GIS in Geoscience Education- Geomorphometric study

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Abstract

The Educational Institutions around the world have realized the possibility of using GIS in Geosciences teaching along with in many other subjects. GIS is been used in a large number of geoscience applications viz. mapping, mineral and petroleum exploration, structural analyses, hazards management and so on among other many applications. Mapping as an integral activity in any geoscience research, GIS with its map making and analytical capabilities plays an important role in Geoscience teaching. The present paper while discusses the role of GIS in Geoscience education, also portray the ease of using ArcGIS for Geomorphometric study for understanding the Geology and Geomorphology of small watershed basins specific to Goa, India.

Introduction

The recent developments in the world economy have had major influence on the trends in education in general and geosciences education in particular. India's growing demand in better utilization of Landuse and natural resources requires the reliable spatial information collection, integration, management and sharing, and the associated relevant education, experience sharing and development of best practices. The focus is now heavily on key areas which have direct link with human environment including the exploration and exploitation of new mineral resources, sustainable development and better management of the natural resources, environmental awareness, disaster management and so on (Mahender, 2012). Geoscience, as we all know, is the study of Earth from core, to deep oceans and up to the outer space and can help mitigate volcanic eruptions, floods, landslides, and further help to explore ground water, mineral resources, fossil fuels and construction materials. Also, it includes the studies of physical, chemical changes to understand the distribution of the nature resources. Therefore, the geoscience encompasses earth, geology, oceanography, atmospheric, petrology, mineralogy, sedimentology, hydrology, and so on and on. Satellite data from the state-of-the art remote sensing satellite platforms have been used to create spatial databases on various themes such as land use/cover, soils, wastelands, wetlands, hydro-geomorphology, coastal landforms etc., although has been in practice in selected

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government organizations and also some commercial firms but for the better use of the data in creation of specialized spatial databases for the use of variety of themes requires the fundamental knowledge and which should become a part of the curriculum at least at graduate or post-graduate level if not at high-school level. Therefore, one of the foremost activities in the reform process is introduction of balanced curriculum with an open learning approach to suit the need of both student who is learning and the institute that is offering the course without forgetting the requirements of society/industry for better management of natural resources. The trend in geospatial education is moving towards a holistic approach, which not just focuses on profit making but keeps in mind the needs of the society and utilizes the best of the technologies in their teaching and learning process.

Further, the Geosciences play a pivotal role in the exploration and extraction of natural resources and earth materials, prediction, prevention and mitigation of natural and human-made hazards, addressing the issues of global warming, climate change, environmental pollution etc. With the ever increasing demand of natural resources and the frequent occurrence of several natural disasters, it is very necessary to provide greater awareness and scientific information towards better management and conservation of natural resources and as well as to help the people to prepare themselves for tackling the issues of natural hazards (earthquakes, tsunamis, severe coastal storms, landslides, volcanic eruptions, etc.). The key goal of geoscience education is to ensure that all inhabitants of the Earth have the awareness and knowledge of the natural processes that shape the earth's physical environment, and understand how the human actions create significant impacts on Earth on local, regional, and global scales. Addressing these and many other geoscience issues requires a well-educated and -trained workforce with practical skills, which is possible with a well-designed geoscience curriculum incorporating the relevant optional paper on latest geospatial technologies in the educational systems at various levels.

As the education in the Geosciences/Geospatial Technologies is multifaceted and includes a broad spectrum of activities exposing a wide range of students to scientific principles and practices through discovery- and inquiry-based learning, the introduction of GIS-based teaching/learning process is quite appropriate. The rapid developments in geospatial industry along with the easy availability of computing systems, made it possible to impart the required skills related to the acquisition of reference data, the spatial nature of environmental data and spatial analysis, the methodologies, and the tools of geographic information systems (GIS).

