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مركز البحوث الجغرافية
والكارتوجرافية
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مجلة مركز البحوث الجغرافية
والكارتوجرافية

العدد الخامس

GIS Automation of Drainage Basin of Wadi Alam, Red Sea_Egypt

دكتور
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كلية الآداب . جامعة القاهرة

ABSTRACT

Geographical information systems (GIS) are extremely important tools in many Geographical, Environmental, and Geomorphologic applications such as The Automated Drainage Network and Watershed Extraction . 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.

This paper, present a general methodology for the generation of Automated Watershed and Drainage Extraction (AWDE) starting from producing digital elevation models (DEMs), and ending to producing drainage watershed and drainage network maps from depression less DEM. The selected watershed - wadi Alam - is about 412Km². and including flat areas and depressions along the valley bottom, and flat areas near drainage divides. The depressions are usually artifacts of the DEM and have been removed by raising the elevation of the cells within the depression to the elevation of the lowest outlet cell of the outside edge of the depression.

The paper also have assessed the accuracy of the Automated Extraction of Watershed, Drainage Network, and Morphometric Parameters of Wadi Alam red sea Egypt, using the calculated deviation percentage of the automated parameters and the one defined by the blue-line method on the Egyptian topographic map sheets. Both of visual check and quantitative assessment are pointing out that the extraction accuracy was more than 97.4%, and the Automated Basin area is accurate to 99.7%.

1- Introduction: -

a) problem Definition

All geomorphologists are facing a very tedious work, time consuming, and subjective task, through drainage basin and network delineations from the topographic maps particularly for large watersheds, in addition to a serious project time problems, and inaccurate drainage basin and network delineations, because of there are many erroneous catchments areas neglected (subtracted) from the real basin boundaries, or added via clipping from the adjacent basins wrongly according to the geomorphlogist experience.

This study attempts to automate the geomorphlogist manual delineation work and quantify location, boundaries, and characteristics throught the derivation and generation of various thematic data base in GIS format, beside the estimation of GIS automation accuracy, applied on Wadi Alam as hilly and mountainous region.

b) Previous Work:

Although there are not previous literature dealing with the research problem applied on Wadi Alam specifically, there are various quantitative methods have been developed for characterizing the morphology of land surfaces (Evans 1972, Mark 1975, Dole and Jordan 1978, Papo and Gelman 1984, Elghazali and Hassan 1986, Zevenbergen and Thorne 1987, McNab 1989, 1993, Fels 1994) and for extracting hydrogeomorphologic characteristics from digital topographic models (Jenson and Domingue 1988, Skidmore 1990.

c) The Study Area

Wadi Alam is located in the central Eastern Desert of Egypt and lies entirely within the Egyptian Red Sea Catchment's Area. The Area is dissected by numerous pronounced valleys (Wadis) that initiate from the mountainous basin and run towards the Red Sea following the general eastwardly slope. Wadi Alam is limited from the east by the Red Sea and from the west by the River Nile-Red Sea Water divide. Wadi Alam also is bounded by Wadi El Nabe El Sagheer (Dubur), and Wadi Ijlah on its northern divide, and by Wadi Ghadir, Wadi Samadai on its southern divide. Wadi Alam takes an elongate area lies between latitude 24° ٥٠/ ١٨ and latitude 2٥° ٠٤/ .٥٦ and between longitude ٣٤° ٣٣/ ١٤ and longitude ٣٤° ٣٣/ ٥٩ .) Fig. (1).

2- Methods and Results:

2-1 Vectorization and building a Geographic Database

Creation of a DEM from a topographic map requires that the elevation contours on the topo map be somehow converted to xyz data. This is done using a multi step process. The raster elevation contours must first be converted to vectors. Next, the vector contours must be "tagged" with their corresponding elevation values. The tagged vector data is then transferred to a superimposed grid by an interpolation algorithm. Finally, the gridded elevation values are written to some type of common GIS format. The Egyptian data set that used to implement the vectorization step and building Wadi Alam geographic database are the topographic series 1 : 50 000 that produced by the Egyptian General Survey Authority (EGSA) incorporated with Finland FINNIDA Agency. Specifically, the current paper is handled the following 6 topographic sheets: Marsa Alam (NG36 H1b), Jabal al-Aswad (NG36 H1a), Jabal Humr Wajjat (NG36 G3b), Jabal Ghadir (NG36 D4d), Jabal Nuqrus (NG36 D4c), Jabal Midarjij (NG36 C6a), this data set are compiled from aerial photography taken in 1988 with vertical interval 20 meter contours , the digtized vector contour layer is presented in (Fig. 2) Wadi Alam Contour Map, All digitized layers are transformed from UTM

