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Slope Studies of Vamsadhara River basin: A Quantitative Approach

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Abstract:- The slope of the drainage basin has an important relation to infiltration, surface runoff, soil moisture and ground water contribution to stream. It is one of the major factors controlling the time of over land flow and concentration of rainfall in stream channels and is of direct importance in relation to the flood magnitude. An attempt as been made to study the slope variations in Vamsadhara River Basin with an aerial extent of 10,601.5 sq.kms. is taken up for the examination of the problem. The river is prone to frequent floods. The study area is divided into 19 sub-basins based on the drainage pattern. The relief in the catchment ranges from 10 to 1540m above MSL. The Vamsadhara Basin was divided into a square grid network, and slope values were calculated for each grid. In each sub-basin average slope and regional slope distribution arrived statistically. The relatively steep frequencies in the NE and NW part of the study area indicate fast runoff. Different percentage slope classes and their areal extents were calculated at sub basin level. This type of study will give an idea to understand the behavior of runoff, groundwater occurrence and erosion process in a river basin.

Key words: **Slope, Relief, Surface runoff, Vamsadhara River Basin.**

I. INTRODUCTION

Vamsadhara River Basin is prone to frequent floods with an aerial extent of 10,601.5 sq.kms. This is an inter-state drainage basin between Andhra Pradesh and Orissa. The main Vamsadhara River rises to the southwest of Balagad village in the Pulbhani district of Orissa The River joins the sea at Kalingapatnam after traversing 230 kms. in both the states (Fig.1). Major tributaries Chuvaldhua Nadi, Poladi Nadi, Gangudu River, Sanna Noi, Pedda Gedda and Mahendratanaya join the main Vamsadhara river before enter into the sea at Kalingapatnam in Srikakulam District. The basin area forms a part of Survey of India topographic sheets Nos. 65M/5-16, 65N/9, 65N/13-15, and 74A/1-8 and B/1-3 and 5. The study area is located between 83^0 15' and 84^0 57' E longitudes and 18^0 15' and 19^0 57' N latitudes (Fig. 1). The only irrigation project on the Vamsadhara River is the Gotta Barrage and it is constructed near Hiramandalam providing irrigation facilities for nearly 0.6 lakh hectares with a discharge of 2.90 lakh cusecs of water.

II. CLIMATE AND RAINFALL

The basin has two types of climate. The area between the coast and the foot hills of the Eastern Ghats enjoys semi-arid climate and the upper reaches fall under the dry sub-humid type of climate. May is the hottest month with a mean monthly maximum temperature of 34.7^0 C and mean monthly minimum of 17.1^0 C at Kalingapatnam where the river joins the sea. The average depth of rainfall during the period 1971-2010 is 1302.5mm by Isohytal method which is increased in general from the south to north and there is also an increasing trend towards the northeast from the southwest. The average amount of rainfall was 940.2mm at Kalingapatnam near the coast and 1551.6mm at Ramagiri-Udaigiri on the northeast and 1250.2mm at Muniguda on the northwest of the basin. About 84.6% of rainfall was received during the five months monsoon period (June to October).

III. METHODOLOGY

Slope and elevation are the two basic but separate concepts in the study of landforms. The slope or inclination of the terrain is the resultant of many factors, such as the relative relief, dissection index, drainage texture, drainage frequency, climate, geology and tectonics operating in the area. The slope analysis is prevalent since the very beginning of geomorphological studies. But a remarkable attention is given by Wentworth (1930) by introducing a simplified method. Latter the computation of average slopes from the topographic maps having contours were made by Raisz and Henry (1937), Smith (1938), Calef (1950), Calef and Newcomb (1953), Strahler (1956), Miller and Summersoo (1960), Eylas (1965) etc. The technique of Wentworth has been used by the Indian authors Singh (1968), Kharkwal (1971), Singh and Srivastava (1977) and many others. David R. Montgomery (2001) identified such a change from a positive to an inverse relationship between drainage area and slope based on averaged trends.

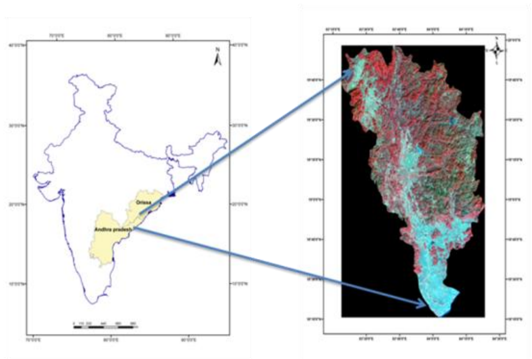

Fig.1. Location map of the Vamsadhara River Basin

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Variations of slope and relief, drainage networks and typical landforms are the glimpses of erosion and also result of tectonic activity (Sandipan Ghosh, 2011).On the basis of the method of Wentworth the area is divided in various slope categories. Slope map is prepared using survey of India topographical maps based on the contour information. The Vamsadhar River Basin (VRB) was devided into a square grid network and slope values were calculated for each grid by the Wentworth's method (1930). The formula adopted is as follows.

