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Prioritisation of miniwatersheds based on Morphometric analysis using GIS

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ABSTRACT

In the present study, the eighteen miniwatersheds of Kadam watershed of Middle Godavari sub basin (G-5) have been prioritized using GIS based on morphometric analysis. The highest Bifurcation ratio is found to be 11.95 for 4E3C5a. The Maximum values of Circularity ratio of 0.642 and Drainage density of 3.510 have been found in Lothuvara miniwatershed. The Maximum values of Stream frequency of 7.25 and Texture ratio of 15.81 have been found in Dorlavagu miniwatershed. Ranks have been assigned to each parameter based on their value with highest value as I rank and the rank values of all parameters have been cumulated to obtain compound parameter. Priorities are arrived at based on compound parameter values. The miniwatershed with the lowest compound parameter value is given the highest priority and vice versa. Allampalli vagu (4E3C4f), Gangapuram vagu (4E3C4h) and Batkamma vagu (4E3C4g) miniwatersheds have been found to be under high priority.

Keywords: Morphometric analysis, ArcGIS, Watershed delineation, Watershed atlas.

1. Introduction

Watersheds are natural hydrological entities that cover a specific aerial expanse of land surface from which the rainfall runoff flows to a defined drain, channel, stream or river at any particular point. The terms region, basin, catchment, watershed etc are widely used to denote hydrological units. Even though these terms have similar meanings in popular sense, technically they are different. Size of a watershed is governed by the size of the stream occupied by it. Size of the watershed is of practical importance in development programmes (CGWB). Watersheds have been classified into different categories based on area viz Micro Watershed (0 to 10 ha), Small Watershed (10 to 40 ha), Mini Watershed (40 to 200 ha), Sub Watershed (200 to 400 ha), Watershed (400 to 1000 ha) and Sub basin (above 1000 ha). The watershed has emerged as the basic planning unit of all hydrologic analyses and designs. Watersheds considered in engineering hydrology vary in size from a few hectares in urban areas to several thousand square kilometers for large river basins. Each watershed shows distinct characteristics, which are so much variable that no two watersheds are identical. All the characteristics affect the disposal of water. Certain physical properties of watersheds significantly affect the characteristics of runoff and as such are of great interest in hydrologic analyses. The order, pattern, and density of drainage have a profound influence on watershed as to influence runoff, infiltration, land management etc. It determines the flow characteristics and thus erosional behaviour [Murthy, 2000]. Morphological characteristics like stream order, drainage density, aerial extent, watershed length and width, channel length, channel slope and relief aspects of watershed are important in understanding the hydrology of the watershed. A detailed analysis of the drainage network in a watershed can provide valuable information about watershed behaviour which will be useful for further hydrological analysis.

The Geographic Information System (GIS) has unique features to relate to the point, linear and area features in terms of the topology as well as connectivity [Murali Krishna, 2006]. Increased interest is being directed to the mapping of hydro-geomorophological characteristics using GIS and Remote Sensing techniques [Epstein et al., 2002]. Walsh (1998) described the applications of remote sensing and GIS for geomorphic research. Watershed boundary map and Drainage network map were prepared and utilized for computation of the morphological characteristics of the watershed using Arc GIS 9.3. In this study, GIS has been used to collect, digitize, organize, model and analyze data on watershed delineation and to create a geo-database to incorporate physical, environmental and socio-economic information on the watersheds. The specific objective of this paper is to develop an atlas of Kadam watershed and carry out morphometric analysis at miniwatersheds level. Morphometric analysis is significant tool for Prioritization of Micro-watersheds even without considering the soil Map [Biswas et al 1999]. Earlier studies indicated a relationship between cumulative stream length and stream order and also bifurcation ratio, drainage density, texture ratio and relief ratio for assessing the level of soil erosion [Nautiyal, 1994, Chaudhary and Sharma, 1998]. Misra *et al.* (1984) studied the effect of different topo elements such as area, drainage density, form factor etc. with the sediment production rate of the subwatersheds in the upper Damodar valley and concluded that the increase of from factor reduces sediment production rate.