GIS in Geoscience education Indian Context

As most of the geoscience education and training programs of many universities operate largely in isolation independent of each other, leading to knowledge gaps among the geoscience graduates, the recent developments in educational reforms leading to introduction of geospatial technology related courses integrated in the geosciences education in particular has received a greater significance. While the earth observation satellite systems from space and aerial platforms are offering a variety of data in spatial domain, the geographic information systems provide tools for varied analysis.

Being one of the fastest growing economies of the world, with its estimated growth rate of over 7% and the large budgetary allocation towards infrastructure development in the last two Five Year Plans, India can contribute further towards rapid growth in GIS Industry (Table-I). GIS being considered as one of the enabling technologies for most of the infrastructure projects, the developments in many of these projects with the use of Geospatial Technologies have created a greater impact in understanding the scope and potential of GIS in planning and development and accordingly created several business opportunities for the industry to conceptualize, introduce and implement innovative solutions in preparing for infrastructure development projects.

Tabel-1. Budgetary Allocation for Geospatial Projects(Source: Government of India, Planning Commission, 2007)

	AREAs	**(INR)**
1	Water Resources	**560.00**
2	Environment and Forest Resources	**305.00**
3	Land Resources	**1000.00**
4	Agriculture	**978.00**
5	Irrigation	**351.50**
6	Urban Development	**9.47**
7	Transport	**1606.50**
8	Space Applications	**1752.00**
	Grand Total	**6562.47**

National GIS mission of the Indian Government for introduction of GIS from grass root level in all the domains like Transportation, Irrigation, water resource management, urban planning, municipal administration, etc, is itself a testimony to the future scope of GIS utility in India. The National GIS Mission also includes all-round development in educational activities related to GIScience Education for human resource development for better implementation of the developmental projects with the application of these enabling technologies. Geoscience education plays an important role in integrating the geospatial technologies for implementing many of these infrastructure development projects. Currently, GIS and Remote Sensing courses have become an integral part of Geoscience Education in India (Table-2).

Table-2 Geoscience Courses with specializations in GIS in government funded institutions

	Name of the Program,	**Level**	**No. of Institutes/ University**
1	**B.Sc. Geology**	Graduate	**43**
2	**B.Sc. (Hons.)Geology**	Graduate	**2**
3	**B.Sc. Applied Geology**	Graduate	**1**
4	**M.Sc. Applied Geology**	Post-graduate	**6**
5	**M.Sc. Geology**	Post-graduate	**44**
6	**M.Sc. Marine Geology**	Post-graduate	**3**
7	**M.Sc. Petroleum Geology**	Post-graduate	**5**
8	**M.Tech. Applied Geology**	Post-graduate	**1**
9	**M.Tech, Petroleum Geoscience**	Post-graduate	**1**

The recently introduced revised Choice Based Credit System (CBCS) of UGC, has thrown a large number of optional papers to acquire geospatial skills. Accordingly many universities/educational Institutions in India have introduced GIS and Remote Sensing as compulsory courses as part of the Geoscience curriculum(Table-2). The present day post-graduate student of Geosciences, when he pass-out of university while understanding the earth processes, formation of mineral resources, is also able to manage the datasets, perform spatial analyses (multicriteria and geostatistical spatial queries), produce new data (elevation, hill shade, aspect and slope maps, interpolation and kriging, etc.) and reports which has made them to tackle many kind of geoscience related issues. Multidimensional analytical and better visualization capabilities of GIS have provided the geoscientists to better understand about the earth surface for better management of resources and preservation of natural environment of the planet earth. The present paper discusses the use of GIS in Geoscience education with a case study of a small area and shows how the Geomorphometric analyses can be performed using the terrain/surface analytical tools that is readily available in most of the GIS software. One of the fundamental strengths of using GIS in Geoscience education is that they enable students to use maps and their databases to understand and engage in ‘scientific visualization’. This approach is also applicable to the geosciences teaching of physical and human geography. In addition, the interpretation/use of such geographical data in real-life phenomena provides many possibilities for implementing problem-based learning approaches in rich, authentic, educationally productive contexts.

