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AUTOMATIC DELINEATION OF WATERSHEDS FOR HYDROLOGICAL APPLICATIONS

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ABSTRACT

Geographical information systems (GIS) are proving to be very valuable tools in many natural resources applications such as hydrological modelling of terrain for water harvesting. The basic entity in such applications is the watershed which is either manually delineated on topographic map sheets or derived from digital elevation model (DEM) data using computational methods. A procedure for automatically delineating drainage and watersheds from the DEM of a terrain is presented in this article. The procedure is implemented on a PC in MS-Windows environment and found to give excellent results even in areas with poor relief. This methodology is also applicable for terrains with low vertical DEM resolution (typically, DEMs derived from contours at 20-meter interval). The procedure is implemented as part of the raster analysis module of the Windows based GRAM++ GIS, developed at Centre of Studies in Resources Engineering, Indian Institute of Technology, Bombay, India. This development is funded by the UNDP project 'GIS Based Technologies for Local Level Development Planning' and Department of Science and Technology, Govt. of India.

INTRODUCTION

A watershed is normally described as the total area of water flowing to a given outlet point or more often known as pour point. The boundary between two adjacent watersheds is the drainage line. Pour point is the point at which the water flows out of the area. This is the lowest point in elevation along the boundary or the drainage lines. Delineation of watersheds depends on the catchment drainage pattern of the watershed. This in turn depends on the relief of the area considered. While considering the digital representation of the terrain using the DEM, errors in data, such as artificial minimum points can lead to large numbers of watersheds, which needs to be overcome by suitably preprocessing the data. The steps involved in delineation of watershed including preprocessing of the digital elevation data are discussed in this paper. The preprocessing step includes removal of artificial depressions (sinks) by an iterative process, superimposition of existing drainage in DEM if necessary, generation of flow direction from each cell, calculation of flow accumulation by accumulating the weight for all cells that flow into each down slope cell and derivation of stream network using a threshold on flow accumulation value. In the second step, automatic delineation of watershed is carried out by interactively selecting an outflow point on the stream network. The size of the watersheds generated is controlled by the number of cells that need to flow into a cell to classify it as a stream . Watersheds of different sizes can be achieved by giving different threshold values while building the stream network. In addition to the delineation of watershed a table containing channel length, channel slope, channel slope length, channel width and channel depth. is generated for each watershed. The results generated from this tool can be used for effective watershed modelling and improved landuse practices.

DIGITAL ELEVATION MODEL (DEM)

For most of the parts of the earth's surface, elevation data exist in analogue form as contour maps. These contour maps are converted into digital contour files and spatial interpolation procedures are applied to interpolate elevation values from irregularly spaced points to regular grid points (Clarke et al., 1982). As a result, elevations are available as a matrix of points equally spaced in horizontal and vertical directions and is called as digital elevation model (Figure 1).

