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Watershed Delineation in GIS Environment

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Abstract: The management and protection of watershed areas is a major issue for human and habitat systems and forms a basic practice for water studies. The first step in watershed creation requires the preparation of Digital Elevation Models (DEM) of the terrain. This paper introduces a sample DEM prepared using digital photogrammetric method. Professional GIS software was used in the analysis to extract watershed boundaries and perform other calculations. Investigations are introduced to explain aspects of GIS uses in basin subdivision and stream networks and DEM accuracy.

I. Introduction

Watershed is the area of land that drains down slope to the lowest points of the terrain. The water moves by gravity means in a network of drainage pathways that may be underground or on the surface into a specified body of water, river or stream. Although there are many ways for water to enter a stream, much of it will enter as run-off from the land. This land is what forms the stream's watershed. However, in some regions, the water drains to a central depression such as a lake or marsh with no surface-water exit.

It is possible to delineate watershed boundaries manually using a topographic map that shows stream channels, or contour plots. The watershed boundaries will follow major ridge-lines around the channels and meet at the bottom where the water flows out of the watershed, commonly referred to as the mouth of the stream or river, see figure 1,. In contour plots, droplets of water usually travel along lines normal to the contour lines down the hills. As the ground retains water for longer periods, more water will penetrate into ground and reduced amount will reach the downstream mouth of the area.

Fig. 1: Watershed as defined on the ground.

Watersheds can be as large as several hundreds of square kilometers. As the streams get smaller and smaller towards the upstream direction, watersheds can be as small as few square meters. A common term in this regard is the basin and sub basin. Each smaller division belongs to a single stream or a collection of streams in the specified area.

Manual delineation of watersheds can be improved using supportive photographs of the region of appropriate scales. This helps humans in comparing and editing boundary lines. Recently, watershed delineation is performed using automatic methods by computer programs such as WSM. Watersheds form part of GIS analysis activities and can be applied through many related software as IDRISI, ArcView and ArcGIS [1],[2],[3]. In all applications, the basic required input is the DEM of the area.

Delineation and analysis of watersheds can be performed in many forms according to the needs of the user and available resources. Works in this topic are varied samples are included in [4][5][6][7].

There are a dozen of methods for collecting DEM data such as field surveying, aerial photogrammetry, laser scanning, GPS and others. Each method has its own advantages and disadvantages and the created DEM inherent varying degrees of errors.

In this work, DEM data was extracted from sample stereo photographs of a rural region using digital photogrammetric methods [8]. Watershed and stream analysis was processed using the IDRISI software, a comprehensive raster-based GIS software package [9].

II. Materials, Methodology and Results

The sample area used comprises a terrain that is moderately hilly with height range of 285-399 m and have no abrupt terrain discontinuities. A stereopair have been scanned and used for automatic DEM extraction. The photogrammetric program used first re-samples the stereopair into epipolar geometry and performs image matching according to the selected patch window size. The values of x-parallaxes obtained are used to calculate heights (and elevations) of points.

The collection of all result points represent the DEM of the area which was formatted and saved as (.grd) grid file that can be analyzed by the SURFER program [10]. See figure 2. More details on photogrammetric methods is beyond the topic of this paper and can be found at related literature [8].

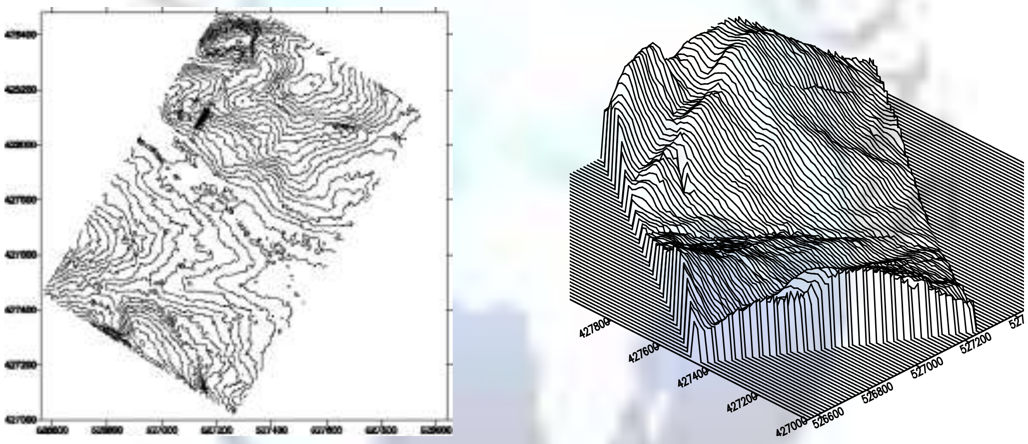

Fig. 2: Contours and 3D plot of the study area.