Geomorphometry: Integration of GIS with Geoscience

Geographical Information Systems (GIS) application in geomorphological research has been increasing since the early works from 1990s paralleling with the developments in computer technologies. Easy availability of high resolution Digital Elevation Models (DEMs) has further facilitated the increased applications of Geomorphometry. GIS and DEMs have enhanced the cartographic representation of earth surface features not as mere topographic representations but a useful support for building scientific hypotheses at an early stage of research. The quantitative analytical capability GIS and DEMs is the main reason for such increased application.

Geomorphometry, is been defined as a science of quantitative land-surface analysis (by Pike, 1995, 2000a; Pike et al, 2009; Rasemann et al., 2004) is also known terrain morphometry, terrain analysis, geomorphological analysis, Land surface analysis, (Hengl and Reuter, 2009 ; Tobler, 1976, 2000). The main aim of geomorphometry is to extract surface parameters and objects using input Digital Terrain Models. Although, the earliest concept of geomorphometry was a routine common activity of exploration and geomorphology, today, the Geomorphometry is an interdisciplinary field of a specialized discipline that has evolved from mathematics, the Earth sciences, and computer science and is linked with geoinformatics, various branches of engineering, and most of the Earth and environmental sciences (Fig.1). The rapidly evolving Geospatial technology enabled geomorphometry to emerge as a technical field possessing powerful analytical capabilities (Burrough & McDonnell, 1998). At the outset, geomorphometry is today been viewed as not only a specialized adaptation of surface quantification (mainly geometry and topology) to Earth's topography, but an independent field comparable to many other disciplines (Pike, 1995, 2000a), which is been taught as an important optional paper for post-graduate level in many universities.

Table-3 Basic Terrain parameters

	Parameters	**Type**	**Derived infromation**
1	Slope	Local	Flow rate
2	Aspect	Local	Flow-line direction
3	Tangential curvature	Local	1st accumulation mechanism
4	Profile curvature	Local	2nd accumulation mechanism
5	Catchment area	Regional	Flow magnitude
6	Hypsometry	Regional	Distribution of height values
7	Catchment height/slope	Regional	Flow characteristics
8	Insolation	Regional/local	Intensity of direct solar irradiation
9	Visual exposure	Regional	Extent of visible area
10	Roughness	Local	Terrain complexity

The extraction of earth surface/terrain parameters (Table-3) and objects from DEMs is the fundamental operation in geomorphometry. DEM is simple raster or a vector map showing the height of the land surface above mean sea level or some other referent horizon. Geomorphometric analysis commonly includes five steps: surface sampling for elevation data, generation and correction of a surface model, land-surface parameters calculations, and finally the application of results. The three main categories of parameters and objects (basic, hydrologic, and climatic/ meteorological) include both landforms and point measures such as slope and curvature. Landform *elements* are fundamental spatial units having uniform properties. Complex analyses may combine several parameter maps and incorporate non-topographic data. Elevation data as a critical element in Geomorphometry, in all there are about 10 land-surface parameters (Table-4) that are commonly derived and used in Geomorphometry for understanding the terrain.

Geomorphometry supports a number of geoscience applications and as well as applications in many other disciplines. There are a number of GIS software that are available integrated with Geomorphometric analytical tools that can be easily usable to derive the various earth surface/morphometric parameters for variety of applications. It is beyond the scope to go in to details of Geomorphometry in variety of application areas and also it is not possible to discuss here on the large variety of GIS software integrated with Geomorphometric tools. The present paper demonstrates the application of Geomorphometry in better understanding of the Geology of a terrain.

Geomorphometric study of Sal river basin, South Goa, India

To portray the application of GIS for geomorphometric study for better resolving the geoscience knowledge, in the present study a small area in the South Goa district of Goa State, India has been included. The study was an attempt to generate base line information onthe morphometric parameters with the use of GIS and generate the slope map of the area with the help of GIS analytical tools available in ArcGIS.