2. Study area

The study area is a part of middle Godavari (G-5) sub basin of River Godavari which lies between latitudes $17^0 04'$ and $18^0 30'$ North and longitudes $77^0 43'$ and $79^0 53$ East. The middle Godavari sub basin has a catchment area of 35723 km^2, which constitutes 11.38% of the total basin area and entirely lies in the State of Andhra Pradesh. The study area of Kadam reservoir catchment lies between latitudes $19^0 05'$ and $19^0 35'$ N and longitudes $78^0 10'$ and $78^0 55'$ E. The areal extent of the study area is 2617.56 km^2, which constitutes 7.4% of the sub basin area. The climate in the study area is semi arid with an average annual rainfall of 765mm. The minimum and maximum temperatures range from 1.8 to 31.5^{o}C and 7.4 to 43.6^{o}C respectively. Daily mean relative humidity ranges from 10 to 100%. The highest wind speed 136 km/hr.

3. Methodology

The topographic maps namely 56-I 3, I 6, I 7, I 8, I 10, I 11, I 12, I 14, I 15 & I 16 on a scale of 1:50,000 were collected from Survey of India, Uppal, Hyderabad. The collected topographic sheets were scanned, geo-referenced and rectified using Arc Map of Arc GIS 9.3. Further, the rectified maps were projected and merged together as a single layer. The present study area of Kadam watershed boundary has been delineated from the toposheets. Stream network of the study area is digitized from toposheets of 1:50000 scale. Kadam watershed is divided into two subwatersheds 4E3C4 and 4E3C5 as per watershed atlas of India (Plate No.4). Further, in the present study, 4E3C4 and 4E3C5 subwatersheds have been delineated into eleven and seven miniwatersheds respectively.

One of the first attributes to be quantified was the hierarchy of stream segments according to an ordering classification system based on ranking of streams proposed by Strahler (1964)[9]. In this system, channel segments were ordered numerically from a stream's Headwaters to a point somewhere down stream. Numerical ordering begins with the tributaries at the stream's headwaters being assigned the value 1. A stream segment that resulted from the joining of two 1st order segments was given an order of 2. Two 2nd order streams form a 3rd order stream, and so on. The trunk stream through which all discharge of water passes is therefore the stream segment of the highest order. The number of stream segments present in each order along with their lengths is recorded in the topology built by GIS. Stream network maps for each of eleven miniwatersheds of 4E3C4 and seven miniwatersheds of 4E3C5 have been clipped in GIS environment using Analysis tool. Important watershed morphometric parameters such as Area of watershed, perimeter, Bifurcation ratio, Elongation ratio, Circulatory ratio, Form factor, Stream order, Drainage density, Average slope of watershed, Main stream channel slope have been computed in GIS environment. Ranks have been assigned to each parameter based on their value with highest value as I rank and the rank values of all parameters have been cumulated to obtain compound parameter. Priorities are arrived at based on compound parameter values. The compound parameter values are calculated and prioritization rating of eighteen miniwatersheds in Kadam reservoir catchment has been carried out. The miniwatershed with the lowest compound parameter value is given the highest priority, while highest compound parameter value is given the lowest priority. Finally, a map representing the prioritized miniwatersheds has been prepared in GIS environment.

