 percent area by the 6<sup>th</sup> order and 0.02 percent area by the 7<sup>th</sup> order. In the watershed most dominant streams are the 1st order streams, followed by the 2nd order and then the 3rd, 4th 5<sup>th</sup> 6<sup>th</sup> and 7th order streams. The 1st 2nd and 3<sup>rd</sup> order streams are located in high elevation areas. In these areas runoff is more. It means there is less recharge taking place in these areas.

### 2.2. Geology and Structures

The Mhadei river basin dominantly comprises of low grade metamorphic rocks of the Goa group overlying the peninsular gneisses. A small region in the northern part of the basin consists of basalt of Cretaceous-eocene age. A thin layer of laterite covers the metasedimentaries. The western half of the basin experienced substantial structural disturbance as a result of this 4<sup>th</sup> order stream shows common trend NW-SE, also the rocks in the region have regional NW-SE trend.

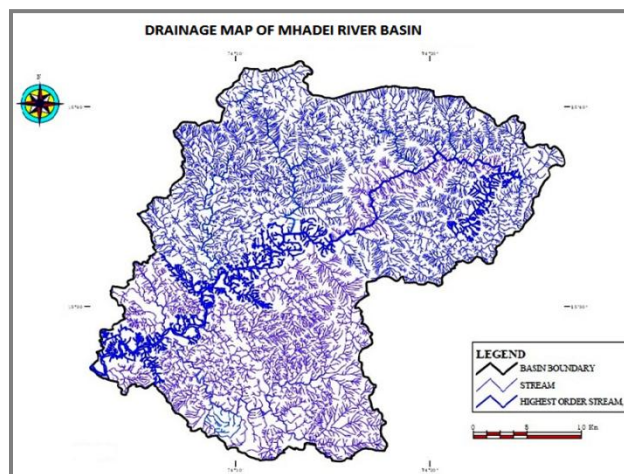


Figure 2: Drainage Network of Mhadei River Basin

## III. PROCEDURE AND DATA USED IN PREPARING IMAGES USING ARCVIEW AND STUDYING MORPHOMETRIC PARAMETERS OF MHADEI RIVER BASIN

The morphometric analysis of the Mhadei watershed was prepared based on published topographic maps on a 1:50,000 scale and also on SRTM data. The SRTM was an 11 day space shuttle mission in February 2000. SRTM has created an unparalleled data set of global elevations that is freely available for modeling and environmental applications. The version 3 processed (SRTM) 90 m Digital Elevation Model (DEM) for the entire globe was compiled by Consultative Group for International Agriculture Research Consortium for

Spatial Information (CGIAR-CSI) and made available to the public at [27]. Spatial Resolution data is 90/90 m, or one pixel represents a terrain cell 90/90 m in size. The SRTM DEM is a fast and inexpensive way for regional geomorphologic analysis. The data was taken from the <http://srtm.usgs.gov/data/obtaining.html> and then imported to Arcview. Based on the data, the slope and topographic elevation maps with contours for the watershed are prepared. The drainage network of the basin was scanned and digitized as available on toposheets (1:50,000). Based on the drainage order, the drainage channels were classified into different orders [Strahler, 4]. Basin parameters viz. area, perimeter, length, stream length, stream order were also calculated which were later used to calculate other parameters like bifurcation ratio, stream length ratio, stream frequency, drainage density, Drainage texture, basin relief, relief ratio, elongation ratio, circularity ratio, and form factor were evaluated with the help of established mathematical equations [Strahler, 4]. The morphometric parameters were divided into three categories: linear, aerial and relief aspects of the basin.

#### IV. RESULTS AND DISCUSSION

The DEM has been obtained with a pixel size of 90 m and has an area of 899.39 km<sup>2</sup> (Figure 3). Furthermore, it has been used to calculate slope and aspect maps. The total drainage area of Mhadei basin is 899.39km<sup>2</sup>. The development of drainage networks depends on geology, precipitation apart from exogenic and endogenic forces of the area. In general, the Mhadei river basin exhibits dendritic drainage pattern. However, most of the streams of 4<sup>th</sup> order in the western half of the basin show a common trend NW-SE resulting in trellis type drainage pattern. Based on the drainage orders, the Mhadei Basin has been classified as seven order basin to analyze linear, relief and aerial morphometric parameters as shown in Table 1 [Horton, 1; 2; Smith, 1950; Schumm, 1956, 1963; Hadley and Schumm, 1961; Strahler, 4; Sreedevi et al., 22; Mesa, 23].