The present study area(Fig.2), a part of the well known tourist destination Goa, located along the west Coast of India, has been studied in the past by De Souza (1965, 1968), Wagle and Mishra(1975), Wagle (1982), Iyer and Wagle(1982) for the general geomorphology and no work exist as regards the quantitative morphometric parameters of the river basins in Goa in general and in the present study area in specific. GIS based thematic maps (Elevation, Drainage, rainfall and soil characteristics) and the related data (Morphometric parameters) which are useful in watershed management study have been generated for the study area for the first time.

Fig.2. Location Map of The Study Area

Study area comprises of four major coastal drainage basins of the South Goa district namely Sal, Saleri, Talpona and Galgibag covering almost entire district. In the present paper, only the Sal river basin is included to demonstrate the use of GIS in geomorphometric study.

Materials and Methodology

The Survey of India toposheets on the scale of 1: 25000 of Government of India are main base maps for the present study. The topographical maps were georeferenced and mosaic of the entire study area was delineated in GIS environment with the help of ArcGIS 9.3 software assigning appropriate geographic coordinate projection system. Since morphometric analysis of a basin requires the delineation of all the existing streams, digitization of the drainage basin was carried out as a first step for morphometric analysis. The stream network of the drainage basin were digitized and classified according to the stream order (1^{st} order, 2^{nd} order etc.) by giving the attribute data. The length of streams, basin parameters, area of the basin and the basin length were calculated with the help of "calculate geometry" tool in Arc GIS software. Topology tool was used to edit line errors like polygon, point and node of overlapping, dangles and gaps for accuracy. Various morphometric parameters such as linear, Arial and relief aspects of the basin were computed. This was followed by calculations of other morphometric parameters like bifurcation ratio, elongation ratio, circularity ratio, drainage density, stream frequency, form factor, constant of channel maintenance texture ratio and average length of overland flow.

The 10 meter interval contour layer prepared from the SOI toposheets and field collection of elevation data has been used for the generation of DEM and for the preparation of the various surface thematic datasets viz. slope, Hill shade maps etc. The slope maps were reclassified according to their slope variations for respective basins.

Results and Discussion:

Geomorphometry incorporates quantitative study of the area, altitude, volume, slope, profiles of the land and the drainage basin characteristics of the study area concerned. Detailed and systematic study of the geometry of the drainage basin and its channel system requires measurements of various aspects like: i) **Linear aspect of drainage network**: Stream Order, Stream Number, Stream Length, Basin Perimeter, Basin Length and ii) **Areal aspects of drainage basin**: Drainage Pattern, Basin Area, Bifurcation Ratio, Elongation Ratio, Circularity Ratio, Drainage Density, Stream Frequency, Form Factor, Constant Of Channel Maintenance, Texture Ratio, Average Length Of Overland Flow. The data is presented in Table-4 & 5.

Table-4. Showing Methodology Adopted and Results of Morphometric Analysis

Sr. No	Morphometric Parameters	Formula	Reference	Sal River Basin	Observation
1	Stream Order	Hierarchical Rank	Strahler, 1953	Tabulated in Table-5	
2	Stream Number (Nu)	Total Number of streams of a particular stream order	Strahler, 1953	Tabulated in Table-5	
3	Stream Length (Lu)	Length of the stream	-	Tabulated in Table-5	
4	Basin Perimeter (P)	Total length of the watershed boundary	-	107.99 Km	
5	Basin Length (L_b)	Maximum length of the basin	-	21.58 Km	
6	Basin Area (A)	Area of watershed	-	222.71 Km^2	
7	Bifurcation Ratio (Rb)	(Nu) / (Nu+1)	Schumm, 1956	4.03	Structurally controlled Drainage
8	Elongation Ratio (R_e)	$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\Pi}}$	Schumm, 1956	0.78	Strong relief and steep grounds with a variation in the climate and geologic types
9	Circularity Ratio (R_c)	$R_C = \frac{4\Pi A_k}{P^2}$	Miller, 1953	0.24	Highly irregular basins (Miller, 1953) Higher lag time & Shorter pick flow (Wough, 1995)
10	Drainage Density (D_d)	$D_d = \frac{\Sigma Lu}{A}$	Thornbury, 1985	0.49 /Km	Course drainage texture in some areas
11	Stream Frequency (F)	$F = \frac{\Sigma Nu}{A}$	Horton, 1932	5.46 $/Km^2$	
12	Form Factor (Rf):	$Rf = A/L_b^2$	Horton, 1932	0.477 Km	Less elongated basin
13	Constant Of Channel Maintenance (Cm)	$Cm = \frac{1}{D_d}$	Schumm, 1956	2.04 Km	Presence of semi-arid regions with lower vegetation cover resulting in lower infiltration rates and higher surface flow. (Horton, 1932)
14	Texture Ratio (T)	$T = \frac{Nu}{P}$	Horton, 1932	11.27 $/Km^2$	Course texture
15	Average Length Of Overland Flow (Lg)	$Lg = \frac{1}{2D_d}$	Horton, 1932	1.02 Km	Higher surface run off