4. Results and discussions

The topographic maps namely 56-I 3, I 6, I 7, I 8, I 10, I 11, I 12, I 14, I 15 & I 16 on a scale of 1:50,000 were collected, scanned, geo-referenced, rectified, projected and merged in GIS environment. Kadam watershed map, stream network map, subwatershed boundaries map and miniwatersheds boundary map have been prepared using Arc GIS 9.3. The Kadam watershed has been divided into two subwatersheds namely 4E3C4 and 4E3C5 in the watershed atlas of India (Plate No.4). 4E3C4 subwatershed has further been delineated in GIS environment into eleven mini watersheds namely 4E3C4a (Sikkumanu River), 4E3C4b (Gajjala Vagu), 4E3C4c (Dorla Vagu), 4E3C4d (Lothuvara), 4E3C4e (Peddamma Vagu), 4E3C4f (Allampalli Vagu), 4E3C4g(Batkamma Vagu), 4E3C4h(Gangapuram Vagu), 4E3C4i (Kadam Reservoir), 4E3C4j (Balli Vagu) and 4E3C4k (Palukeru Vagu). Similarly, 4E3C5 subwatershed has been delineated into seven miniwatersheds namely 4E3C5a (Kadam River), 4E3C5b (Gundi Vagu), 4E3C5c (Ragidobanala), 4E3C5d (Datki Vagu), 4E3C5e (Wankedi), 4E3C5f (Kadam Upper right) and 4E3C5g (Pedda Vagu). The miniwatershed 4E3C5a (Kadam River) has been found to be of highest perimeter with 193.867 km and 4E3C4j (Balli Vagu) miniwatershed was found to be with minimum perimeter of 26.132 km. The miniwatershed 4E3C5a (Kadam River) has been found to be of highest area with 494.179 sq.km and 4E3C4g (Batkamma Vagu) miniwatershed was found to be with minimum area of 27.065 sq.km. The miniwatershed 4E3C5a (Kadam River) has been found to be of longest basin length with 44.46 km and 4E3C4g (Batkamma Vagu) miniwatershed was found to be with lowest basin length of 8.54 km. It is observed from the above analysis that the miniwatershed 4E3C5a (Kadam River) represented highest perimeter, area and basin length.

Total number of stream segments as well as number of stream segments under each stream order have been calculated in GIS environment. The total number of stream segments for the entire watershed as been found to be 13337 with 6985 number of stream segments in 4E3C4 and 6352 number of stream segments in 4E3C5. The miniwatershed 4E3C4a (Sikkumanu River) has been found to be associated with highest number of stream segments (2028) and 4E3C4j (Balli Vagu) miniwatershed represented the lowest number of stream segments i.e. 123. The miniwatershed 4E3C5a (Kadam River) has been found to be associated with highest number of stream segments (2595) and 4E3C5d (Datki Vagu) miniwatershed represented the lowest number of stream segments i.e. 172. The number of stream segments under each stream order has been computed in GIS. The number of stream segments under stream order I to VII is 9053, 2994, 900, 362, 18, 6 and 3 respectively. The principal trunk stream with highest stream order of VIII is found to be associated with the miniwatershed 4E3C4i. The total lengths of all stream segments under each stream order have been calculated in GIS environment and presented in Table 1. The total length of all stream segments under stream order I to VIII is 1541.5, 689.63, 412.35, 243.5, 61.19, 54.23 and 3.09 km respectively. The total length of all streams for the entire watershed has thus been found to be 4691.23 kms representing a dense drainage network. It is observed that the study area i.e., Kadam watershed is well drained and the drainage is in a well integrated pattern and the area is underlain by highly resistant permeable material with vegetative cover and lower relief. Present study demonstrated that GIS is found to be flexible and is relatively easy to apply on large areas enabling gathering of all data and information in a common data base for watershed delineation and stream network analysis. The stream morphometric parameters namely, Bifurcation ratio, Circularity ratio, Compactness ratio, Elongation ratio, Form factor, Stream frequency, Texture ratio have also been calculated. The highest Bifurcation ratio is found to be 11.95 for 4E3C5a (Kadam River miniwatershed) higher drainage densities are expected where soils are easily eroded or relatively impermeable, slopes are steep and vegetal cover is scanty. It also indicates a strong structural control on the drainage. The Batkamma vagu (4E3C4g) miniwatershed is having the maximum Elongation ratio indicating possibility of less erosion. The Maximum values of Circularity ratio of 0.642 and Drainage density of 3.510 have been found in Lothuvara miniwatershed.

