COMPARATIVE ANALYSIS OF DRAINAGE NETWORKS EXTRACTED FROM DEMS AND CONVENTIONAL APPROACHES IN LEBANON

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ABSTRACT

Drainage networks are major elements of watershed assessment as they reflect its topographic, geologic, hydrogeologic and tectonic characteristics. The conventional identification of drainage networks from aerial photographs and topographic maps is effort and time consuming. Therefore, many algorithms have been developed in the last three decades for the extraction of drainage networks from satellite imageries (Spot, Landsat, Radar). But these digital delineations still prove to have some gaps and disagreements with those obtained by conventional methods.

Accordingly, this paper aims to analyze the gap by a comparative analysis between drainage networks extracted from a digital elevation model (DEM) obtained from radar imageries and those delineated from topographic maps at scale 1:50,000. Accordingly, a coincidence value of overlap of same features (39%) was found between the two approaches. Adaptation of various thresholds in the algorithms of the digital pixels, taking into account the geological and geomorphologic properties of the basins, has improved the agreement between the automated and the manually delineated drainage network. An improvement of 7% was achieved in the elevated crests, 4% in the gentle slopes, 10% in the plateau and 26% in the plain, giving a total overlapping of 51%.

Keywords: drainage network, digital elevation model, morphology, automated extractions

INTRODUCTION

Drainage networks are one of the major elements characterizing basins' topology and geometry. They have been described as the aggregate of all terrain surfaces adapted to hydrological flow and accumulation (Deffontaines & Chorowicz, 1991). Hydrologists, geologists, agricultural engineers, and many other environmental experts depend to a large extent on these networks to extract information on topography, lithology, geological structure, soil, vegetation cover and climate. They are significant for proper assessment of physical and ecological phenomena, as well as land-use planning.

Delineation of details of the drainage network is proportional to the scale factor, and when accurate information are needed, tremendous efforts are required. Normally, conventional methods like the stereoscopic vision of aerial photographs accompanied with field truthing were used to delineate drainage networks and plot them on topographic maps. These methods were time-consuming and costly, and the presence of errors was depending on the aerial photograph scale, the geomorphology of the area and the subjectivity of the interpreter.

In the last three decades, Digital Elevation Models (DEMs) are becoming crucial tools in investigating natural and anthropic influences especially for spatial geo-information purposes. They are usually generated using various techniques, *i.e.* interferometry, image stereoscopy, contour elevation lines, *etc*. Accordingly, several algorithms have been developed allowing the extraction of drainage networks using different specialized programs (Rianzanoff *et al.*, 1988; Donker, 1992; Kovar & Nachtnebel, 1993; Ichoku *et al.*, 1996; Li & Li, 1999; Li & Sui, 2000; Wood, 2000; Samuels & Maidment, 2001). All the algorithms follow a general approach based on four essential data level matrices: an elevation matrix, a flow direction matrix, a ranked elevation matrix and a flow accumulation matrix. The elevation matrix comprises the real topographic surface represented by a regular continuous grid, *i.e.* DEM. The flow direction calculates the flow for each cell to its steepest down-slope neighbor. In the ranked elevation matrix, the cells of the DEM are ranked from the highest to the lowest elevations. The flow accumulation matrix calculates the value of flow from one cell to another, accumulating values from uphill cells into each cell. Thresholds are defined giving the minimum number of cells required to form the connected drainage network. In addition to the applied algorithms, the extraction of drainage network is highly dependent on the accuracy and precision of the DEM used. Best possible standard planimetric elevation errors with spaceborne systems currently range between 1 and 10 meters, but altimetric elevation errors can be much larger, under unfavorable conditions (Sasowsky *et al.*, 1992; Harding *et al.*, 1994; Zebker *et al.*, 1994; Lanari *et al.*, 1997).

This paper thus focuses on a comparative analysis of drainage networks extracted from the advanced DEM tools, through applying the above described matrices, to those extracted conventionally from topographic maps considered as reference maps.

