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Remote Sensing and GIS based Comparative Morphometric Study of Two Sub-watershed of Different Physiographic Conditions, West Godavari District, A.P.

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Abstract: In this present study, Remote Sensing (RS) and Geographical Information System (GIS) techniques were used to update drainage and surface water bodies and to evaluate linear, relief and aerial morphometric parameters of the two sub-watersheds viz. Jilugumilli and Regulapadu in the northern part of West Godavari District, Andhra Pradesh. The area of Jilugumilli and Regulapadu watersheds spread over about 110 & 80 sq. km respectively. The morphometric analysis of the drainage networks of Regulapadu and Jilugumilli sub-watersheds exhibit sub-dendritic and sub parallel drainage pattern. The variation in stream length ratio changes due to change in slope and topography. It was inferred from the study that the streams are in a mature stage in Regulapadu and Jilugumilli watersheds, which indicated the geomorphic development. The variations in bifurcation ratio values among the sub-watersheds are described with respect to topography and geometric development. The stream frequencies for both sub-watersheds exhibit positive correlation with the drainage density, indicating increase in stream population with respect to increase in drainage density. The Jilugumilli watershed has a coarse drainage texture and Regulapadu sub-watershed is a fine drainage texture in nature. In the present study an attempt has been made to analyse the morphometric analysis of two sub-watersheds under different physiographic conditions. Morphometric analysis is one of the essential analyses required for development and management of watershed.

Keywords: Remote Sensing (RS), Geographical Information System (GIS), Watershed and Morphometric Analysis.

INTRODUCTION

The advent of remote sensing technology and geographical information system (GIS) tools opened new path in water resource interpretation. Temporal data from remote sensing enables identification of groundwater aquifers and assessment of the changes, whereas, GIS enables user specific management and integration of multi thematic data. These techniques are in use for natural resources planning and management for the past few decades. GIS and remote sensing applications have been used by many scientists in mapping groundwater potential zone, monitoring of command area, rainfall-runoff modeling and many other applications (Das, 1997; Pal, 1999).

Morphometric analysis provides quantitative description of basin geometry to understand initial slope or inequalities in the rock hardness, structural controls, recent diastrophism, geological and geomorphic history of a drainage basin (Strahler, 1964). Watershed management is the process of formulation and carrying out action involving modification of the natural system if watershed to achieve specified objectives. It implies proper use of land and water resources. Remote sensing and GIS techniques have emerged as powerful tool for watershed management. The quantitative analysis of drainage system is an important aspect for characterization of a watershed (Strahler, 1964). Earlier studies indicated a relationship between cummulative stream length and stream order and also bifurcation ratio, drainage density, texture ratio and relief ratio for assessing the level of soil erosion characteristics was in a watershed (Nautiyal, 1994, Chaudhary and Sharma, 1998). Mishra et al (1984) studied the effect of different topo elements such as area, drainage density, form factor etc. with respect to sediment production rate of the sub-watersheds in the upper Damodar valley and concluded that increase of form factor reduces the sediment production rate.

In the present study, the remote sensing & GIS techniques were used to analyses drainage & surface water bodies and to evaluate linear, relief and aerial morphometric

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parameters of the two sub-watersheds and also to advocate scientific application of the results for natural hazard vulnerability assessment which is a major environmental problem of the study area. Natural hazards in the region cause great loss to life and property and pose serious threat to the process of development have far-reaching economic and social consequences. In view of this, the proposed work may fill up the gap and thus provide great scientific relevance in the field of natural hazard and risk management in other mountainous parts of the world. Application of remote sensing and GIS comparative study of two sub-watersheds have clearly brought out evaluation of morphometric analysis of the two sub-watersheds.

STUDY AREA

The watersheds are located between in West Godavari District, Andhra Pradesh. Regulapadu sub-watershed is located in between 16°7' and 17°15' N Latitudes and 81°0' and 81°9' E Longitudes and covered by SOI toposheet 65 G/7 on 1:50,000 scale. The Jilugumilli sub-watershed lies between 17^0 16' and 24' 30" N Latitudes and 81^0 28' and 81^0 22' E Longitudes falls in SOI toposheet 65 G/4. The total extents of Jilugumilli and Regulapadu sub-watersheds are 110 sq km and 80 sq km respectively. The location map of the study area is represented in Fig.1. The Jilugumilli sub-watershed is on a relatively flat terrain with isolated hills in the North West part of study area. The drainage of the watershed joins the Yerrakalava tributary in the area. Rangvarigudem Reserved Forest (R.F) is located in West, Darbhagudem (R.F) in the East, and Jilugumilli R. F is located in central part of the sub-watershed. The Regulapadu sub-watershed is occupied mostly by high relief hilly terrain. The hills namely Mamidi konda at North, Arakonda in the West, Bullikonda in the South, Potukonda in the Northeast. The Kollumamidi protected forest is located in North and Koppalle R.F in the East of sub-watershed. Bineru vagu and Kalugu vagu drains the sub-watershed.