Form factor values are found to be in range of 0.25 to 0.37. The Maximum values of Stream frequency of 7.25 and Texture ratio of 15.81 have been found in Dorlavagu miniwatershed. The miniwatershed with the lowest compound parameter value is given the highest priority, while highest compound parameter value is given the lowest priority. Compound parameter values and prioritization rating have been presented in Table 2. Highest priority indicates the great degree of erosion in the particular miniwatershed and it becomes potential choice for applying soil and water conservative measures. Allampalli vagu (4E3C4f), Gangapuram vagu (4E3C4h) and Batkamma vagu(4E3C4g) miniwatersheds have been found to be under high priority and should be provided with immediate soil and water conservation measures as they are likely to be subjected to maximum soil erosion. The compound parameter values obtained for these miniwatersheds are 6.125, 6.625 and 6.75.The final prioritized map for the study area is shown in Figure 1. Thus soil conservation measures can first be applied to Highest priority miniwatershed and then to other miniwatersheds depending upon their priority in order.

Table 1: Miniwatershed code and stream lengths under each stream order

Sl No	Miniwatershed code	Stream Length (Km)							
		I	II	III	IV	V	VI	VII	VIII
1	4E3C4a	753.65	255.02	124.08	60.75	26.14	11.54	15.12	

2	4E3C4b	290.98	96.96	51.08	21.68	20.46			
3	4E3C4c	373.57	111.58	60.82	42.91	15.22	14.63		
4	4E3C4d	117.87	33.02	21.43	16.86	6.78			
5	4E3C4e	161.17	46.64	23.68	22.15	0	2.49		
6	4E3C4f	73.37	25.87	11.61	11.27				
7	4E3C4g	46.98	14.66	6.94	14.6				
8	4E3C4h	84.76	27.48	19.19	7.94				
9	4E3C4i	126.01	57.61	14.21	7.56	0	0	2.78	3.09
10	4E3C4j	51.58	14.48	12.88	2.16				
11	4E3C4k	349.99	109.98	50.51	41.37	41.37	9.35		
12	4E3C5a	836.18	287.4	138.12	60.45	20.72	14.88	36.33	
13	4E3C5b	165.81	53.02	22.14	15.33	21.32			
14	4E3C5c	275.4	79.84	42.6	11.66	31.77			
15	4E3C5d	63.88	27.23	8.95	11.83				
16	4E3C5e	368.22	116.15	55.17	37.27	18.56			
17	4E3C5f	148.13	47.07	19.48	8.54	12.31			
18	4E3C5g	403.68	137.49	6.74	18.02	28.85	8.3		
Total		**4691.23**	**1541.5**	**689.63**	**412.35**	**243.5**	**61.19**	**54.23**	**3.09**

Table 2: Prioritization of miniwatersheds based on morphometric analysis

Mini-watershed code	**Bifurcationratio**	**Compactnessration**	**Circularity ratio**	**Drainage Density**	**Elongation Ratio**	**Form factor**	**Stream Frequency**	**Texture Ratio**	**Compound Parameter**	**Priority**
4E3C4a	11	2	17	13	17	17	13	7	12.125	16
4E3C4b	7	12	7	12	12	12	7	6	9.375	8
4E3C4c	13	7	12	2	13	13	1	1	7.75	5
4E3C4d	14	18	1	1	6	6	3	8	7.125	4
4E3C4e	9	3	16	10	8	8	15	15	10.5	12
4E3C4f	2	9	10	7	4	4	4	13	6.625	2
4E3C4g	6	8	11	6	1	1	5	16	6.75	3
4E3C4h	5	15	4	3	5	5	2	10	6.125	1
4E3C4i	8	4	15	18	9	9	18	14	11.875	15
4E3C4j	4	17	2	17	2	2	17	17	9.75	9
4E3C4k	3	14	5	5	14	14	8	3	8.25	6
4E3C5a	1	1	18	14	18	18	6	5	10.125	10

4E3C5b	15	10	9	16	10	10	16	12	12.25	17
4E3C5c	12	5	14	9	11	11	14	9	10.625	13
4E3C5d	10	6	13	4	3	3	10	18	8.375	7
4E3C5e	18	16	3	8	15	15	9	2	10.75	14
4E3C5f	16	11	8	11	7	7	12	11	10.375	11
4E3C5g	17	13	6	15	16	16	11	4	12.25	18