DESCRIPTION OF STUDY AREA

The study was made on a pilot area “Hasbani-Wazani watershed”, which is a river basin with permanent watercourses located in southern Lebanon (Figure 1). It is a relatively big catchment in Lebanon with an area summing up to 670 km^2, 6% of the total area of the country. This basin has an elongated oval shape of NE-SW direction, with 20% of its area having slopes exceeding 67%. It lies at the Lebanese international boundaries, with highest peak of elevation 2814 m along Mount Haramoun. It is blessed with the Hasbani-Wazani river flowing southward into the Jordan river basin. The annual precipitation rate in the study area ranges between 600 mm/year in the W and NE parts and 1100 mm/year over Mount Haramoun chains (E-W part). The total amount of precipitation is equal to about 551 Mm^3/year, from which around 50% is evapotanspirated, 29% is running to Jordan river basin and 27% infiltrates towards the Syrian territory (Jaber, 1995).

The Hasbani-Wazani watershed is a basin that has experienced several evolutionary phases during the Tertiary and Quaternary ages. Geomorphologically, it can be subdivided into four main parts, the elevated areas, the gentle slopes, the plateau and the basaltic plain (Figure 1). The crests (1350-2800 m), with slopes exceeding 30°, constitute 32% of the whole basin and are formed of highly fissured, well karstified carbonate rocks with very steep slopes.

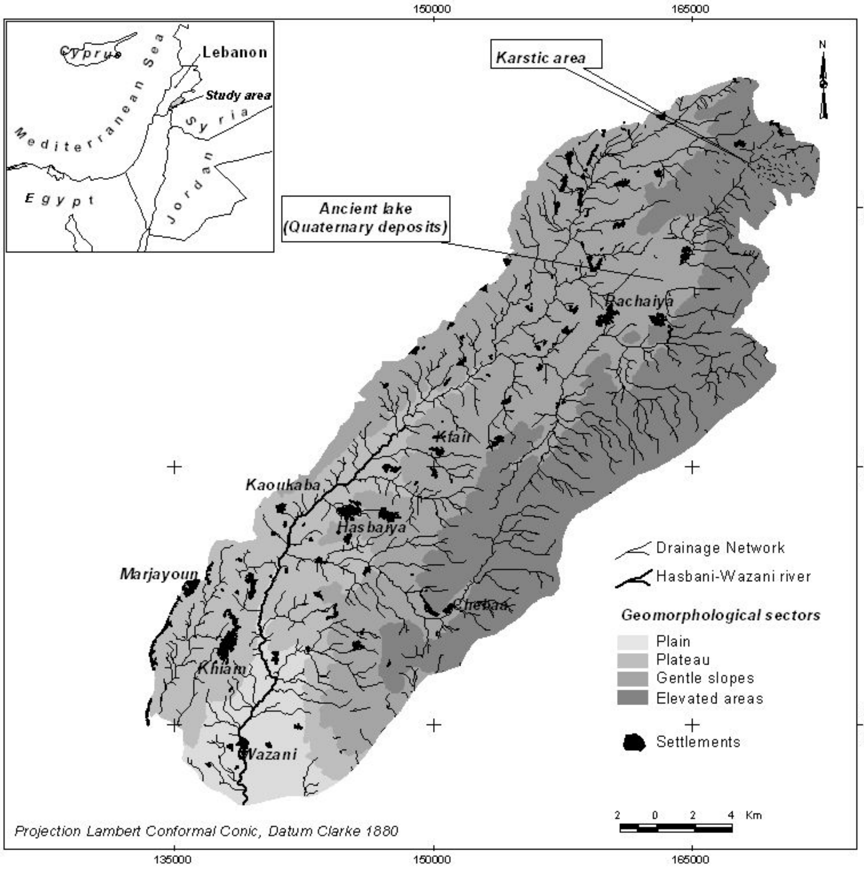

Figure 1. The Hasbani-Wazani basin and its four geomorphological sectors.

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Gentle slopes (800-1350 m), with slopes varying between 10 and 25°, are developed on different rock types, *i.e.* limestones, marly limestones, sandstones, marls and clays, belonging to the Cretaceous and Quaternary deposits. They occupy 42% of the total study area and embrace most of the basin villages. The plateau (500-800 m) with an area of 19% and slopes ranging between 0 and 5°, is composed of limestones and marly rocks with some drainage courses not connected to the main stream in the Lebanese basin (Khiam area) but discharges southward to meet the principal Jordan river basin. The plain (200-500 m) constituting the lower part of the basin with slopes inferior to 2°, is formed of basalts of the Pliocene and occupies an area of 7%.