Table 1: Linear, Relief and Aerial Morphometric Parameters

Parameters	Formulae	References
<b>Linear Aspects</b>		
Stream Order (U)	The smallest permanent streams are called “first order”. Two first order streams join to form a larger, second order stream; two second order streams join to form a third order, and so on. Smaller streams entering a higher-ordered stream do not change its order number.	Strahler [4]
Stream Length (Lu)	The average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio.	Horton [2]
Stream Length Ratio (RL)	$RL = Lu / Lu - 1$	Sreedevi et al., [22]
Bifurcation Ratio (Rb)	$Rb = Nu / Nu + 1$	Horton [1]
<b>Aerial Aspects</b>		
Drainage density (Dd)	$Dd = Lu / A$	Horton [2]
Drainage texture (T)	$T = Dd \times Fs$	Smith (1950)
Stream Frequency (Fs)	$Fs = \sum Nu / A$	Horton [2]
Elongation ratio (Re)	$Re = D / L = 1.128 \sqrt{A / L}$	Schumm (1956)
Circularity ratio (Rc)	$Rc = 4\pi A / P^2$	Strahler [4]
Form factor (Ff)	$Ff = A / L^2$	Horton [2]
<b>Relief Aspects</b>		
Relief	$R = H - h$	Hadley and Schumm (1961)
Relief Ratio	$Rr = R / L$	Schumm (1963)
Slope	$Sb = H - h / L$	Mesa [23]

#### 4.1. Linear Aspects

Computation of the linear aspects such as stream order, stream number for various orders, bifurcation ratio, stream lengths for various stream orders and length ratio are described below.

##### 4.1.1. Stream Number (Nu)

It is obvious that the total number of streams gradually decreases as the stream order increases with the application of GIS, the number of streams of each order and the total number of streams were computed (Table 2).

##### 4.1.2. Stream Order (U)

The streams of the Mhadei Basin have been ranked according to the Strahler’s [4] stream ordering system and the number of streams of each segment (Nu) of the order (U) is presented in Table 2. The details of stream characteristics confirm Horton’s first law [2] “Law of stream numbers” which states that the number of streams of different orders in a given drainage basin tends closely to approximate an inverse geometric ratio. It also confirms to Horton’s [1] “Law of stream length” which states that the average length of streams of each of the different orders in a drainage basin tends closely to approximate a direct geometric ratio. The variation in order and size of the tributary basins are largely due to physiographic and structural conditions of the region.

Application of this ordering procedure through GIS shows that the drainage network of the study area is of a seven order basin.

4.1.3. Basin Perimeter (P)

Basin perimeter is the length of watershed boundary that encloses the catchment area. It is used in conjunction with the basin area to give a measure of the departure of the basin from a true circle and in conjunction with relief to give a measure of the general steepness of the basin. The basin perimeter of the study area is 170.62km.

4.1.4. Basin Length

Basin length of the watershed is the distance between the watershed outlet and the farthest point on the perimeter of the watershed. The basin length of the study area is 47.1km.

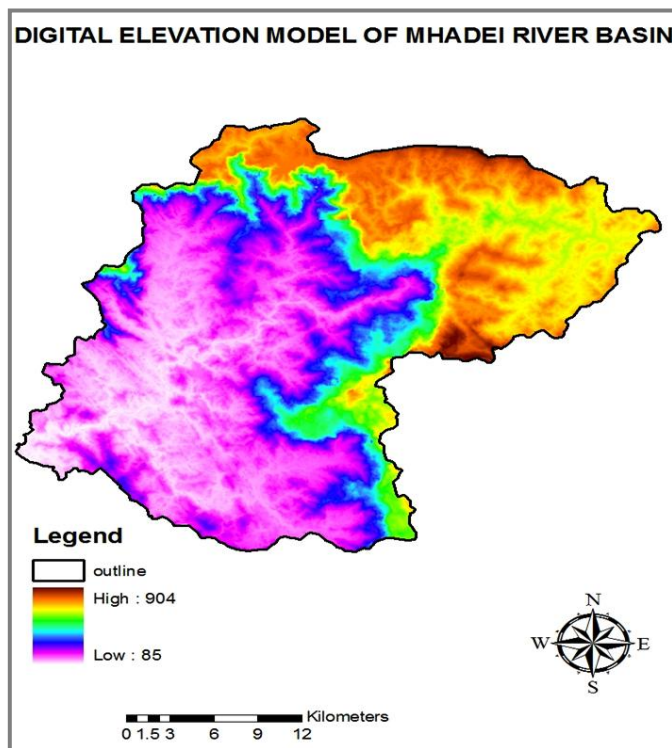


Figure 3: Digital Elevation Model of Mhadei River Basin

4.1.5. Stream Length (Lu)

The stream lengths of various orders have been measured on digitized map with the help of Map Maker gratis of GIS. The total stream length of each order (Lu) is computed. The maximum length of the total watershed is 2446.25km.