The IDRISI program was selected as a GIS analysis software. It is an easy to use high performance program with various analysis functions to work on spatial and attribute data [9]. This program requires feeding the name of the DEM file. It accepts a variety of file formats. The output is saved in the special .rst format which can also be converted and saved as ordinary .bmp image file.

For watershed mapping, the WATERSHED function in IDRISI program asks for the seeding value which forms the area threshold, the minimum number of cells required for an area to be defined as a watershed. In this case, only watersheds that include at least the specified number will be identified. We tested a range of area threshold seed sizes of 10, 25, 50, 100, 250 and 1000 cells. The created watersheds are shown respectively in figure 3., (a, b, c, d, e, f).

Various levels of details can be obtained according to the supplied seed value. Selecting the appropriate seed value depends on the needs of the user. Small watershed areas obtained for seed threshold of <50 cells, medium areas between 100 and 250 cells and large areas for seeds of > 250 cells. The pixelwise appearance of the outputs that is shown in figure 3 is due to the fact that IDRISI program is basically a raster based. Raster based GIS programs use matrix of cells covering the whole area. Using the original photographs of the study area help to check and interpret the final watershed map.

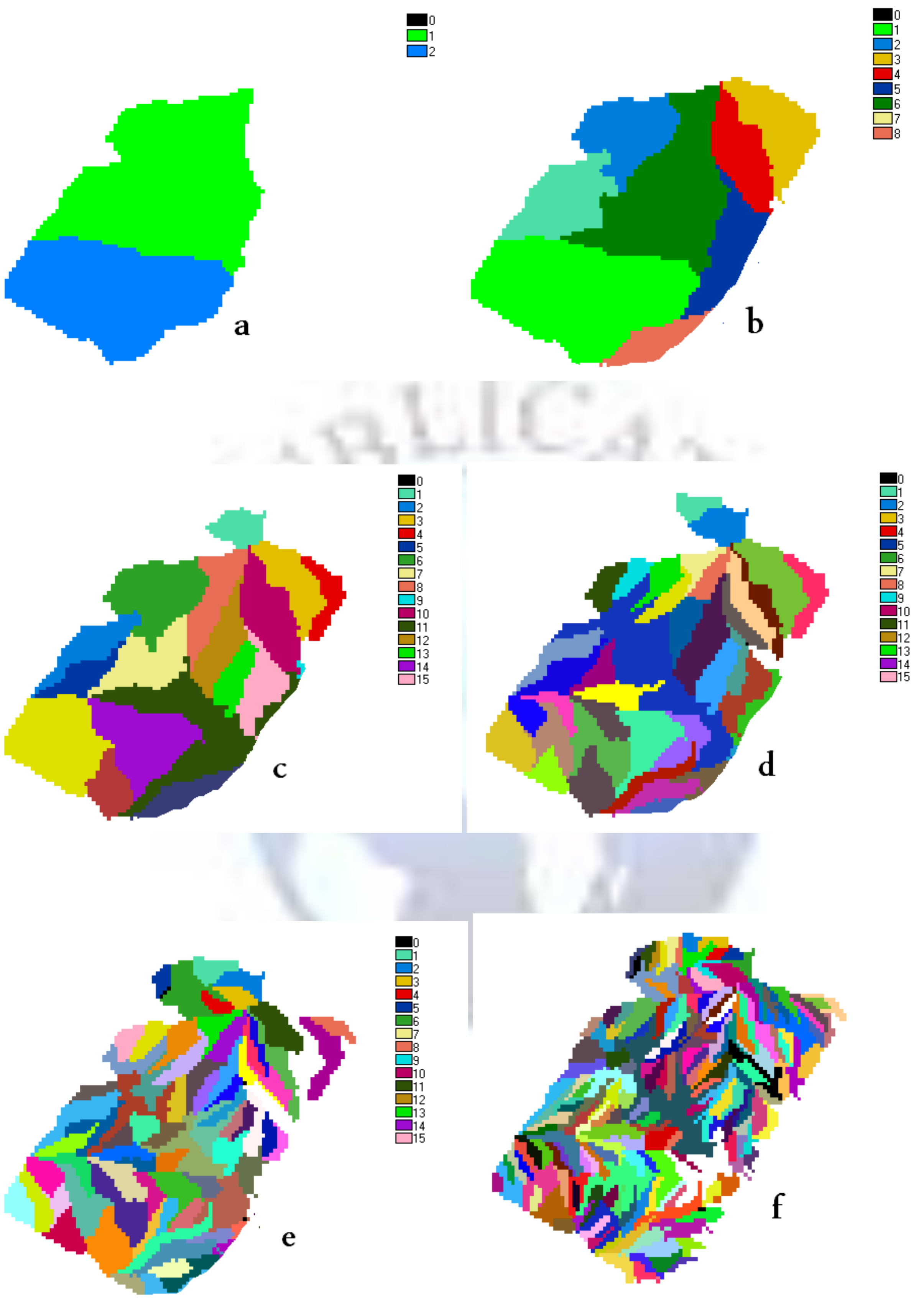

Fig. 3: Watersheds with different number of seed cells,. a 1000, b 250,c 100, d 50, e 25, f 10.

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Accordingly, the number of watersheds observed in the study area at various seed area thresholds are listed in Table 1. By careful examination of table 1 and figure 3, a characteristic curve can show the watershed size and distribution. Figure 4 shows a graphical representation of table 1.

Table 1: Seed areas versus number of watersheds

Seed area threshold,cells	Number of watersheds
1000	2
250	8
100	18
50	56
25	112
10	250

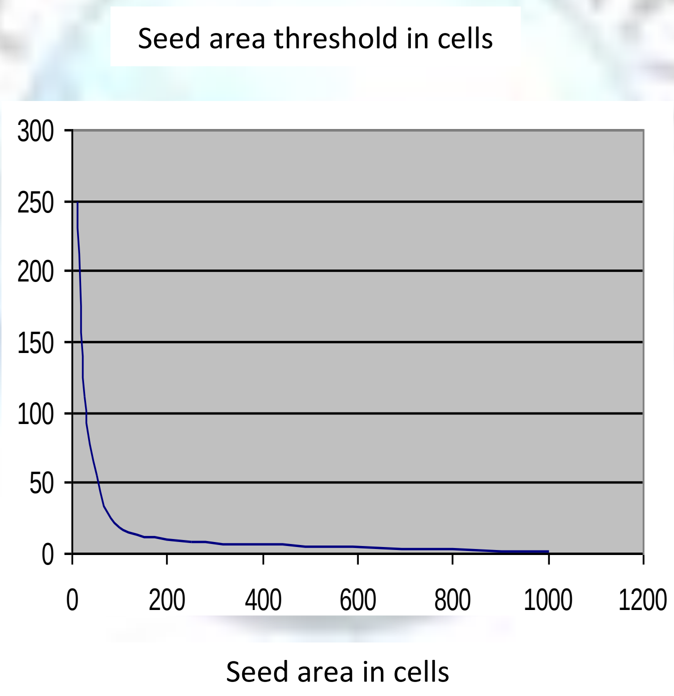

Fig. 4: Seed areas versus number of watersheds.

In the figure, nonlinear inverse relation is observed. Lowering seed area in cells increases the number of watersheds considerably. The shape of this plot is governed by the terrain characteristics, ruggedness and number of major and minor streams.

In order to interpret the distribution of the watersheds shown above, It will be important to augment the output maps to the stream networks of the region. The IDRISI module (RUNOFF) displays the stream network based on the original DEM data of the area. Figure 5 shows a raster form of the output of two levels of stream details.