MATERIALS AND METHODS

The methodology followed in this study comprises three main steps: 1) conventional manual delineation of drainage networks from topographic maps; 2) Automated delineation of these networks using DEM; and 3) Comparative analysis between the manual and automated methods.

Manual delineation of drainage networks

The study area is covered by six topographic maps at a scale of 1:50,000 (DGA, 1963). These maps were scanned and registered based on the affine transformation with a first polynomial order and using the *Erdas imagine 8.7* software. Drainage networks were delineated on each digital topographic map using heads up digitizing. The main stream (permanent one) was given a different ID to be differentiated from the temporary water courses during digitizing procedures. All the six digital drainage networks maps were joined and appended by using *ArcGIS 8.3* software. Therefore, topology was built and maps were cleaned to ensure network connections and erase errors in the obtained coverage (Figure 2).

Automated extraction of drainage networks from DEM

The automated extraction of the drainage system was performed on a DEM generated from synthetic aperture radar (SAR) interferometry images provided by Cornell University (USA) in 2002. This DEM was enhanced by raising GPS field campaigns (150 points) and thus leading to 20 m altimetric and planimetric accuracy.

The DEM has been registered into Lambert Conformal Conic system that matches the coordinate system commonly used in Lebanon. Despite the fact that DEMs through SAR interferometry are becoming one of the most active research topics nowadays, they still lack the quality control and the standard procedures for quality assessment (Sasowsky *et al.*, 1992; Bolstad & Stowe, 1994). Therefore, the nearest neighbor subsampling method was applied on the DEM allowing the removal of surface noise and enhancement of the presentation of surface shape. But this method is usually associated with coarsening the DEM resolution to 30 m. Special hydrological algorithms are used depending on known matrices to derive the surface runoff characteristics (Figures 2, 3).

**DEM surface correction*

The produced elevation surface (DEM) still contains several errors, usually classified either as sinks or peaks (one or two cells below or above the local surface). These errors vary between 0.1 m and 4.7 m in a typical 30 m DEM (Tarboton *et al.*, 1991). Although many authors agree that sinks and peaks may actually represent the true nature of topography

(Chorowicz *et al.*, 1992), they may act as local barriers that trap water flow and cause a major problem for drainage network extraction. To avoid this problem and before performing any hydrologic analysis, sinks in the DEM were identified and eliminated using *ArcView 3.2 software* with Spatial Analyst extension (Figure 3).

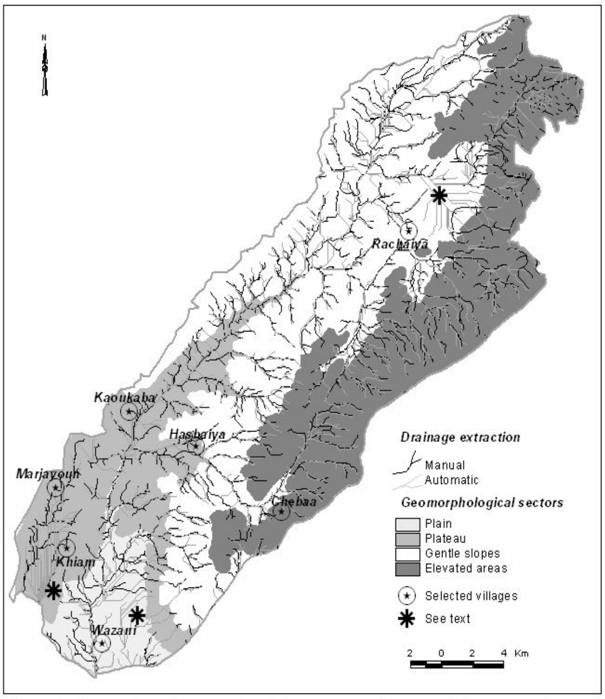

Figure 2. Comparison between the drainage networks extracted manually from topographic maps and automatically from a DEM.

Figure 2. Comparison between the drainage networks extracted manually from topographic maps and automatically from a DEM.

**Flow direction matrix*

Water at any given pixel location will flow to one of the eight adjacent neighboring pixels. Flow direction can be simplified as follows: "Dump a bucket of water on your surface and see which way it flows". The direction of flow was determined using ArcView 3.2 by finding the direction of steepest descent from each cell. The latter can be defined as the change in elevation values by distance. If the descent to all eight neighbors is equal, then the neighborhood is enlarged until a solution is found and the flow path follows a continuous down hill path. Other methods exist (*i.e.* multiple flow algorithm) and can affect significantly the steepest descent of the drainage network.