4.1.6. Stream Length Ratio (RL)

The length ratio (RL) is defined as the ratio of mean stream length (Lu) of segment of order u, to mean stream segment length (Lu-1) of the next lower order u-1. The values of the RL vary from 1.67 to 2.23 for the whole basin. It is noticed that the RL between successive stream orders of the basin vary due to differences in slope and topographic conditions [Rakes Kumar et al., 18; Sreedevi et al., 22]. The RL has an

important relationship with the surface flow discharge and erosional stage of the basin (Table 2).

4.1.7. Bifurcation Ratio (Rb)

The term ‘bifurcation ratio’ (Rb) was introduced by Horton [1] to express the ratio of the number of streams of any given order to the number in the next lower order. According to Strahler [4], the ratio of number of streams of a given order (Nu) to the number of segments of the higher order (Nu+1) is termed as the Rb. The mean Rb of the entire basin is 4.2. Usually these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern. Strahler [4] stated that an Rb range ‘3 to 5’ for watersheds of a geologic structure does not exercise a dominant influence on the drainage pattern.

Table 2: Linear and Aerial Aspects of Mhadei River Basin

Stream Order	Stream Number (Nu)	Stream Length for given Order (Lu) (km)	Average Stream Length of each order (km)	Stream Length Ratio (RL)	Bifurcation Ratio (Rb)
1	3908	1471	0.376		5.647
2	692	478.75	0.692	1.840	4.046
3	171	228.75	1.338	1.933	3.638
4	47	134.75	2.867	2.142	5.875
5	8	70.5	8.813	3.073	4.000
6	2	29.5	14.750	1.673	2.000
7	1	33	33	2.237	
	$\sum Nu=4$ 829	$\sum Lu=2$ 446.25		MEAN RL=2. 149	MEAN Rb= 4.20

4.2. Aerial Aspects

4.2.1. Basin Area

Basin area is the area in square kilometers of the watershed of the channel network as projected onto a horizontal plane. The basin area of mhadei River basin is 899.46km<sup>2</sup>.

4.2.2. Drainage Density (Dd)

The relationship between various environmental variables and Dd has been extensively analyzed. Several studies indicate the influence of climate on drainage density. According to Gregory and Gardiner (1975) and Gregory [6] showed that drainage density broadly increases with precipitation intensity index defined as the ratio between the maximum reported 24h rainfall and the average annual rainfall. Generally it is a positive correlation between Dd and rainfall parameters [Montgomery & Dietrich, 13; Tucker & Bras, 16]. Abrahams [9] showed that several climatic factors simultaneously affect drainage density in a complex way. Field observations generally show that high drainage density is favoured in arid regions with sparse vegetation cover as also in temperate and tropical regions subjected to frequent heavy rains [Melton, 3; Strahler, 4; Toy, 8; Morisawa, 10]. Slope gradient and relative relief are the main morphological factors controlling drainage density. Strahler [4] noted that

low Dd is favoured where basin relief is low, while high Dd is favoured where basin relief is high. The combined role of relief and climate on Dd has also been investigated by Kirkby [12], suggesting that the relationship between Dd and relief depends on the dominant hill slope processes. He predicts a positive relationship for semi-arid environments and an inverse one for humid climate. Gardiner [15] showed that greater drainage densities are generally associated with impermeable rocks. Dd is generally inversely related to hydraulic conductivity of the underlying soil. For steep slopes, an inverse correlation has been modeled by Montgomery & Dietrich [14]. Generally, Dd increases with decreasing infiltration capacity of the underlying rocks and/or decreasing transmissivity of the soil. Horton [2] defined Dd as the total length of channels (Lu) in a catchment divided by the area (A) of the catchment. The Dd for the whole basin is  $2.719 \text{ km/km}^2$ , Dd gives an idea about the physical properties of the underlying rocks in the study area. Low Dd occurs in the regions of highly resistant and permeable sub soil materials with dense vegetated cover and low relief; whereas high Dd is prevalent in the region of weak impermeable sub surface materials which are sparsely vegetated and show high relief in the study area.

#### 4.2.3. Drainage Texture (T)

According to Horton [2], drainage texture is the total number of stream segments of all orders per unit perimeter. The drainage texture (T) depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development (Smith, 1950). He classified drainage density into five different drainage texture. Dd less than 2 indicates very coarse, between 2 and 4 is relative to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage texture. Secondly, the soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. The texture of a rock is commonly dependent upon vegetation type and climate [Dornkamp & King, 5]. In simple terms T is the product of Dd and Fs. The T of the whole basin is 14.59, According to Smith classification T of the whole basin comes under coarse texture, as the value of Dd is less than 4.0.