F1 F2

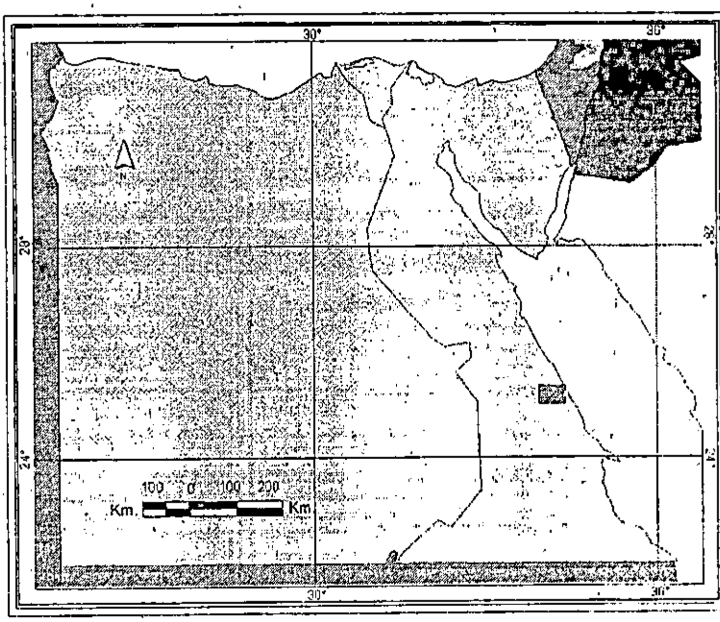

Fig. 1 Location of Wadi Alam

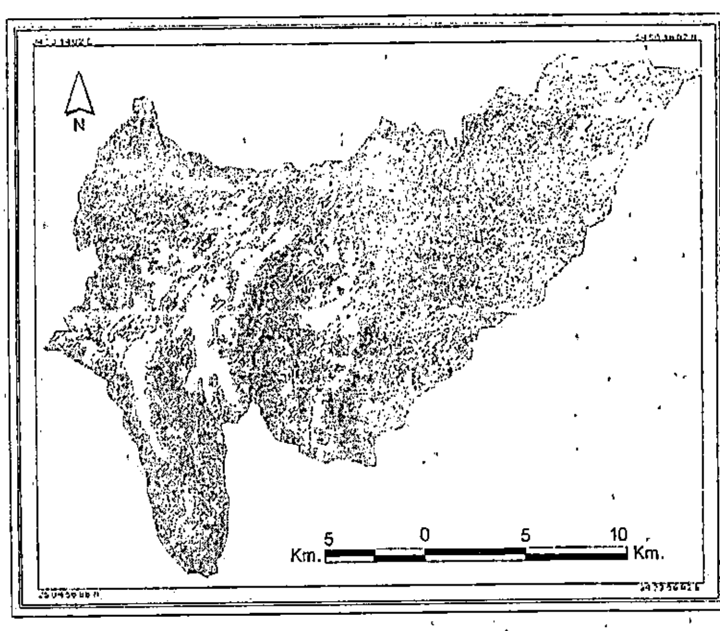

Fig. 2 The Contour Map of Wadi Alam (Vertical Interval 20 meter)

projection, Helmert ellipsoid 1906, national geodetic network (AzZahra, 1874) as a Horizontal Datum, and the Mean Sea Level (Alexandria, 1906) as a vertical Datum, to Universal Transverse Mercator (UTM), Zone 36 500000 North, False_Easting, 0 False_Northing, 33Central_Meridian, Meter Linear Unit, and World Geodetic System 1984 as Ellipsoid and Datum. And finally the study assigned the following Coordinate parameters for layouts and results presentations: Geographic Coordinate System: GCS_WGS_1984, Datum: D_WGS_1984, and 0 Prime Meridian. Angular Unit: Degree. As shown in figure (2) which is entitled with the contour map of Wadi Alam.

2-2 Digital Elevation Mapping:

Digital elevation maps or models (DEMs) are arrays of numbers representing the spatial distribution of terrain elevations. They can be seen as grey scale images whereby the value of a pixel represents an elevation rather than luminance intensity (the brighter the gray tone level of a pixel, the higher the elevation of the terrain point corresponding to this pixel). (Moore et al., 1991).