Table-5. Morphometric Data for Sal River Basin

Stream order	Number of streams (Nu)	Length of the streams (Lu) (kms)	Average length of streams (Kms)
1	932	334.472	0.359
2	219	129.404	0.59
3	51	86.459	1.69
4	10	51.320	5.132
5	4	30.543	7.63
6	1	10.364	10.364
	∑Nu=1217	∑Lu=642.562	

a. **Drainage Pattern:** A variable Drainage Pattern is observed in the study area due to the variable geological nature of the terrain (Fig.3). The southeastern part of the basin, display the trellis, rectangular and parallel drainage pattern indicating a strong structural control. The parallel drainage pattern is also observed in the north eastern part, whereas the southern part consists mainly of sub-dendritic and sub-radial drainage patterns. The lower reaches river, appear to be controlled by either NW-SE or NE-SW lineaments, which are the regional trends of the Dharwarian rocks.

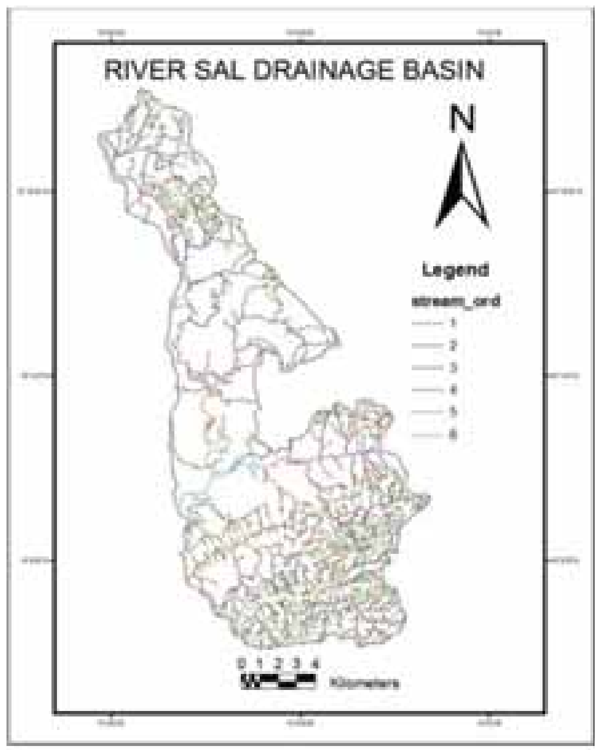

Fig.3 Drainage Map.