#### 4.2.4. Stream Frequency (Fs)

The stream frequency (Fs) of a basin may be defined as the number of streams per unit area [Horton, 2]. The Fs of the whole basin is  $5.368 \text{ km/km}^2$ , it mainly depends on the lithology of the basin and reflects the texture of the drainage network.

#### 4.2.5. Elongation Ratio (Re)

Elongation ratio (Re) is defined as the ratio between the diameter of a circle with the same area as that of the basin (A) and the maximum length (L) of the basin. The elongation ratio ranges between 0.6-1.0 over a wide variety of climatic

conditions and geological formations. The elongation ratio is equal to 1 for a circular basin and approaches 0 for a straight line. The values in the range of 0.6-0.8 are generally associated with strong relief and steep grounds. The values around 1.00 are typically of regions of very low relief. Elongation ratio for the basin is estimated as 0.71, indicating that the relief of the area is very strong and with steep slope.

#### 4.2.6. Circularity Ratio (Rc)

The circularity ratio (Rc) has been used as an aerial aspect and is expressed as the ratio of basin area (Au) to the area of a circle (Ac) having the same perimeter as the basin [Strahler, 4]. It is affected by the lithological character of the basin. Rc values approaching 1 indicates that the basin shapes are like circular and as a result, it gets scope for uniform infiltration and takes long time to reach excess water at basin outlet, which further depends on the prevalent geology, slope and land cover. The ratio is more influenced by length, frequency (Fs) and gradient of various orders rather than slope conditions and drainage pattern of the basin. The Rc of the whole basin is 0.388.

#### 4.2.7. Form Factor (Ff)

Form Factor (Ff) is defined as the ratio of the basin area to the square of the basin length. Horton [2] proposed this parameter to predict the flow intensity of a basin of a defined area. The Ff of the whole basin is 0.41.

### 4.3. Relief Aspects

Evaluation of some of the relief aspects of the basin is discussed below.

#### 4.3.1. Relief

Relief is the maximum vertical distance between the lowest and the highest points of a basin. Basin relief is an important factor in understanding the denudational characteristics of the basin. The maximum height of the whole basin is 904 m and the lowest is 85 m. Therefore, the relief of the basin is 820 m.

#### 4.3.2. Relief Ratio

According to Schumm (1963) the relief ratio is the dimensionless height-length ratio equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal, the other passing through the highest point of the basin. The relief ratio of the mhadei Basin is 0.017. High values are characteristic of hilly regions low values are characteristic of piedplains and valley. In relation to stream slope, the inclinations of the ground surface are closely tied with its channel gradients and relief. In field it has been observed that there is a high degree of correlation between high relief and high drainage frequency, high stream frequency and high stream channel slopes which bring out high discharges in short duration [Gopalakrishna et al., 21]. These characteristic of basin indicates that the discharge capability of these water sheds is very high and the groundwater potential is meagre.