METHODOLOGY

The survey of India Toposheets, IRS P6 LISS-III (FCC) hard copies on 1:50,000 scale of 19-3-2005 and digital data acquired on 19-11-04 were used in the present study. Image interpretation was made with the aid of image characteristics such as tone, texture, shape, size, pattern and association along with sufficient ground truth and local knowledge were used in the preparation of final maps using Arc/Info (7.2.1 version) GIS software. The attributes were assigned to create the digital data base. The morphometric analysis is carried out by measuring of linear, aerial and relief aspects of the sub-watershed.

PHYSIOGRAPHICAL SETUP

The continued interaction between different elements like atmosphere, lithology, structure etc. plays a vital role in the evolution of different soils and geomorphic features. It also helps in determining water balance of a watewrshed for development and management of water resources in it.

HYDROMETEOROLOGY

The climate is moderate both in winter and summer seasons in delta area. The maximum and minimum temperatures recorded in the watershed t are 48°C to 19°C

Fig.1. Location map of the Study Area

respectively. The maximum temperature is usually recorded in the months of April and May. The air is humid through out the year, more at coastal regions and less towards the upland areas. The period from February to May is the driest part of the year and relative humidity in the afternoon ranges from 45% to 55%. The wind varies widely in direction and is normally East-South-East in the winter seasons and West-South-West during monsoons. The prevailing monsoon winds during April to September come from West. The winds during September to March blow from Northeast, East, and Southeast direction. The total average annual rainfall of the district is about 1243 mm. Majority of the rainfall is received from Southwest monsoon. The southwest monsoon contributes 67.99% and Northeast monsoon contributes 21.33% of the total annual rainfall.

TOPOGRAPHY AND SLOPE

The sub-watersheds and its environs are located having a matured topography reflected by undulating terrain with hills, knolls and inselbergs of Eastern Ghats and composed of relatively weathered and unweathered rocks. The moderately weathered zones occupy the low lying areas. The maximum and minimum elevations of Jilugumilli and Regulapadu sub-watersheds are 344 & 100 m and 707 & 501 m above MSL respectively. Slope is one of the most important terrain characteristics and play a vital role in geomorphological and run-off processes, soil erosion and land use planning. The general slope of Regulapadu sub-watershed is towards Southwest. The major portion of the sub-watershed exhibits steep to very steep slope. The Jilugumilli sub-watershed generally slopes towards Southeast and major portion of the watershed is nearly level to very gently sloping terrain.

GEOLOGY AND GEOMORPHOLOGY

The Jilugumilli sub-watershed is covered by Gollapalli sandstone and Kota formation of East coast Gondwanas (Fig.2). The Regulapadu sub-watershed is occupied by Khondalite formations of Archean age. The sub-watersheds under study are traversed by fractures/ lineaments which are occurring as vertical to sub-vertical and horizontal to sub-horizontal deep seated fractures. The fractures are generally associated with topography depressions and controlling drainage network in the area. The fractures in the area generally trend in NE-SW, N-S, and NW-SE directions. The sub-watersheds are mostly covered by red loamy soils. The thickness of the soil cover in Jilugumilli sub-watershed is more than that of Regulapadu sub-watershed. The Regulapadu sub-watershed is mostly occupied by structural hills trending in NE-SW direction and as mostly runoff zones. Intermontane valleys covering small areas are situated in the central part of the sub-watershed. The Jilugumilli sub-watershed is mostly covered by Pediplain with moderate weathering and Pediplain with