Tan ө =N*CI/3361

Where N-average number of contour crossings per mile

CI-contour Interval

3361-constant

ө - Slope in degrees

Grid values have been plotted on the base map and are classified into the following categories (Leamy and Panton, 1966) shown in Table.1.

Table .1: Slope categories

Value of slope	Slope class
$0-2^0$	Level to nearly level
$2-6^0$	Gently sloping
$6-12^0$	Strongly sloping
$12-20^0$	Moderately steeply sloping
$20-25^0$	Steeply sloping

IV. RELIEF

Elevations within the basin, range slightly less than 10 mts. above MSL in south (Kalingapatnam) to 1545 mts. on the northwest hills (Near Bissam Cuttack). Except in the extreme lower reaches of the basin the relief of the land is highly undulating in character. The central portion of the basin is characterized by a flat alluvial filled valley interspersed with forest on mountains on the east. The lower reaches with an altitude of less than 150 mts. above MSL falls within the plain area of the basin. The altitudinal range of the upper reaches are of the order of 150-1200 mts. except for a few peaks. On an average the relief on the upstream of Gotta Barrage varies 300 to 900 mts. Downstream of Gudari on either side of the river course, the relief varies from 20 to 150 mts for a few kms extent. The VRB is devided into 19 sub-basins (Fig.2) and average relief calculated for each sub-basin is presented in Table.2. The average elevation ranges from 81.8 mts. (sub-basin 18) to less than 746.8 mts. (sub-basin 3).

Table .2: Area and average relief in Vamsadhara for different sub-basins

Sub-basin No.	Area of sub-basin (Sq.kms)	Average Relief(m)
1	1295.4	629.6
2	830.9	572.3
3	591.9	746.8
4	195.9	267.4
5	179.1	294.0
6	178.2	663.1
7	1720.9	573.9
8	95.3	336.8
9	210.0	276.0
10	210.4	661.5
11	469.6	443.0
12	1329.2	665.1
13	196.4	348.8
14	326.5	317.8
15	171.8	351.2
16	273.4	371.0
17	1202.4	568.5
18	587.1	81.8
19	536.1	167.7

V. GEOLOGY

The area under study forms a part of the Eastern Ghats group of Achaeans, consisting of mainly charnockites, kondalites and granite gneisses. These rocks trend NE-SW to NW-SE. Three sets of joints are well developed as major sets in these rock types (Swain, 1982). The left flank of main river course mainly consists of charnockites and kondalites with intermittent granite gneiss, whereas on the right flank of the river course granite gneiss dominates. Majority of the structural trends as delineated from AWiFS are due NE-SW direction following the trend of Eastern Ghat tectonic system. Interpretation of AWiFS for delineation of sub-surface structural features has revealed a wide spread fracture system in the upper half of the basin. The fracture system is complex and intense. The lineaments trend in near E-W and near N-S directions. In the lower reaches majority of lineaments run parallel to the river course and extend over several kilometers. A major fault lineament could be deciphered in the lower reach running in E-W direction which resulted in abrupt changes in river course from southeast to south (Mahendratanaya course). The fracture system discussed above may be one of the contributing factors for the observed complex drainage pattern of the basin. R. B. Golekar et al. (2013) noticed that the high values of Rh indicate steep slope and high relief.

Table .3: Average slope in Vamsadhara for different sub-basins.

Category Name	Slope Limits	Area (sq. km.)	% of the Basin area
Level or nearly level	$0-2^0$	704.3	6.64
Gently sloping	$2-6^0$	1297.1	12.24
Strongly sloping	$6-12^0$	3222.4	30.40
Moderately steeply sloping	$12-20^0$	5251.4	49.53
Steeply sloping	$20-25^0$	126.3	1.19
Total		10601.5	100.00

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Table.4: Area-Slope distribution in VRB