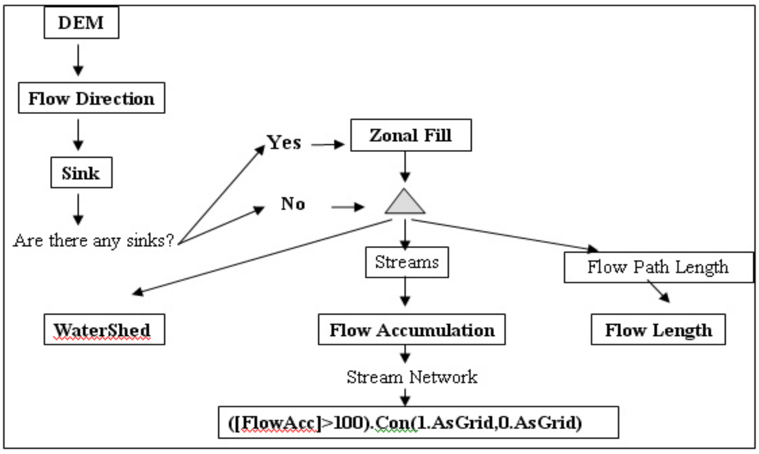

Figure 3. Flow chart showing the various procedures in extracting drainage networks from DEMs.

**Flow accumulation matrix*

Flow accumulation calculates the value of flow from one cell to another, accumulating values from all uphill cells into each cell. Most cells will have very small accumulation values, but the few cells that represent major streams will accumulate very large values (ESRI, 1996). In other words, it is assumed that one unit of water is available at each cell, that unit of water is then moved into the neighbor cells downhill. With the result that the cell of origin has a value of 1 and the downhill neighbor has a value of 2, the process continues until the bottom of the drainage.

**Stream network matrix*

From the flow accumulation matrix, a threshold value was assigned. The term threshold is used to determine cells with the highest accumulated cell values (cells with the highest values are stream channels). Thresholds are related to streams order and they are setup by algorithms through the ArcView software. Several authors emphasize the need for an appropriate choice of threshold as the morphometric properties of the network vary considerably depending on its value (Helmlinger *et al.*, 1993; Gandolfi & Bishetti, 1997). According to Strahler classification (1952), the drainage network of the Hasbani-Wazani river belongs *to the seventh order*. The mean area of first order in the Hasbani was identified and a value of 0.06 km^2 was given which is equivalent to 67 cells.

Comparison between manual and automated network extractions

Obviously neither of the obtained drainage networks is free of errors. For comparison purposes, the manually extracted drainage networks from topographic maps are considered as a reference. To make the comparison possible, the automated drainage network layers extracted from DEM were converted from raster into vector. A STREAMLINE command (ArcGRID Workstation) was used to prevent adjacent cells holding the same value in creating parallel segments. The extracted drainage networks from DEM were then superimposed on the manual drainage networks. Two main features were considered in the comparison method, the spatial degree of coincidence (total overlapping) between the network and the drainage density computed for each network. This latter was defined as the total length of the network in km divided by the total basin area in km^2. This comparison also took into consideration the morphometric properties of the Hasbani-Wazani basin.

RESULTS AND DISCUSSION

The automated comparison reveals a poor agreement between the two drainage network maps (Figure 2). Only 39% of the total automatic network (DEM) coincides with the manual pattern. However, if one takes into consideration the four geomorphological areas separately (mentionned previously), the degree of coincidence increases to 67% in the headwaters sector (elevated areas), to 45% in the plateau area, and decreases in gentle slopes (19%) and plain (22%) (Figure 4).

According to drainage density, a value of 2.4 km/km^2 was obtained for the whole manual network and 2.9 km/km^2 for the automatic one. Because these values are fairly similar, they can be considered as a good indicator of the spatial correspondence of the networks.