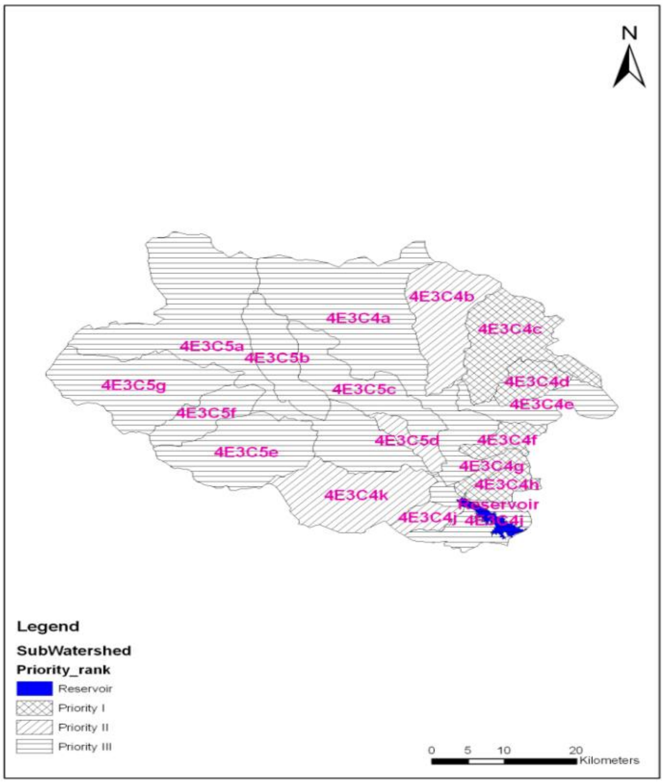

Figure 1: Prioritization of miniwatersheds based on morphometric analysis

5. Conclusions

The Kadam watershed has been divided into two subwatersheds namely 4E3C4 and 4E3C5 in the watershed atlas of India. In the present study, 4E3C4 subwatershed has further been delineated in GIS environment into eleven mini watersheds namely 4E3C4a to 4E3C4k and 4E3C5 subwatershed has been delineated into seven miniwatersheds namely 4E3C5a to 4E3C5g. The miniwatershed 4E3C5a (Kadam River) has been found to be of longest basin length with 44.46 km and 4E3C4g (Batkamma Vagu) miniwatershed was found to be with lowest basin length of 8.54 km. It is observed from the above analysis that the miniwatershed 4E3C5a (Kadam River) represented highest perimeter, area and basin length. The total length of all stream segments under stream order I to VIII is 1541.5, 689.63, 412.35, 243.5, 61.19, 54.23 and 3.09 km respectively. The total length of all streams for the entire watershed has thus been found to be 4691.23kms representing a dense drainage network. The highest Bifurcation ratio is found to be 11.95 for 4E3C5a (Kadam River miniwatershed) higher drainage densities are expected where soils are easily eroded or relatively impermeable, slopes are steep and vegetal cover is scanty. It also indicates a strong structural control on the drainage. The Batkamma vagu (4E3C4g) miniwatershed is having the maximum Elongation ratio indicating possibility of less erosion. The Maximum values of Circularity ratio of 0.642 and Drainage density of 3.510 have been found in Lothuvara miniwatershed. Form factor values are found to be in range of 0.25 to 0.37. The Maximum values of Stream frequency of 7.25 and Texture ratio of 15.81 have been found in Dorlavagu miniwatershed. It is observed that the study area i.e., Kadam watershed is well drained and the drainage is in a well integrated pattern and the area is underlain by highly resistant permeable material with vegetative cover and lower relief. Present study demonstrated that GIS is found to be flexible and is relatively easy to apply on large areas enabling gathering of all data and information in a common data base for watershed delineation and stream network analysis. Allampalli vagu (4E3C4f), Gangapuram vagu (4E3C4h) and Batkamma vagu(4E3C4g) miniwatersheds have been found to be under high priority and should be provided with immediate soil and water conservation measures as they are likely to be subjected to maximum soil erosion.

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