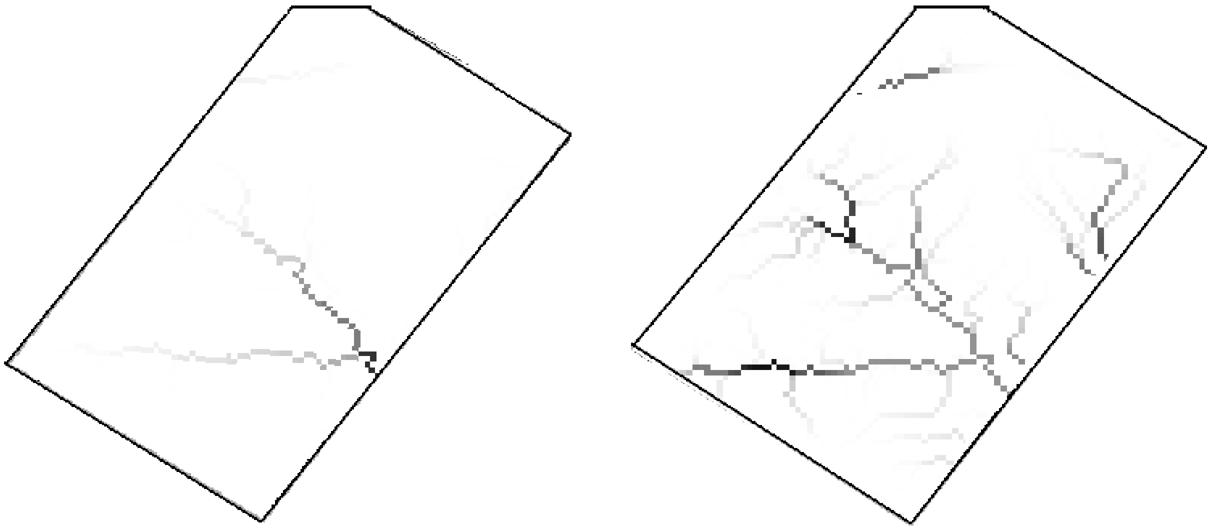

Fig. 5: Two degrees of details of stream networks obtained from watershed.

III. Simulated watershed

DEM precision vary according to the method of collecting elevations of ground points. To show the effects of random errors in calculated DEM, we produced simulated watersheds using fictitious DEM data. Simulated version of ground surface was created by adding a random noise in elevation values of mean 0 m, and standard deviation of 0.5 m to the original DEM. The produced output was then used to create watersheds using the same program. Two seed values (1000 and 10 cells) were used as they represent extreme cases for the comparison shown earlier in figure 3. Figure 6 shows the two simulated outputs.

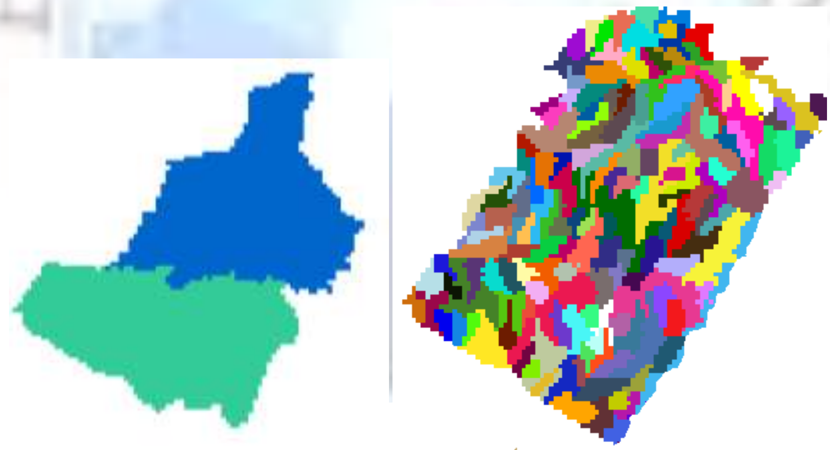

Fig. 6: Simulated watersheds created at 1000 and 10 seed cells (compare with figures 3a and 3f.)

As compared to figure 3(a and f), larger watershed areas are less affected by the introduced error, while the smaller watersheds are affected considerably in shape and extent. There is considerable deviation from that produced from the original run shown earlier in figure 3.

The tools of GIS have been used to simulate a new version of the original DEM by exaggerating the elevation component (Z values). A factor of 3 have been used to produce a more representative output for easier interpretation as shown in figure 7. Watershed result of the exaggerated DEM with seed value of 250 cells is shown in the figure.