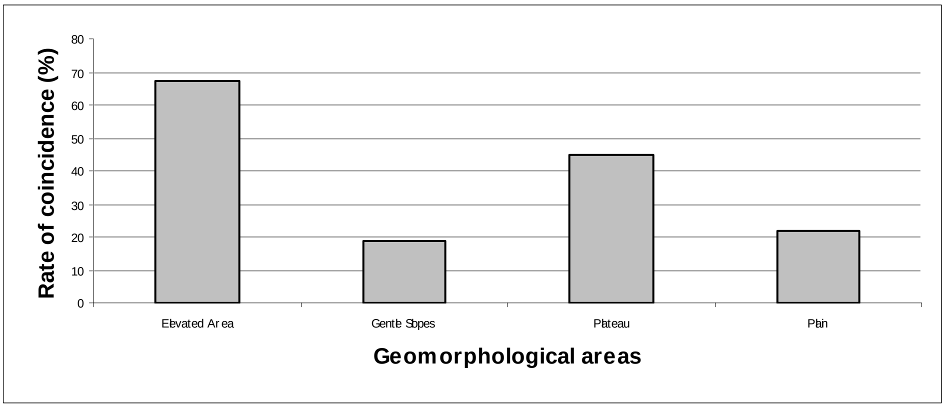

Figure 4. Rate of coincidence between the manual and automated drainage networks onto the four geomorphological areas.

Table 1 shows the values of drainage density obtained for each geomorphological area in the manual networks and those obtained for the automatic ones.

TABLE 1

Drainage Density (km/km^2) of the Manual and Automated Networks of the Geomorphological Areas

Type	Elevated Area	Gentle Slopes	Plateau	Plain
Automatic	2.7	3.3	2.8	3.1
Manual	3.1	1.6	2.0	1.9

Geomorphological processes and network development

The poor correspondence between the two networks could be due to the inability of the automated extraction method to consider the dynamic aspects of the drainage systems. This method uses a single flow accumulation value to characterize the whole basin. The drainage basin is considered merely as a geometric surface divided into drainage and channel cells and is open to discussion. It is the result of a complex geomorphological evolution, and is better considered as an open process-response with energy and matter (climatic regime interactive with surface lithology) inputs, and running water and sediments outputs (Chorley & Kennedy, 1971; Schumm, 1977; Morisawa, 1985). Basin forms adapt to the dominant processes in a dynamic way (erosion/accumulation) and, consequently, the morphology of the basin responds to the energy budget.

Additionally, the network, as a prime component of fluvial morphology, is conditioned by a dynamic behavior. In general, erosive processes dominate in upstream areas, transport processes dominate in the middle sector, and accumulation dominates in the lower basin. Consequently, networks tend to have numerous channels in the headwaters (with a small number of flow accumulation cells per channel unit), few channels of a superior order in the middle basin (with a higher number of flow accumulation cells), and a unique well developed channel in the plain (where the number of flow accumulation cells will tend to be the total area of the catchment).

In the Hasbani-Wazani basin, the comparison between the automated and the manually extracted networks showed better agreement in the elevated crests (headwaters) because the threshold value used for network extraction (mean first order channel area) corresponds to the channel order that predominates in the area. The automated method depicts a high density of channels, which does not agree with the main geomorphological processes dominating these areas. The largest errors were found in gentle slopes areas (81%) and in the plain (78%), while the plateau showed (55%) errors.

Although the elevated crests had the best agreement, areas undergoing karstic absorption, especially in the North East part of the basin, showed errors. Usually, the presence of karstic features is easily discriminated on the topographic map by their disconnected drainage networks. Thereof, the correction performed previously on the DEM surface has filled the naturally existing sinkholes, which gave an inaccurate connected drainage networks.

The calcareous plateau has an endogenous hydrological behavior with karstic absorption depressions and small valleys, which carry only water during severe flooding.

These poorly developed small valleys are disconnected from the main network. Additionally, some parts of the plateau (Khiam) are highly reworked areas. These two aspects are reflected on the DEM and generate drainage lines that are erroneously connected to the main network during the automated extraction (Figure 2).

In the plain, the basalts of the Pliocene is highly jointed and fractured. These linear features (fractures and joints) are expressed on the DEM by false drainage networks (Figure 2).

In the gentle slopes, the poor agreement can be seen in the different channel routes and in the channel densities. It seems that the big disagreement (81%) is related to different lithological formations (limestones, marly limestones, sandstones, and marls) (Figure 2). The rills and small gullies in the soft materials (marls and sandstones) confuse the automated drainage extraction and add networks to the current ones. Also the presence of flat Quaternary depressions (old lakes) line up and connect the drainage networks where they should not. The anthropic influences (most of the villages are located in this area) aggravate the automated drainage network especially with the widespread irrigation channels. In addition, one of the six topographic maps had contour intervals of 20 m (the others being 10 m). This fact depicts itself through the density of the blue lines found on the topographic maps, usually less density.