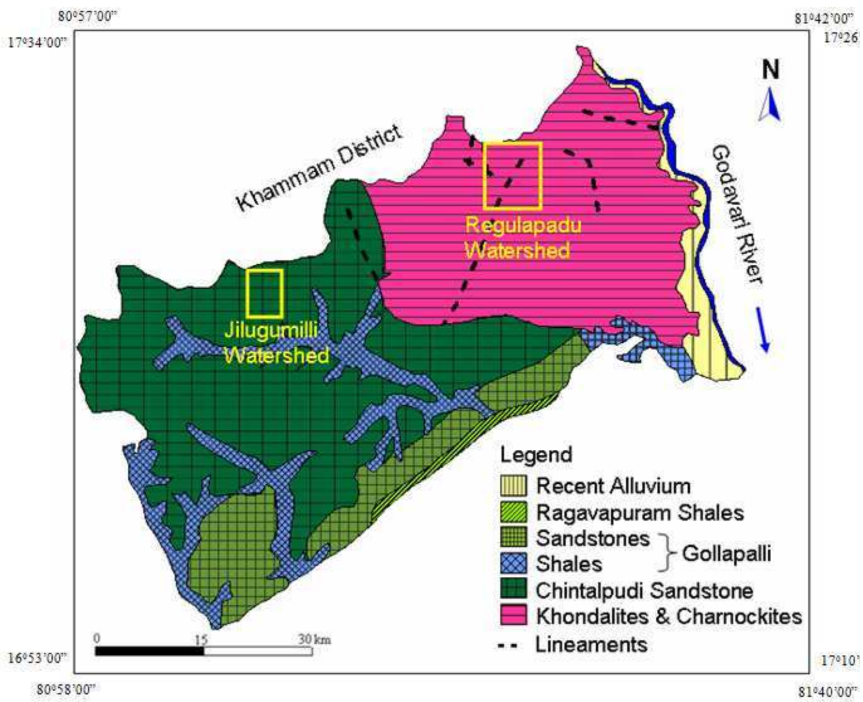

Fig.2. Geology map of the study area

shallow weathering. Isolated structural hills and inselbergs are observed in the NW part. The entire Regulapadu sub-watershed is occupied by degraded forest. Built up land in the form of small hutments exist in the area. The Jilugumilli sub-watershed is mostly occupied by agriculture land of cropland and plantations.

DRAINAGE AND SURFACE WATER BODIES

The study areas are drained by numerous first, second, third and fourth order streams mostly originating in the northern part and flowing towards south. The Regulapadu sub-watershed is drained by Bineru vagu and its tributaries(Fig. 3). No tanks have been noticed across the drainage in the sub-watershed. The drainage in the sub-watershed represents sub-dendritic pattern (Fig. 4). The drainage in the Jilugumilli sub-watershed is intercepted by presence of 65 tanks particularly in the northern and southern parts. The drainage in the sub-watershed represents sub-parallel pattern. The drainage in the two sub-watersheds is controlled by the geological structures like lineaments, dykes and fractures. All the streams are ephemeral in nature in both the sub-watersheds and mostly fed by SW monsoon rains.

MORPHOMETRIC ANALYSIS

Systematic description of the geometry of a drainage basin and its stream-channel system requires measurement of linear aspects of the drainage network, aerial aspects of the drainage basin, and relief aspects of channel network and contributing ground slope.

Drainage Analysis is also known as fluvial morphometry which provides information regarding the factors which control in the development of the drainage. Morphometric analysis means measurement of shape of the watershed, area of the watershed and the length of the stream. On the basis of projection of the system to horizontal plane, the linear properties such as length, area, arrangement etc. are calculated. This type of study is known 'planimetric' which means measurement in a single plane.

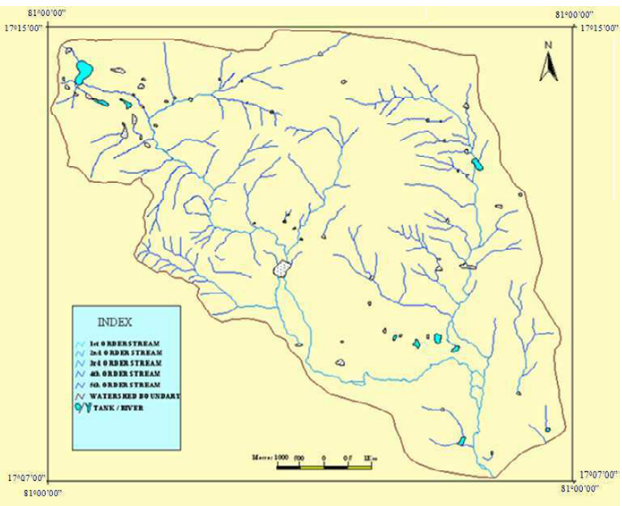

Fig.3. Drainage and Surface water bodies map of the Jilugumilli Sub-watershed

Stream Order (Nu)

The designation of stream orders is the first step in drainage watershed analysis and is based on a hierarchic ranking of streams. In the present study, ranking of streams has been carried out based on the method proposed by Strahler (1964). The order wise stream numbers, area and stream lengths of both watersheds (Table 1). It is observed in the present study that the maximum number of stream was in lower order. It is also noticed that there is a decrease in stream frequency as the stream order increases in both sub-watersheds. Drainage patterns of work stream network from watersheds was mainly dendritic type which indicates the homogeneity in texture and lack of structural control. The pattern is characterized by a tree like or fernlike pattern with branches that intersect primarily at acute angles.