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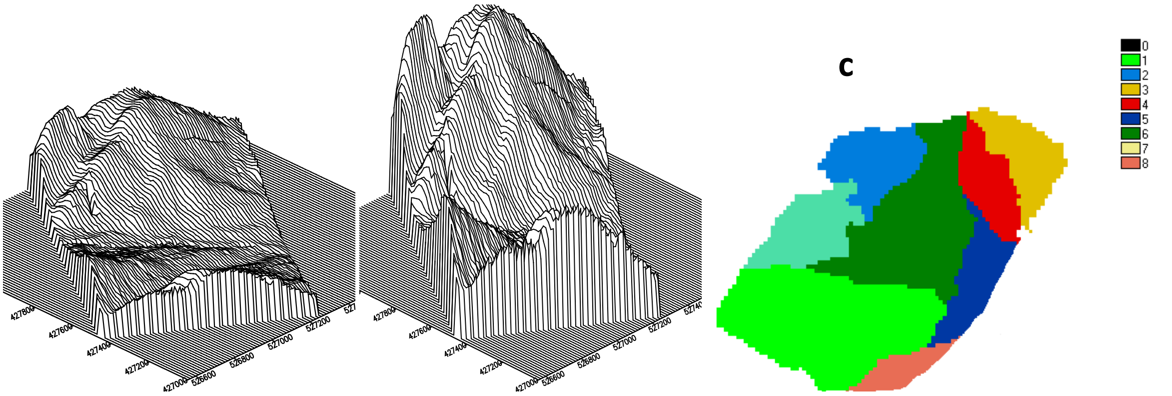

Fig. 7: Original DEM, 3X exaggerated DEM, and the result watershed of exaggerated DEM.

Comparing figures 3b and 7 shows that the two versions of DEM produce identical watershed areas. If we calculate slope images we can note that the two results differ considerably as seen in figure 8. Higher slope values in degrees (lighter tones) are noticed in the exaggerated version of the DEM test set. The slope image helps analyzing water velocity and soil erosion in the studied area.

Soil erosion within the watershed region increases with increased ground slope and amount of flowing water.

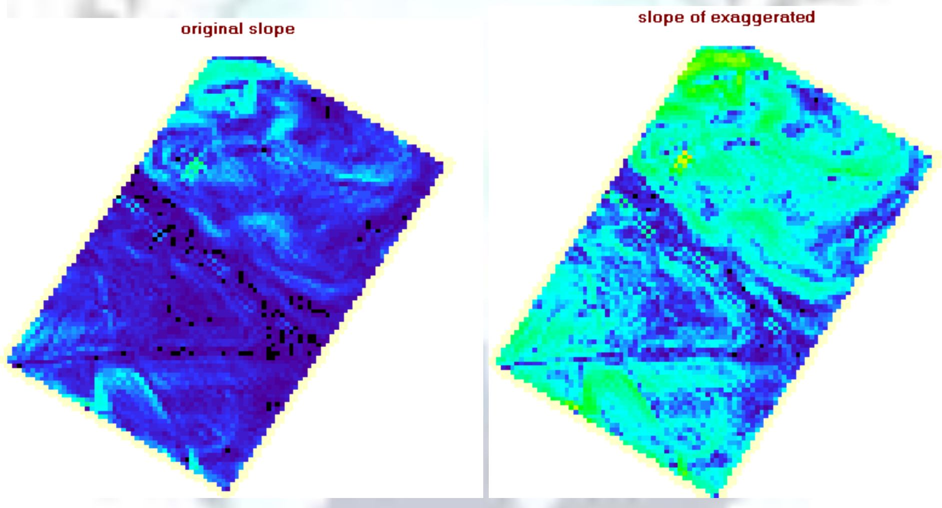

Fig. 8: Slope images of original and exaggerated DEMs. Color scale represents slope angles in degrees. Dark blue represents low ground slope angles

IV. Discussions and conclusions

Manual methods of watershed delineation are now uncommon. Automated watershed delineation can be performed using GIS application programs such as IDRISI which is mainly a raster based program. The basic requirement is the DEM of the region. Different methods of collecting DEMs differ in the precision of output. Digital photogrammetric methods provide very fast and acceptable accuracy results for water studies. The number of produced watersheds will depend on their sizes. An inverse nonlinear relation characterizes watershed distribution in the region.

Using simulated data, it is found that non precise DEMs create watersheds that differ in shape and area from those obtained using precise data. The difference is more noticeable and serious in smaller watersheds. The author suggests more studies in this aspect to fix the required precision that is suitable for specific work.

An exaggerated DEM (in elevation) gives exactly the same watershed shape and area obtained using the original DEM. But the slope image of the latter is also exaggerated.

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