Sub-basin No.	Average slope	Sub-basin No.	Average slope	Sub-basin No.	Average slope
1	$11^{0}\ 01^{'}$	8	$9^{0}\ 57^{'}$	15	$6^{0}\ 30^{'}$
2	$13^{0}\ 30^{'}$	9	$4^{0}\ 12^{'}$	16	$8^{0}\ 54^{'}$
3	$15^{0}\ 45^{'}$	10	$12^{0}\ 15^{'}$	17	$12^{0}\ 01^{'}$
4	$11^{0}\ 54^{'}$	11	$10^{0}\ 09^{'}$	18	$2^{0}\ 42^{'}$
5	$12^{0}\ 17^{'}$	12	$15^{0}\ 24^{'}$	19	$3^{0}\ 38^{'}$
6	$15^{0}\ 06^{'}$	13	$7^{0}\ 42^{'}$		
7	$14^{0}\ 30^{'}$	14	$7^{0}\ 06^{'}$		

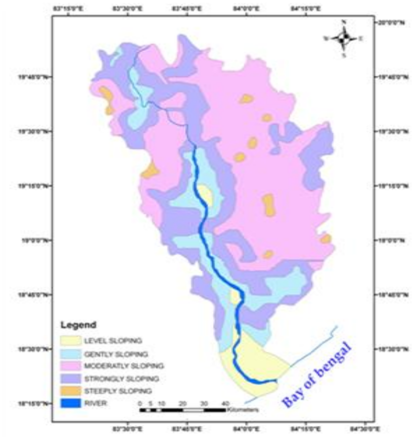


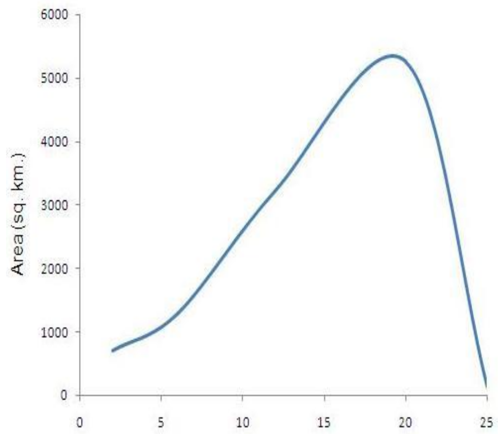
Fig.3. Slope map of VRB

VI. SLOPE STUDIES

Slope maps play a crucial role in addition to flow direction and flow accumulation in hydrological modeling. Slope is one of the important terrain parameter which is explained by horizontal spacing of the contours. In general, closely spaced contours represent steeper slopes and sparse contours exhibit gentle slope. Slopes in the basin area have been shown in figure 3. Most of the upstream area from Gotta Barrage is covered with moderate to steep slopes (12 to 20^{0}). Hills with slopes more than of than 20^{0} are also observed in sub-basin numbers 1,7,12 and 17. Gentle slopes are on either side of the main Vamsadhara from upstream of Gotta Barrage. Hills with gentle slopes are also observed on either side of the Mahendratanaya (Sub-basin-17) tributary. The valley near Gummada bridge has slope of less than 2^{0}. The extent of area under slopes less than 2^{0} is more on the left bank than on the right bank. Valley with slope less than 2^{0} is also observed just above the confluence point of Mahendratanaya with main Vamsadhara. The average slope for each sub-basin is presented in Table 3. The average slope is computed by multiplying each increment of area by its mean slope and the sum of the product divided by the drainage area. The average slope varies for sub-basin to sub-basin in the catchment. It is more on the northern sub-basins. The average slope ranges from 2^{0} 42' (sub-basin 18) to 15^{0} 45' (sub-basin 3). Except in sub-basin 9, 18 and 19 the average slope is more than 6^{0}. Where as in sub-basins 1-7, 10-12 and 17 it is more than 10^{0}. Because of this fact most of the basin area is brought under dry cultivation

VII. AREA-SLOPE DISTRIBUTION

The average slope map provides information on slope-distribution over the entire basin. In general, the inclination of slope increases from south to north. The highest inclination (above 20^{0}) of terrain is naturally marked on the high altitudes of the ranges. An appraisal of the Table 4 will reveal the area-slope distribution, which is the proportion of the total surface falling within each group of slope. Table 4 indicates that nearly 50% of the total area is lies between 12-20^{0} of slope and almost all which lies in the uplands. Mostly these sub-basins are characterized by higher slope with higher altitudes. The highest percentages of the total area (49.53 and 30.40) lie in the slope-group of 12-20^{0} and 6-12^{0} respectively.