Stream Length (Lu)

Stream length is one of the most significant hydrological features of the watershed as it reveals surface runoff

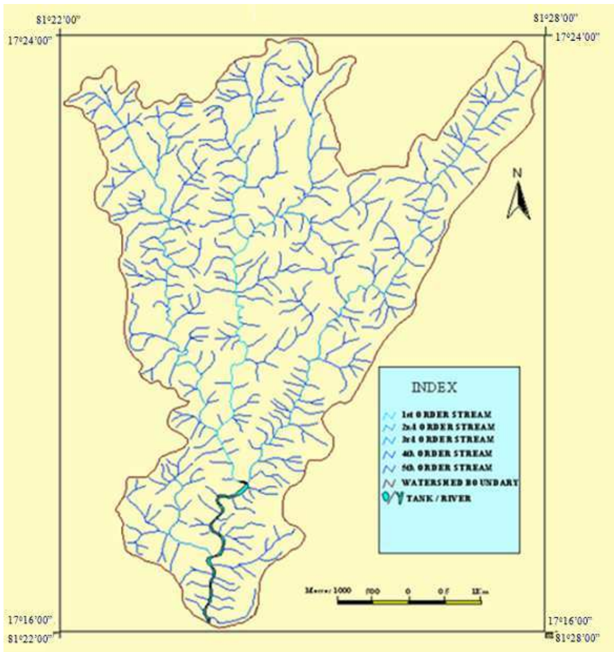

Fig.4. Drainage and Surface water bodies map of the Regulapadu Sub-watershed

Table.1. Results of Morphometric analysis showing basin area, order/number of stream, stream length and perimeter of two sub-watershed.

Sub-watershed Name	Stream order	Basin Area (Sq. km)	No. of streams (Nu)				Stream Length in km (Lu)				Perimeter (p) (km)
			I	II	III	IV	I	II	III	IV	
Jilugumilli	IV	110	141	32	7	7	91	29.7	29	16.8	47.3
Regulapadu	IV	80	375	80	15	7	171.7	44.4	18	9.4	56.6

Table 2. Results of Morphometric analysis showing mean stream length, stream length ration, relief ratio and basin length of two sub-watershed

Sub-watershed Name	Mean Stream Length in km (Lsm)				Stream Length Ratio (RL)			Relief Ratio (Rh)	Basin (km) Length
	I	II	III	IV	II/I	III/II	IV/I		
Jilugumilli	0.645	0.928	4.142	2.4	0.3263	0.9761	0.5793	10.4024	23.456
Regulapadu	0.4578	0.555	1.2	1.3428	0.2585	0.4054	0.5222	11.2078	18.38

characteristics streams of relatively smaller lengths have characteristics areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flat gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The number of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of GIS soft-wares. The stream length (Lu) has been computed based on the law proposed by Horton (1945) for both watersheds. The lengths of stream segments of various orders in the two sub-watersheds(Table 1). The change may indicate flowing of streams from high altitude, lithological variation and moderately steep slopes (Singh and Singh, 1997).

Mean Stream Length (Lsm)

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler 1964),. The mean stream length (Lsm) has been calculated by dividing the total stream length of order 'u' and number of streams of segment of order 'u',(Table 2). Mean stream length (Lsm) of any given order is greater than that of the lower order and less than that of its next higher order in both the two sub-watersheds which might be due to variations in slope and topography.

Stream Length Ratio (RL)

Stream length ratio (RL) may be defined as the ratio of the mean length of the one order to the next lower order of stream segment.

$$\text{Stream Length Ratio } RL = Lu / Lu - 1$$

Where, RL = Stream Length Ratio, Lu = Total stream length of the order 'u'. Lu – 1 = Total stream length of its next lower order.

Horton's law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geometric series with streams length increasing towards higher order of streams. The RL values between streams of different order in the both the sub-watersheds reveals that there are variations in slope and topography. The stream length ratio of both the sub-watershed(Table 2).