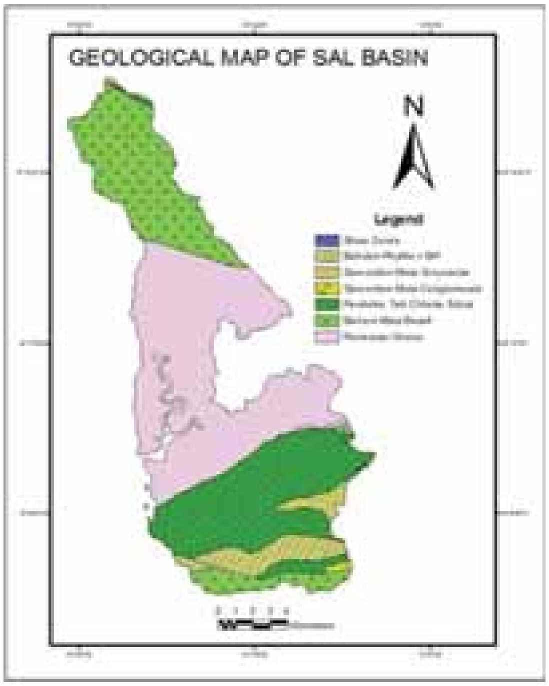

Fig.4 Geological Map.

Sal basin in general shows a very coarse drainage texture in the regions with peninsular gneisses (Fig.4).

This may be accounted for the high permeability of the rocks resulting in low surface runoff where as in the northern & southern portion of the basin with lithologies like metabasalts and peridotites show a fine drainage texture (Fig.4).

b. **Stream Order V/S Number of the Streams:** Streams of the drainage basin follow the **Horton's law of stream numbers**. It states that, when stream order is plotted against stream number on a semi log scale, the number of stream segments of successively lower orders tend to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio (Fig.5). The stream orders which do not follow the law may be structurally controlled.

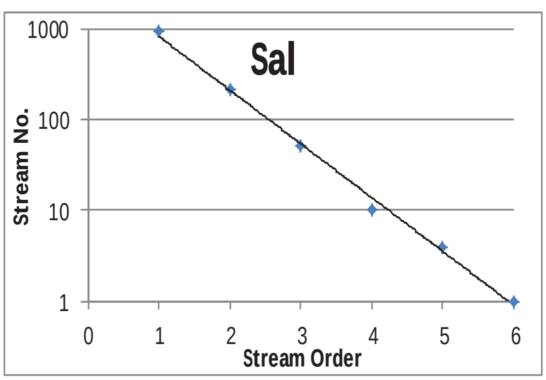

Fig. 5. Plot of Stream Order V/S Number of the Streams

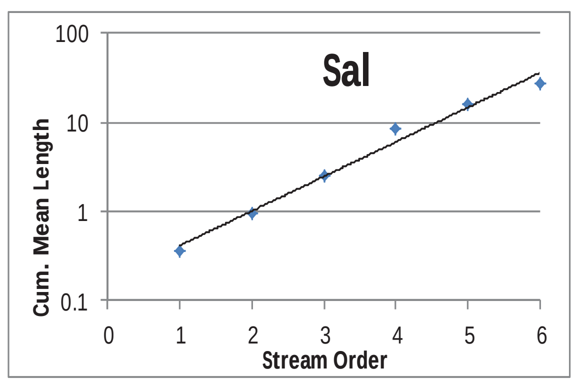

Fig. 6. Plot of Stream Order V/S Lenghts of the Streams

c. **Stream Order V/S Cumulative Mean Length of the Streams:** Streams of the Sal drainage basin follows the **Horton's law of stream lengths**. It states that, when stream order is plotted against stream lengths on a semi log scale, cumulative mean lengths of the stream segments of successive higher orders increase in geometrical progression starting with the mean length of the first order segments with constant length ratio(Fig.6)

d. **Slope Map analysis and:** Prepared slope map of the area which was reclassified based on the range of the slopes, show that Peninsular Gneisses show a general low angle gentle slopes, whereas younger Meta-basalts show steeper slopes in the area (Fig.7). Thus the slopes of the area are related to the underlying geology and indicate the resistance offered by the underground lithologies.