Slope in Degrees

Fig.4. Area-slope curve in VRB

The second and third highest percentages of the total area (30.4 and 12.24) lie in the slope group of 6-12^{0} and 2-6^{0} respectively. In addition, some small patches of steep slope of 20-25^{0} also observed in the sub-basins 2, 3, 5, 6, 7, 10, 12 and 17 in total with a percentage of 1.19. The low slope category of 0-2^{0} mostly covered in sub-basins 18 and 19 having more low-lying areas and also on either side of the main river course. The relation between area and slope distribution has been shown in Fig.4. The area-slope curve clearly shows, most of the basin area enjoys with steep terrain. The slope Ogive (Fig. 5) indicates gradually raising of the curve from 6-12^{0} showing a large coverage of the area. The rise is normal, after the slope of 20^{0}, indicating less accumulation of the area in the respective slopes.

VIII. FREQUENCY DISTRIBUTION OF SLOPE VALUES IN VAMSADHARA BASIN

The present study of slopes is the related studies of Eric (1967), Kharkwal (1971) and Singh and Srivastava (1977). Kharkwal (1971) in his studies followed the slope category of Singh(1967) on 1 inch to 1 mile map.

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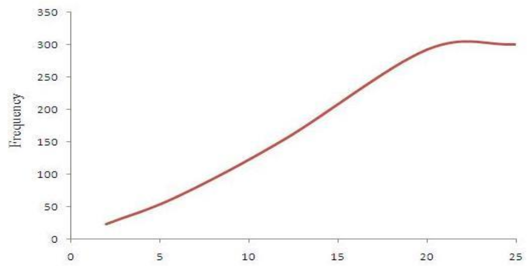
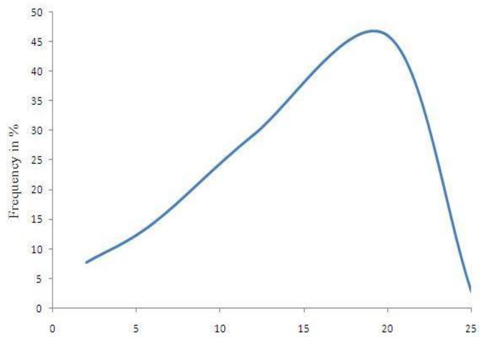
Similarly Singh's (1976) classification of slopes is also different from the category followed by Kharkwal (1971). In the present classification the limitations given by Leamy and Panton (1966) are used. The slope scale has been grouped into 5 classes Table 5 reveals that maximum frequencies (46%) lie in the category of moderately steep slope and with about 29.3% in the second category of strongly slope. Taking into consideration each slope class, frequencies are in the slope scale groups of $12\text{-}20^0$, $6\text{-}12^0$ and $2\text{-}6^0$ sharing about 46%, 29.3% and 14.3% of the total frequencies. The frequency percentage curve (Fig.6) shows a negative skew ness showing thereby that the majority of the area enjoys a steep terrain.

Table.5: Frequency distribution of slope values

Slope	Frequency	% of frequency	% of cumulative frequency	Class
$0\text{-}2^0$	23	7.7	7.7	level
$2\text{-}6^0$	43	14.3	22.0	Gentle slope
$6\text{-}12^0$	88	29.3	51.3	Strong slope
$12\text{-}20^0$	138	46.0	97.3	Moderately steep
$20\text{-}25^0$	8	2.7	100.0	Steep slope



Slope in Degrees
Fig.5. Slope Ogive of VRB



Slope in Degrees
Fig.6. Frequency (%) - Slope curve of VRB

The curve is skewed to the low values on the left. The curve shows that aerial coverage of over 20^0 is insignificant whereas the areal coverage between $12\text{-}20^0$ is very significant. The insignificant value is due to the heavy erosion because the study area is an ancient landscape where river and streams eroded away most of the land. The area is turned into a broken and divided country leaving out the remaining as isolated hills.

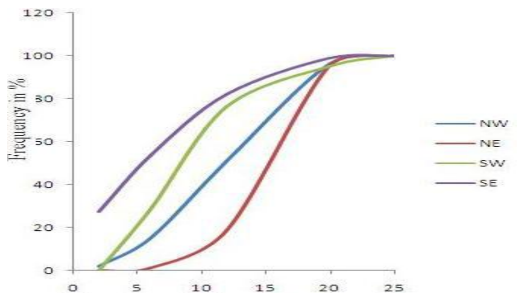
IX. THE FORM AND DISTRIBUTION OF SLOPE MAGNITUDES IN FOUR LOCALITIES (NE, NW, SE and SW).