Relief Ratio (Rh)

The relief ratio, (Rh) is ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line is termed as relief ratio (Schumm, 1956).

$$\text{Relief Ratio } Rh = H / Lb$$

Where, Rh = Relief Ratio, H = Total relief (Relative relief) of the basin in Kilometers. Lb = Basin length

The Rh normally increases with decreasing drainage area and size of sub-watersheds of a given drainage basin (Gottschalk, 1964). The values of Rh of Jilugumilli and Regulapadu sub-watersheds are 10.4024 to 11.2078 respectively (Table 2). It is noticed that high values of Rh indicate steep slope and high relief (m), while the lower values may indicate presence of basement rocks that are exposed in the form of small ridges and mounds with lower degree of slope.

Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) is defined as the ratio of number of the stream segments of given order to the number of segments of the next higher order (Schumn, 1956).

Table 3. Results of Morphometric analysis showing bifurcation ratio, drainage density, stream frequency and drainage texture ration of two sub-watershed

Sub-watershed Name	Bifurcation Ratio (Rb)			Mean Bifurcation Ratio (Rbm)	Drainage Density (D) (km/ sq.km)	Stream Frequency (Fs)	Drainage Texture Ratio (Rt)
	I/II	II/III	III/IV				
Jilugumilli	4.4062	4.5714	1	3.3258	1.1129	1.7	3.9534
Regulapadu	4.6875	5.333	2.1428	4.0544	3.0437	5.9625	8.4275

$$\text{Bifurcation Ratio } Rb = Nu / Nu + 1$$

Where, Rb = Bifurcation Ratio, Nu = Total no. of stream segments of order 'u'. Nu + 1 = Number of segments of the next higher order.

Strahler (1957) demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. Bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds in which the geologic structures do not distort the drainage pattern (Strahler, 1964). The mean bifurcation ratio of Jilugumilli & Regulapadu sub-watersheds are 3.3258 and 4.0544 respectively (Table 3). This indicates that the drainage pattern has not been distorted because of structural disturbances.

Drainage Density (D)

Horton (1932) has introduced drainage density (D) into American hydrologic literature as an expression to indicate the closeness of spacing of streams. It is defined as the total length of streams of all orders per drainage area.

$$\text{Drainage Density } D = Lu / A$$

Where, D = Drainage Density, Lu = Total stream length of all orders. A = Area of the Basin (sq km).

The drainage density indicates closeness of spacing of channels, thus providing a quantitative measure of average length of stream channel for entire watershed. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of high resistant and high permeable subsoil material under dense vegetative cover, and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahaler, 1964). The drainage density values of Jilugumilli and Regulapadu sub-watersheds are 1.1129 and 3.0437 km/ sq.km respectively (Table 3). The low drainage density in Jilugumilli sub-watershed indicate that the region has highly permeable subsoil and dense vegetative cover. High drainage density in Regulapadu sub-watershed may be attributed to impermeable subsurface materials and mountainous relief.

Stream Frequency (Fs)

Horton (1932) introduced stream frequency (Fs) and defined as stream frequency which is the total number of stream segments of all orders per unit area.

$$\text{Stream Frequency } (Fs) = Nu / A$$

Where, Fs = Stream Frequency, Nu = Total no. of streams of all orders. A = Area of the Basin (sq km).

The Fs for the Jilugumilli and Regulapadu sub-watersheds is 1.7 and 5.9625 respectively (Table 3). It is noted that the Fs exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density.

Drainage Texture Ratio (Rt)

Drainage texture ratio (Rt) is one of the important concepts of geomorphology which means the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. According to Horton (1945), Rt is the total number of stream segments of all orders per perimeter of that area.

$$\text{Drainage Texture } (Rt) = Nu / P$$

Where, Rt = Drainage Texture, Nu = Total no. of streams of all orders, P = Perimeter (km). The drainage textures values of Jilugumilli and Regulapadu sub-watersheds are 3.9534 and 8.4275 respectively (Table 3). The Jilugumilli sub-watershed has a coarse texture and where as Regulapadu sub-watershed has very fine texture.

Form Factor

The form factor (Rf) may be defined, as the ratio of basin area to square of the watershed length (Horton 1932).

$$\text{Form Factor } (Rf) = A / Lb^2$$

Where, Rf = Form Factor, A = Area of the watershed (sq km). Lb^2 = Square of watershed length. The Rf value of 0 indicates a highly elongated shape and the Rf of 1.0, a circular shape with high peak flows for short duration. But for elongated watershed with low Rf maintain a flat peak flows for longer duration. The Rf values of Jilugumilli and Regulapadu sub-watersheds are 0.1999 and 0.2368 respectively (Table 4). This indicates that both the Jilugumilli and Regulapadu sub-watersheds are elongated in shape with lower Rf.