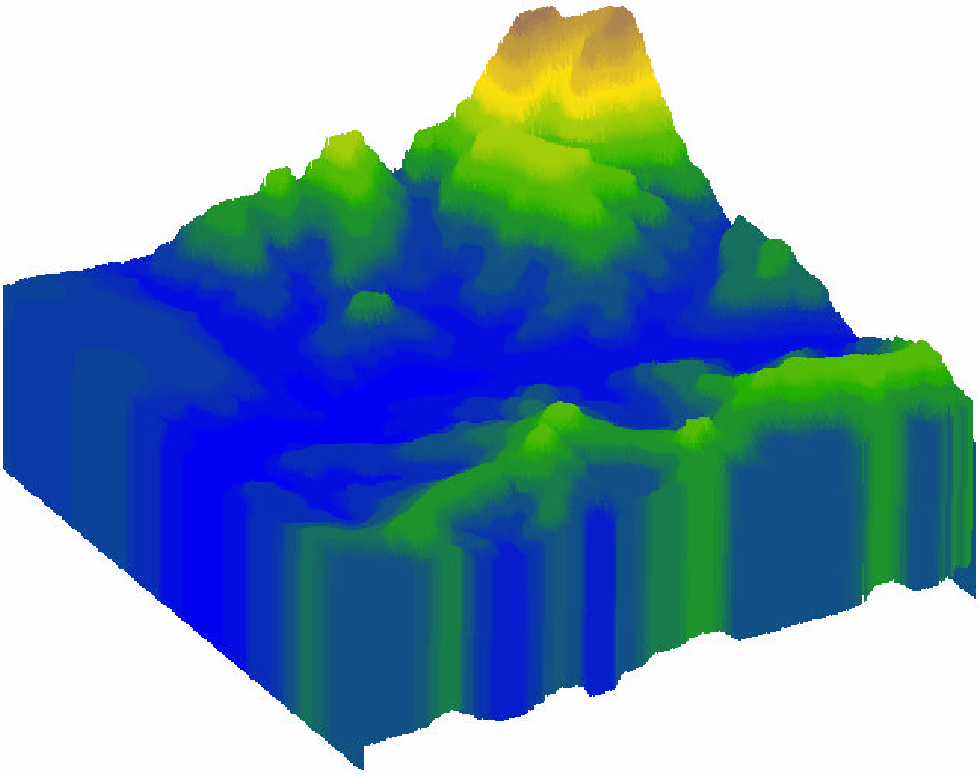

Figure – 1 Digital Elevation Model

PREPROCESSING IN DEM

Preprocessing the DEM is one of the important steps needed to be carried out as a first step in automatic extraction of drainage networks and delineation of watersheds. During DEM generation using the spatial interpolation method, artificial spurious depressions get generated. These depressions or sinks are the cells which do not have neighbours at a lower elevation and consequently, have no down slope flow path to a neighbour cell. They include both flat and depression areas. O'Callaghan and Mark, 1984 suggest that smoothing a DEM prior to analysis reduces the size and the number of sinks. Band , 1986 increases the elevation of sink cells until a down slope flow path to an adjacent cell becomes available under the assumption that flow may not return to the sink cell. Jensen and Domingue, 1988 raise each depression cell's elevation to the lowest elevation value on the rim of the depression. Each cell in the depressionless DEM will then be part of the at least one monotonically decreasing path of cells leading to the edge of the data set. Subsequently they modify the flow directions in all flat areas so as to direct flow from each inflow cell on the perimeter of the depression to the nearest outflow cell on the perimeter. Martz and de Jong, 1988 first accumulate catchment area along flow paths determined from the DEM prior to the depression filling, and then modify catchment area after depression filling to simulate the overflowing of a depression at the lower point on its perimeter. This method has been shown to work well for low-relief landscapes. In this paper, the treatment of depressions and flat areas are carried out modifying suitably the procedure suggested by Martz and Garbrecht, 1992.

First the sinks are identified and the cells contributing flow to the sinks are delineated. Then a potential outlet adjacent to the sink contributing area is found out and the elevations of all the cells in the sink contributing area are replaced with the elevation value of the potential outlet. This results in flat areas which have undefined flow directions. The elevations in the flat area cells are incremented by a small value on iterative way until no cell can be identified as a flat area.

DETERMINATION OF FLOW DIRECTION AND ACCUMULATION

Once the depressions and flat areas are treated, the flow directions are determined for each all. The flow direction is determined by identifying the neighbouring cell which has the highest positive distance weighted drop (Jensen and Domingue, 1988). Direction codes are assigned to mark the flow direction. When the largest positive weighted drop occurs in more than one direction, the cell is assigned the sum of the direction codes of all the direction codes of the direction towards which the largest positive drops occur. During the subsequent pass of the flow direction matrix, such cells are assigned direction codes using a lookup table.

Flow accumulation of a cell is determined as the sum of the flow accumulation values of the neighbouring cells which flow into it. It is an iterative process. Each iteration has a forward and backward pass. The process continues until the flow accumulation values calculated by two successive iterations are identical.

DERIVATION AND ORDERING OF DRAINAGE NETWORK

The drainage network is defined by those cells in the matrix that have flow accumulation value greater than the user defined threshold value. For this purpose, the matrix is scanned and all the cells with accumulation value greater than the threshold are marked to form the drainage network. The network cells which do not receive inflow from any other network cells are identified as source nodes or the upstream ends of the first order channels. The numbering of stream junction nodes and the ordering of the stream network have been carried out using Horton – Strahler stream ordering procedure (Figure 2 and 3).