An attempt has been made to analyze and compare the form and aerial distribution of the slope magnitudes developed in the basin area. The present analysis is largely on the lines of Eric (1967). The entire area has been divided into four broad divisions, i.e. northeast (NE), northwest (NW), southeast (SE) and southwest (SW), and a comparative study has been made for each locality. The statistical results have been expressed by cumulative frequency curves (Fig.7). The frequency of the slope categories, recognized in the four localities as mentioned above, show some marked variations in the percentage of area covered.

Table.6: Slope-frequency distribution in four localities

Slope categories	% distribution of slope frequencies				
	NW	NE	SW	SE	Total
$0\text{-}2^0$	1.9	-	-	27.4	7.7
$2\text{-}6^0$	13.2	1.2	28.6	26.2	14.3
$6\text{-}12^0$	35.8	17.2	47.6	28.6	29.3
$12\text{-}20^0$	45.3	77.0	19.0	16.6	46.0
$20\text{-}25^0$	3.8	4.6	4.8	1.2	2.7

An appraisal of the Table.6 reveals that the maximum frequencies are concentrated between $12\text{-}20^0$ of slope in NE and NW localities and $6\text{-}12^0$ of slope in SW, and some areas in NW and NE. Percentage variation of slope values of these four localities reveals that the areas lying on the NE and NW have higher frequencies of high slope values than that of SE and SW. Table.6 indicates this category mostly lies on the North-Eastern and North-Western regions of the basin covering the sub-basins 2, 3, 5, 6, 7, 10, 12 and 17. (Fig.2 and Fig.3).



Slope in Degrees
Fig.7. Slope- Frequency distribution in four localities

The studies clearly indicates about 50% of the basin area enjoys the steep terrain. The concentration is mainly on the NE and NW portion. In general, the inclination of slope increases from south to north. The relatively steep frequencies in the NE and NW indicate fast runoff. The sub-basin Nos. 1 to 10 and parts of sub-basin 12 are situated on the northeast and northwest portions.

X. SUMMARY AND CONCLUSIONS

The Vamsadhara River Basin (VRB) is an inter-state drainage basin, and is very frequently prone to floods. The basin is divided into 19 sub-watersheds. The areal extent is 10601.5 sq.kms. The area between the coast and the foot hills of the Eastern Ghats enjoys semi-arid climate and the upper reaches fall under the dry sub-humid type of climate. The distribution of rainfall during the period 1971- 2010 increased in general from south to north. There is also increasing trend towards the northeast from the southeast direction. The study area forms a part of the Eastern Ghats charnockites-kondalites plutonic metamorphic complex with complex structural history. Major fracture and fault lineaments tending in near east-west and near north-south directions have been deciphered from AWiFS imagery in the basin. These are the major fractures resulting in the complex drainage of the basin. Data on relief and slopes have been collected. Average relief in the basin varies from maximum for sub-basin 3 (746.8 mts.) and minimum is for sub-basin 18 (81.8 mts.). An attempt has been made to analyze and compare the form and areal distribution of the slope magnitudes in the basin areas. Nearly 50% of the total area enjoys moderately steeply sloping (12-20^0) category, mostly in the northern region of the basin. The study on frequency distribution of slopes indicates the areas lying on the northeast (NE) and northwest (NW) have higher frequencies of high slope values than that of southeast and southwest. Normally the relatively steep frequencies in the NE and NW regions indicate fast runoff. The sub-basin Nos. 1 to 10 and parts of sub-basin 12 are situated on the NE and NW portions. The rainfall intensity during cyclones varies in these localities by 20-35 mm/hour, concentrating for about 4 to 5 hours. Steep slope areas facilitates faster runoff allowing less residence time for rain water, where as in the gentle slope areas the surface runoff is slow, allowing more time for rainwater to peculate and hence comparatively more infiltration. The sub-basin Nos. 1 to7, 10 to 12 and 17 enjoys the steep slopes, hence the greater will be the runoff speed with least percolation. Most of the area in the NE and NW parts of the basin has poor groundwater prospects due to high slope gradient of more than 12^0. On the contrary the SE and SW part of the study area as good groundwater prospects due to gentle slope of less than 6^0. Wherever the stream-gauging stations for direct runoff observations are scarce, this type of study give an opportunity to understand the behavior of runoff and also useful to know the occurrence of groundwater and erosion process in Vamsadhara river basin.

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Prof. E.Amminedu was born in 1955 and is presently working as a Professor and Chairman, Board of studies in the Department of Geo-Engineering, College of engineering, Andhra University, Visakhapatnam. He was also the former Head of the same Dept. He published 30 scientific papers in National and International scientific journals and contributed 18 papers in seminar proceedings. He has guided more than 40 for their M.Tech. thesis and 4 students for their

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