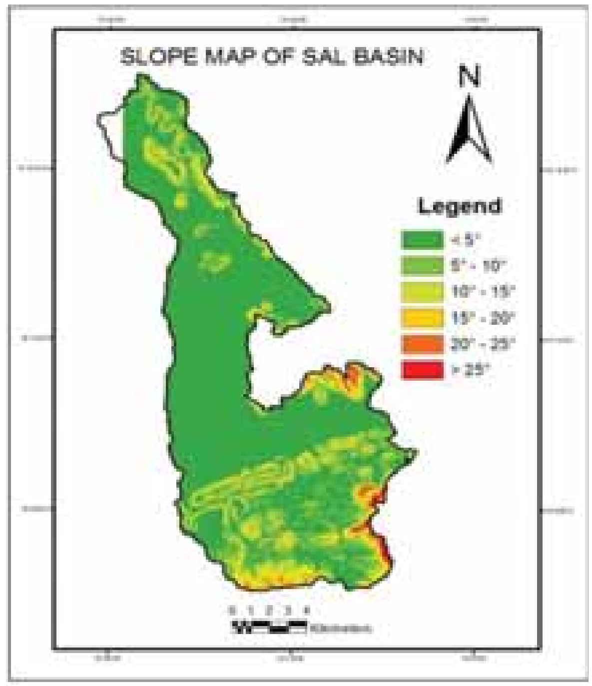

Fig.7 Slope Map.

e. **Hillshade Map**: A clear visualization of the 3-D model prepared of the basin (Fig.8) indicates that the topography or the relief of the area is largely dependent of the underlying geology. In general peninsular gneisses are seen to form low lands with low relief compared to all the other lithologies in the study area.

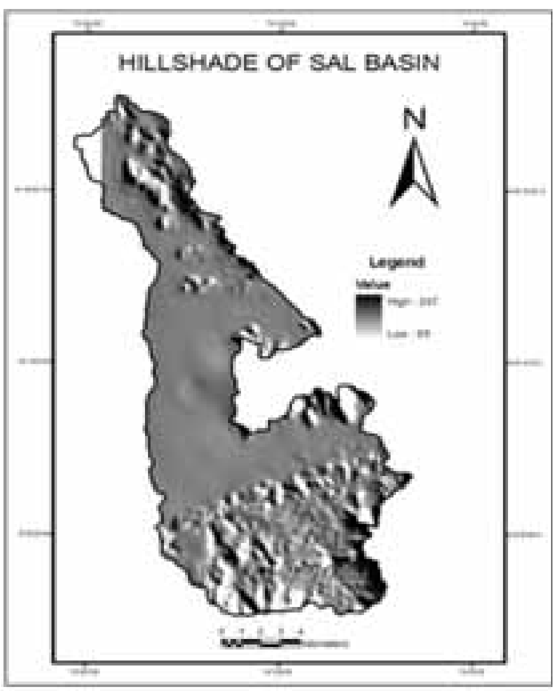

Fig.8 Hillshade Map.

Conclusions:

The Geomorphometry is one of many applications of GIS for better understanding of the morphometric analysis of the drainage basin and channel network play an important role in understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural antecedents of the catchment.

The drainage basin is often selected as a unit of morphometric investigation because of its topographic and hydrological unity. GIS use is of immense utility in the quantitative analysis of the geo-morphometric aspects of the drainage basins. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more easier and appropriate than the conventional methods.

GIS based approach facilitates easy analysis of different morphometric parameters and to explore the relationship among the drainage basin morphometry and topographical, geological, lithological, structural, biogeographical, pedological and hydrological aspects.

Hence from the study it is highly comprehensible that GIS in Geoscience education is a competent tool in geomorphometric analysis for geo-hydrological studies of drainage basins.

ACKNOWLEDGEMENTS: The Geomorphometric analyses related case study included in the present paper is a part of the ongoing doctoral research work of the first author. The authors thank the Goa University authorities for extending all the necessary facilities to undertake the work presented in the paper.