Moreover, many alterations occur on the landscape during the past years. This can increase the poor agreement between drainage networks delineated on topographic maps dated in 1963 and those extracted from DEMs (2002).

Various thresholds in automated extraction

Taking into account the specific characteristics of the Hasbani-Wazani basin, new automated network extractions were performed using different threshold areas for each geomorphological sector. The optimum thresholds used in each sector was selected according to the predominant channel order in each zone. An average area value was estimated and converted into the corresponding number of cells (flow accumulation value) (Table 2). The elevated crest area shows steep slopes and high energy with a predominance of first-order channels (average area of 0.06 km^2 = 67 cells). In the gentle slopes, third order channels are predominant (average area of 0.7 km^2 = 782 cells). In the plateau, the fourth and the fifth channel orders are widely dominant (average area of 13.65 km^2 = 15243 cells). For the basaltic plain, an area of 166.4 km^2 (185813 cells) was assigned, corresponding to the seventh channel order.

TABLE 2

Optimum Thresholds of Channels in the Geomorphological Areas

Sectors	Elevated area	Gentle Slopes	Plateau	Basaltic plain
Stream Order	1	3	4-5	6-7
Threshold (cells)	67	782	15243	185813
Area (km^2)	0.06	0.7	13.65	166.4

The karstic areas in the elevated crests were masked and the refill process was repeated on the raw DEM to obtain depression-less topographic surface. Another mask was performed on the gentle slopes sector before the application of the automatic extraction. This mask prevents erroneously closed network striations. Then four new automatic networks were obtained and compared with the manual delineated network, which was also reclassified into four new networks, *i.e*. from the first order channel for the elevated crests, from the third order (gentle slopes), from the fifth order (plateau), and from the seventh order channel (plain). Figure 5 shows the coincidence ratio between manual and automatic networks obtained for each sector, both for the new networks as well as the previous data shown in Figure 4.

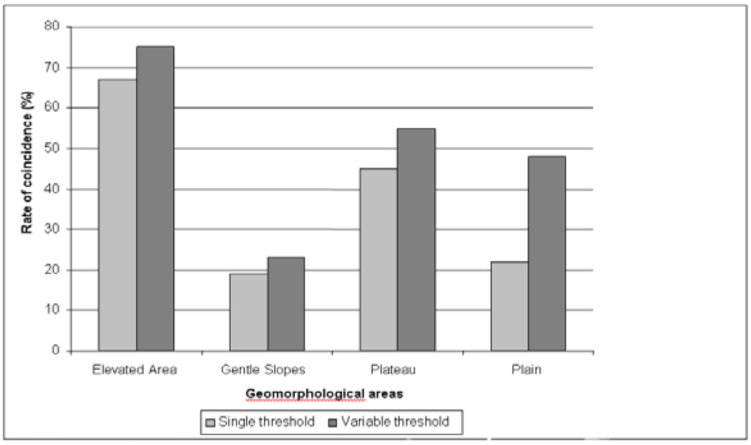

Figure 5. Comparison between single and variable threshold areas and the rate of coincidence between manual and automated drainage extraction in the four geomorphological sectors.

Although the coincidence between manual and automatic networks was still poor, better agreement could be observed when specific thresholds were used for each morphological area (variable order network) than when a single threshold is used for the entire basin. An improvement of 7% was achieved in the elevated crests, 4% in the gentle slopes, 10% in the plateau and 26% in the plain sector.

The results of the analysis of drainage density are summarized in Table 3, which shows better agreement between the values of drainage density obtained in the manual and those obtained for automatic network. The automated drainage network extraction is improved in the Hasbani-Wazani basin by choosing different threshold values (flow accumulation cells) in each geomorphological sector of the basin. This value is directly related to the main stream order of each sector, and indirectly related to the geomorphological processes.