Circularity Ratio (Rc)

It is the ratio of the area of the basin to the area of a circle having the same circumference as the perimeter of the basin ((Miller, 1953)

$$\text{Circularity Ratio (Rc)} = 4 * Pi * A / P^2$$

Where, Rc = Circularity Ratio, Pi = 'Pi' value i.e., 3.14. A = Area of the Basin (sq km), P^2 = Square of the Perimeter (km)

The values of Jilugumilli and Regulapadu sub-watersheds are 0.6175 and 0.3136 respectively Rc (Table 4).

Elongation Ratio (Re)

Schumm (1956) defined elongation ratio (Re) as the ratio between the diameter of the circle of the same area as the drainage basin and the maximum length of the basin.

$$\text{Elongation Ratio (Re)} = 2 v (A / Pi) / Lb$$

Where, Re = Elongation Ratio, A = Area of the Basin (sq km). Pi = 'Pi' value i.e., 3.14, Lb = Basin length

It is a very significant index in the analysis of watershed shape which helps to give an idea about the hydrological character of drainage in the watershed. Values near to 1.0 are typical of regions of very low relief (Strahler, 1964). The Re values for Jilugumilli and Regulapadu sub-watersheds are 0.5042 to 0.5491 respectively (Table 4). The lowest values of Re indicates less elongated shape of the watersheds with high relief and steep slope.

Length of Overland flows (Lg)

The length of overland flow (Lg) approximately equals to half of the reciprocal of drainage density (Horton, 1945).

Table 4. Results of Morphometric analysis showing length of overland flow, form factor, circularity ration and elongation ratio of two sub-watershed

Sub-watershed Name	Length of over land flow (Lg)	Constant of channel maintenance (C)	Form Factor (Rf)	Circularity Ratio (Rc)	Elongation Ratio (Re)
Jilugumilli	0.4492	0.8985	0.1999	0.6175	0.5042
Regulapadu	0.1642	0.3265	0.2368	0.3136	0.5491

$$\text{Length of Overland flow } Lg = 1 / D * 2$$

Where, Lg = Length of Overland flow, D = Drainage Density. The computed values of Lg for Jilugumilli and Regulapadu sub-watersheds are 0.4492 and 0.1642 respectively given in Table 4.

Constant of Stream Maintenance (C)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. Thus

$$\text{Constant of stream maintenance (C)} = 1/ D$$

This constant, in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the scale of the land-form units increases. Specifically, the constant C provide information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value C of Jilugumilli and Regulapadu sub-watersheds are 0.8985 to 0.3265 respectively (Table 4). It means that on an average 0.8 sq.ft surface is needed in Jilugumilli sub-watershed and 0.3 sq ft surface is needed in Regulapadu sub-watershed for creation of one linear foot of the stream channel.

SUMMARY AND CONCLUSIONS

Remote sensing and GIS application used in the delineation and update of the drainage in the present study and these updated drainage have been used for the morphometric analysis. The morphometric analysis a drainage networks of the Regulapadu and Jilugumilli sub-watersheds exhibit the sub-dendritic and sub-parallel drainage pattern respectively. The variation in stream length ratio might be due to changes in slope and topography. It is inferred from the study that the streams have created a mature stage in Regulapadu and Jilugumilli sub-watersheds, which is an indication of good geomorphic development. The variation of bifurcation ratio in the sub-watersheds is ascribed to the difference in topography and geometric development. The stream frequencies in the both sub-watersheds exhibit positive correlation with the drainage density, indicating the increase in stream population with respect to increase in drainage density. The Jilugumilli sub-watersheds has a related to coarse texture and Regulapadu sub-watershed has a very fine texture. Elongation ratio of the both sub-watersheds represent a less elongated in shape. The Rf values indicates that both the Jilugumilli and Regulapadu sub-watersheds have elongated in shape. The Remote Sensing and GIS techniques have become indispensable management tool for efficient management of natural resources even at micro-watershed level. A holistic approach of this natural resource analysis further provides in optimizing the use of available resources to meet the growing demands of food, fodder and fuel wood on sustainable basis without affecting the ecosystems in the two sub-watersheds.

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