References:

- Bakhale, Y., Dias, R., Pereira, S., Desai, S., Naik, V., Volvoikar, A.; 2006-2007; Morphometric analysis and hydrological study of Khandepar river basin-Goa, India, Unpublished Project Report, 55p.
- Burrough, P.A. & McDonnell, R. A. 1998. Principles of Geographical Information Systems. Oxford University Press Inc., New York, 333pp.
- De Souza, N. G.,1965. Some aspects of the geomorphology of Goa. Vasundhara, Jour. Soc. Univ., Sagar, 2, p.13.
- Gokul, A. R., Srinivasan, M. D., Gopalkrishnan, K and Vishwanathan, L. S., 1985. Stratigraphy and Structure of Goa. In. Seminar Volume on Earth Resources for Goa's development. pp. 1 – 13
- Gregory K. J. and Walling D. E., 1985. Drainage Basin Form and Process - A Geomorphological approach, pp. 47, 54.
- Hengl, T., Reuter, H.I. (eds) 2009. Geomorphometry: Concepts, Software, Applications. Developments in Soil Science, vol. 33, Elsevier, 772 pp. ISBN: 978-0-12-374345-9
- Horton, R. E., 1932. Drainage Basin Characteristics. Trans. Amer. Geophys. U. Vol. 14, pp. 350-361
- Iyer, S. D. and Wagle, B. G., 1981. Morphometric Analyses of River Basins in Goa, In. Geographical Review of India, Vol. 49. pp. 11 – 18

- Malcon, S., Mahender, K. and Kunte, P., 2001. Geomorphometry and micro-watershed delineation using RS &GIS: A Case study of Micro-level; geodatabase creation of Salcete Taluka, Goa.
- Miller, V. C., 1953. A quantitative Geomorphologic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. Department of Geology – Columbia University, Tech. Report 3.
- Pike, R,J. 2000. Geomorphometry- diversity in quantitative surface analysis. Progress in Physical geography, Vol.24, No.1, P.1-20.
- Pike, R.J. 2002. A bibliography of terrain modeling (geomorphometry), the quantitative representation of topography – supllement 4.0. Open-File report 02-465. USGS, Denver, 116.pp. http://geopubs.wr.usgs.gov.
- Rasemann, S., Schmidt, J., Schrott, L., Dikau, R. 2004. Geomorphometry in mountain terrain. In: Bishop, M.P. & Shroeder, J. F. (Eds). GIS and mountain Geomorphology. Springer, Berlin, pp.101-145.
- Samanta, S., Kunte, P. D. and Mahender, K., 2001. Coastal Geomorphology and Landuse Changes along Coastal Parts of Goa: An RS - GIS approach, M. Sc. Dissertation. Unpublished.
- Schumm, S. A., 1956. The evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey, Bull. Geol. Soc. Amor, Vol. 67, pp. 597-646.
- Strahler, A.N., 1964. Quantitative geomorphology of drainage basins and channel networks, in Handbook of Applied Hydrology (edited by V.T. Chow) pp. 4.39-4.76.
- Thornbury, W. D., 1985. Principles of Geomorphology (2nd Edition) . John Wiley & Sons, Inc, New York.
- Tobler,W.R., 1976. Analytical cartography. The American Cartographer Vol.3, No.1, pp.21–31.
- Wagle, B. G., 1987. Geomorphology of Goa coast. Proc. Indian Acad. (Earth Planet Sci) 91. pp. 105 – 117
- Wagle, B. G., 1991. Shores of the Central West Coast of India – A Case Study Using Remote Sensing Data. In: Mahasagar, Vol 24, No. 1. pp. 13 - 20
- Waugh, D.; 1995. Geography - An Integrated approach. 2nd Ed. Chaptor-3 Morphometry of drainage basins. pp. 51-62.
- Barstow, D., 1994, An introduction to GIS in education, In First National Conference on the Educational Applications of Geographic Information Systems (EdGIS), National Science Foundation, U.S. Government Printing Office, Washington, D.C., p. 14-19.
- Chadwick, P., 1978, Some aspects of the development of geologic thinking, Journal of Geology Teaching, v. 3, p. 142-148.

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