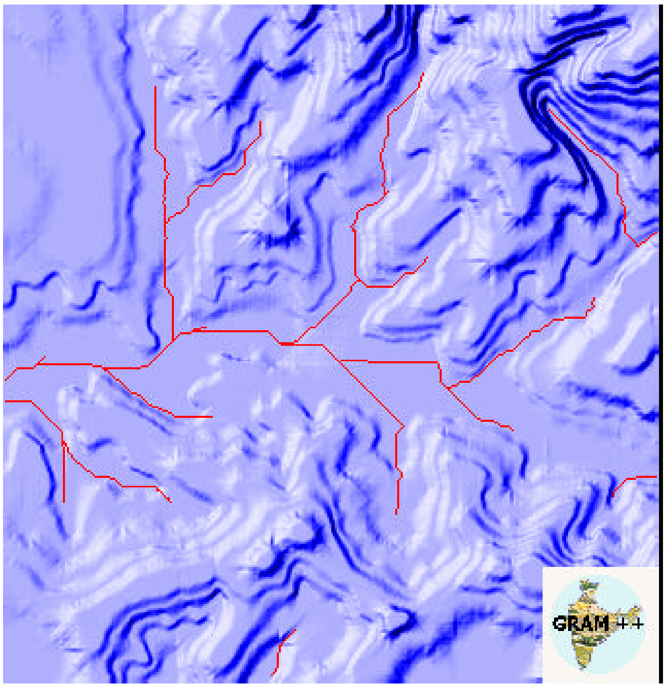

Figure – 2 Drainage Network

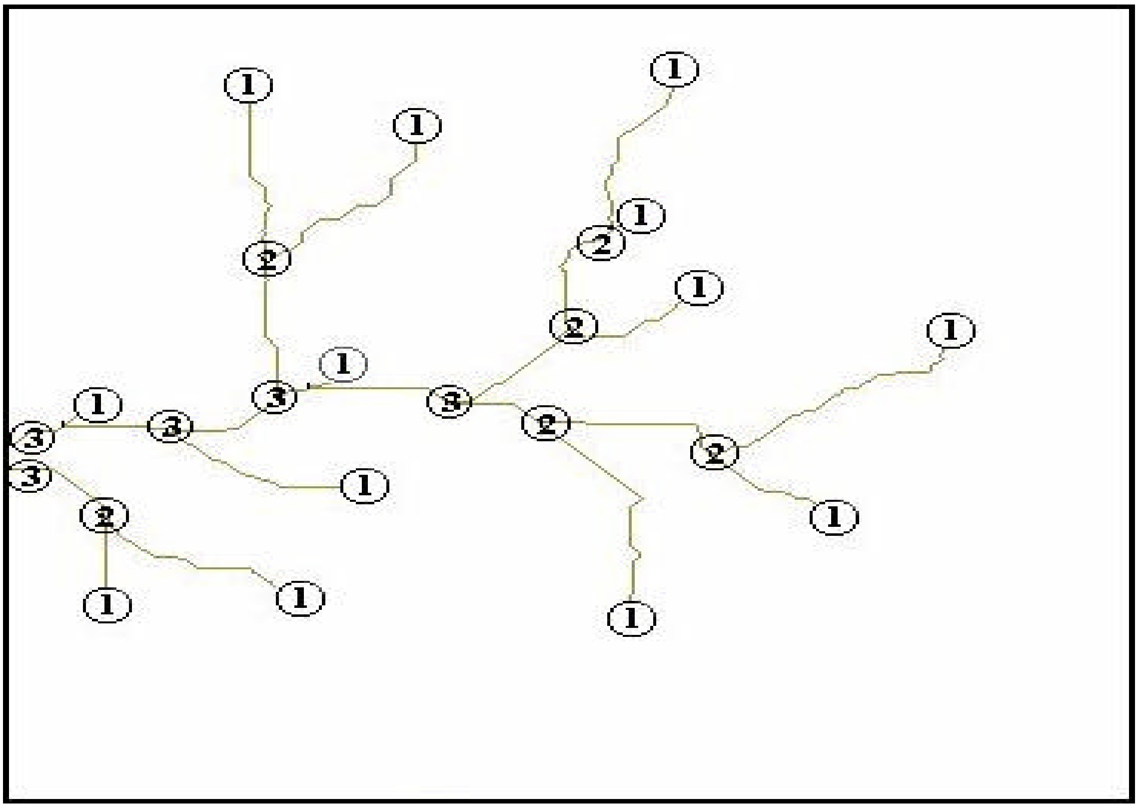

Figure – 3 Order Drainage

DELINEATION OF WATERSHEDS

Along the drainage network the difference between the flow accumulation value of the cell it flows to from its own flow accumulation value is found for each cell. When the difference is greater than the given threshold, the cell is marked as a pour point or outlet point. This procedure identifies all the possible pour points on the drainage network. For delineation of watershed, a pour point of a stream is selected and the cells contributing the flow to that stream are marked as a subwatershed (Jenson and Domingue, 1988). For each subwatershed, the channel length, channel slope, channel overlength slope, channel slope length, channel width and depth are calculated and stored in a table (Figure 4). The result of this study gives depressionless DEM, flow direction matrix, ordered drainage network, delineated subwatersheds and the properties of subwatersheds. These results can be effectively used in hydrological modelling and landuse planning.

WaterShedDetails : Table

SID	UID	AREA(ha)	LENGTH(m)	SLOPE	OVERLENGTHSLOPE	SLOPELENGTH	WIDTH	HEIGHT	XCENTROID	YCENTROID
1	1	223.9491	1513.3201	0.105713	2.431204	9.146341	0.008331	0.004508	217	32
2	2	108.1867	29.1752	4.126493	0.335766	9.146341	0.005384	0.00337	231	70
3	3	387.2932	1534.5582	0.065158	0.866033	9.146341	0.011572	0.006613	62	56
4	4	270.3391	1664.202	0.0721	1.45499	9.146341	0.009327	0.004861	137	54
6	6	147.1288	1139.0483	0.105351	1.732504	9.146341	0.006475	0.003811	172	101
7	7	155.811	887.949	0.179451	1.401117	9.146341	0.006701	0.003899	230	118