TABLE 3

Drainage Density (km/km^2) in the Four Geomorphological Sectors through Utilizing Variable Threshold Areas

Type	Elevated Area	Gentle Slopes	Plateau	Plain
Automatic	2.3	2.7	2.3	2.1
Manual	3.0	1.6	2.0	1.9

Figure 6 shows the network extracted automatically by using different threshold values and the enhancements obtained by this procedure. Although errors are still present in different parts of the basin, the resulting network agrees much better with that extracted manually than when the extraction uses a single threshold value for the whole basin. Moreover, drainage network delineation is highly related to the scale of work and source of information. This concept is considered when delineating first order channels where the extent and even the presence of these channels could vary depending on the contour intervals on topographic maps of the same scale.

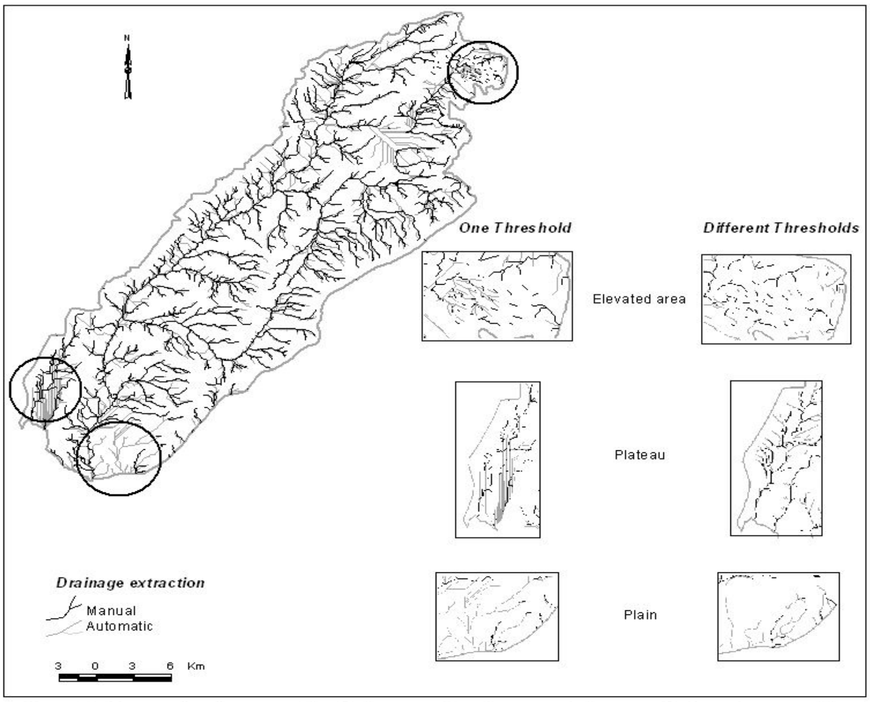

Figure 6. Comparison between the drainage networks extracted manually from topographic maps and automaticaly from a DEM using diffrent threshold areas

Figure 6. Comparison between the drainage networks extracted manually from topographic maps and automatically from a DEM using different threshold areas.

CONCLUSION

Some conclusion can be drawn comparing manual and automated extractions of the drainage network in the Hasbani-Wazani basin. Despite the limitations found during comparison, an overall poor agreement was found. Nevertheless, some degrees of coincidence appear in different parts of the basin. The automated extraction techniques seem to be more appropriate in the elevated areas "Headwaters" but not in the gentle slopes and plateau, especially when soft materials and reworked areas are highly developed.

The obtained results of the automated extraction are highly related to the selected threshold value (minimum number of cells required to form a channel unit). The latter, in its turn, is very dependent on the geomorphological features of the basin and varies considerably from one part of the basin to another. Therefore, a good knowledge and a prior analysis of the basin characteristics should be considered to have the appropriate choice of the threshold that has to be used. The automated extraction could be improved by dividing the basin into geomorpholgical sectors and selecting a different and appropriate threshold value for each sector. This subdivision allows the definition of a threshold area that can take into consideration the dominant channel order and the processes (erosion, transportation and deposition). Constraints in treatment of flat areas and actual sinkholes (karstic features) can modify the quality of the automated extracted network. Additionally, studying the geomorphology of the basin is very important and can give good explanation of some topographic features that do not always belong to the current drainage channels (irrigation channels, relic forms, fractures, *etc*…).

The reliability of drainage networks that have been extracted automatically from DEMs seems to be dependent on the geomorphological characteristic of the terrain (lithology, density, pattern, channel order, slope, *etc*…). Although further studies should be done on different basins to confirm these results, conclusions can be extrapolated to similar areas.

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