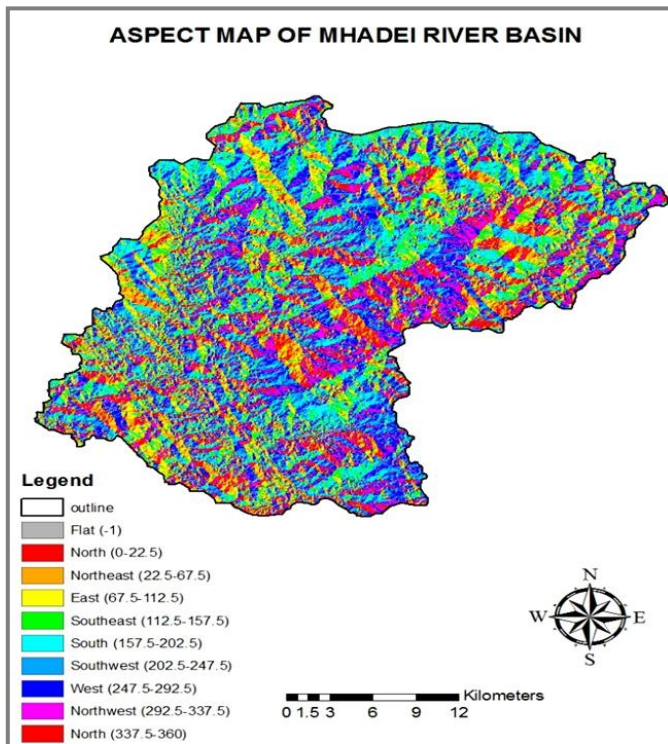


Figure 4: Aspect of Mhadei River Basin

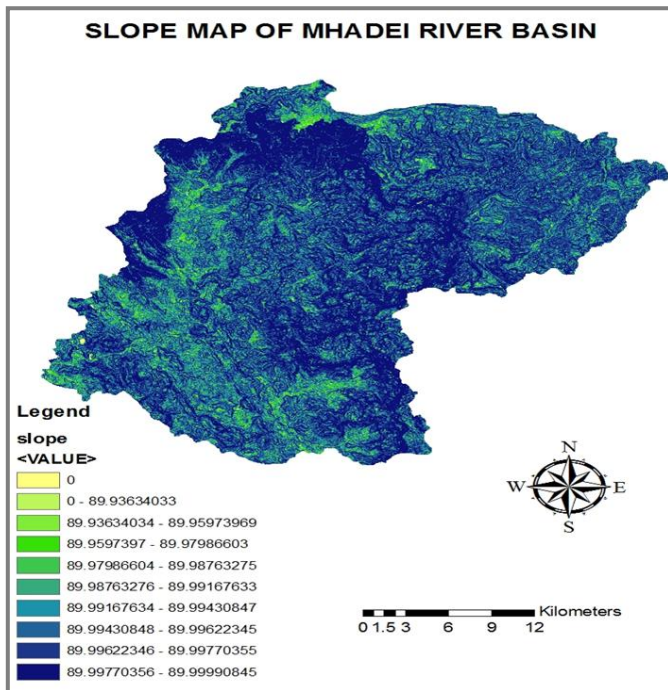


Figure 5: Slope of Mhadei River Basin

#### 4.3.3. Slope

Slope analysis is an important parameter in geomorphic studies. The slope elements, in turn are controlled by the climatomorphogenic processes in the area having the rock of varying resistance. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morphoconservation practices etc. [Sreedevi et al., 22]. In the study area slope map

was prepared based on SRTM data were converted into slope and aspect grids using Arcview method (ESRI, 2000). Aspect grid is identified as “the down-slope direction of the maximum rate of change in value from each to its neighbours” [Gorokhovich & Voustantiouk, 24] (Figure 4). Slope grid is identified as “the maximum rate of change in value from each cell to its neighbours, using methodology described in Burrough [11]. The Mhadei watershed area slope varies from 0° to 89.99° (Figure 5).

### V. IDENTIFICATION OF GROUNDWATER POTENTIAL ZONES USING MORPHOLOGICAL PARAMETERS

Drainage pattern of an area is very important in terms of its groundwater potentiality. It is the source of surface water and is affected by structural, lithological and geomorphological set up of an area (Schumm, 1956). The drainage pattern in the present study area is dendritic in nature. This may be due to more or less homogeneous lithology and structural controls. In the study area, high drainage density is observed over the hilly terrain with impermeable hard rock substratum, and low drainage density over the highly permeable sub-soils and low relief areas. Low drainage density areas are favourable for identification of groundwater potential zones. Slope plays a very significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is runoff and vice-versa.

### VI. CONCLUSION

Mhadei river basin has an area of 899.46Km<sup>2</sup> and basin perimeter of 170.62km. About 64% of the basin lies in Goa and 36% in Karnataka. Based on the drainage orders the Mhadei river basin classified as seventh order basin. Average bifurcation ratio of the basin is 4.2, which implies that the basin is not greatly distorted by geological factors. In general Mhadei river basin exhibit dendritic drainage pattern, most of the stream of 4<sup>th</sup> order in the western half of the basin shows a common trend NW-SE, suggesting the major structural control. The elongation ratio of the basin is 0.71 and the Circularity ratio is 0.388 indicating that the basin is moderately elongated and irregular in shape. The shape and size of the basin affects the total volume of rainwater received, the total runoff produced and thus the stream discharge. The Dd of Mhadei basin, reveal that the subsurface strata are permeable. This is a characteristic feature of coarse drainage as the density values are less than 5.0. The study reveals that the drainage areas of the basin are passing through an early mature stage of the fluvial geomorphic cycle. Lower order streams mostly dominate the basin. The development of stream segments in the basin area is more or less affected by rainfall. Relief ratio indicates that the discharge capability of these watersheds is very high and the groundwater potential is meager. These studies are very

useful for rainwater harvesting and watershed management plans. 1st and 2nd order streams are not useful for constructing check dams in the study area because these streams are situated on hilly terrains.

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