8	8	108.6549	132.3252	0.456166	0.328668	9.146341	0.005398	0.003376	129	144
9	9	43.113	968.9915	0.062536	2.704502	9.146341	0.0031	0.002332	140	190
10	10	91.5033	1289.0714	0.076272	2.191191	9.146341	0.004869	0.003152	80	130
11	11	11.9593	219.8509	0.274679	1.956972	9.146341	0.001436	0.001396	107	169
12	12	38.6868	1102.1868	0.090729	3.983789	9.146341	0.002905	0.002233	168	149
13	13	68.3934	695.8071	0.133654	1.512177	9.146341	0.004089	0.002805	166	188
14	14	102.9519	1330.3313	0.075146	2.671175	9.146341	0.005226	0.003304	217	171
15	15	352.8198	1947.4094	0.071638	1.235391	9.146341	0.010943	0.006407	200	253
16	16	193.6891	87.5257	0.685509	0.171822	18.292683	0.007636	0.004254	31	144
17	17	4.8944	697.8806	0.085974	17.268517	9.146341	0.00084	0.000977	48	186
18	18	60.0943	841.6833	0.071283	1.59328	9.146341	0.003783	0.002664	90	171
19	19	206.6273	1339.7356	0.071571	0.898366	9.146341	0.007938	0.004365	108	219
20	20	28.6852	398.4419	0.04202	2.292365	9.146341	0.002428	0.001982	16	183
21	21	302.0035	2042.0137	0.068627	1.585336	9.146341	0.009968	0.006081	281	146
22	22	177.559	860.2399	0.116247	0.992169	9.146341	0.007248	0.004108	258	238

Figure 4 - Subwatersheds and Properties

CONCLUSION

Automated delineation of drainage network and watershed using digital elevation model has been described in this paper. The methodology has been incorporated as a module in GRAM++ GIS package developed at CSRE, IIT, Bombay, India. The results derived from this module can have wider application s in the areas of hydrological modelling, watershed studies and landuse management.

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