The terrain surface model is most commonly described either as a DEM, or as a digital terrain model (DTM) in literature. The form of DEM is defined as a regular two dimensional array of heights sampled above some datum that describes a surface. The other description of DEM is regular gridded matrix representation of the continuous variation of relief over space. On the other hand, the form of DTM contains elevation information with the addition of some explicit coding of the surface characteristics such as breaks in slope, drainage divides etc. Examples of DTMs include the triangulated irregular network (TIN), digital contours with form lines, and the rich line model of Douglas that uses ridge, valley and form lines to define an elevation model(Wood,1996).

The contour lines and spot-height points of the Wadi Alam area were merged together and a composite map having information about contours as well as spot height was formed. This combined map was further interpolated at 20-metre pixel resolution using map interpolation function available in Erdas Imagine software version 8.5 to generate a DEM of the study area as shown in figure (3) which is entitled with The Digital Elevation Model of Wadi Alam.

2-3 Sink Mapping and Sink filling:

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.

In this step the created DEM was further checked for flats and pits present in it. Since the area lies in steep mountainous terrain, only few flats and pits were observed in Wadi Alam DEM. The Spatial analysis of sink mapping have been done, and showes that the Wadi Alam area DEM contains 21 depressions.

The sink filling analysis using Jenson and Domingue(1988) approach have been done by Hydrological Modeling script which is operating under Spatial Analysis module to eventually generate depression less DEM figure (3).

These flats and pits were then removed using iterative map calculation functions of Hydrological Modeling software to fill the sinks and final DEM was generated. Removal of flats and pits in a DEM is necessary to maintain continuity of water to the catchment outlet from any point inside the catchment.

2-4 Flow Direction Mapping:

One of the keys to deriving hydrogeomorphologic characteristics about a surface is the ability to determine the direction of flow from every cell in the raster. This is done with the Flow Direction function of Wadi Alam as illustrated in figure (4).This function takes a surface as input and outputs a raster showing the direction of flow out of each cell. If the output drop raster option is chosen, an output raster is created showing a ratio of the maximum change in elevation from each cell along the direction of flow to the path length between centers of cells, and is expressed in percentages. If the force all edge cells to flow outward option are chosen, then all cells at the edge of the surface raster will flow outward from the surface raster.

There are eight valid output directions, relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight direction (D8) flow model and follows an approach presented in Jenson and Domingue (1988).

The direction of flow is determined by finding the direction of steepest descent, or maximum drop, from each cell. This is calculated as:

Maximum drop = change in z-value / distance

If the maximum descent to several cells is the same, the neighborhood is enlarged until the steepest descent is found. When a direction of steepest descent is found, the output cell is coded with the value representing that direction. If all neighbors are higher than the processing cell, the processing cell is a sink and has an undefined flow direction. So, to obtain an accurate representation of flow direction across a surface, the sinks should be filled. (Jenson, S.K. and Domingue, J.O., 1988)

2-5 Flow Accumulation Mapping:

This GIS function makes use of the flow direction data set to create the flow accumulation data set, where each cell is assigned a value equal to the number of cells that flow to it. Cells having a flow accumulation value of zero (to which no other cells flow) generally correspond to the pattern of

F3-4

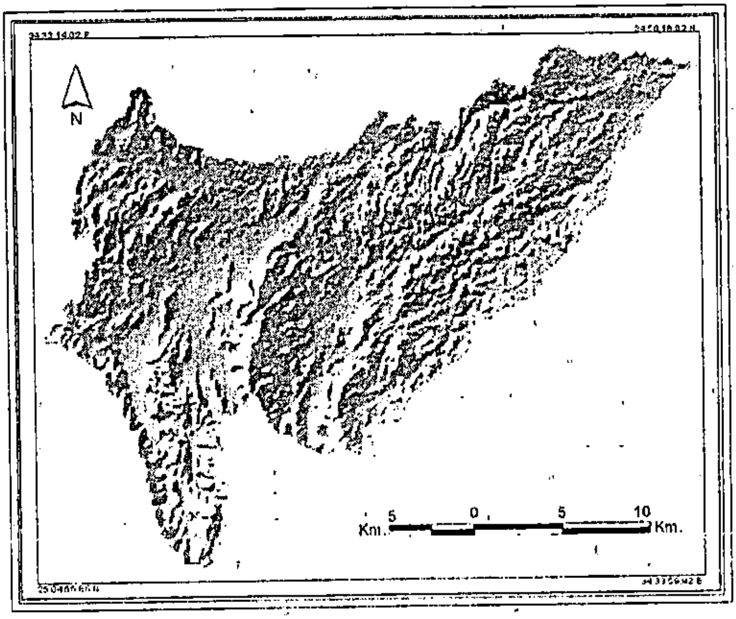

Fig. 3 Digital Elevation Model of Wadi Alam

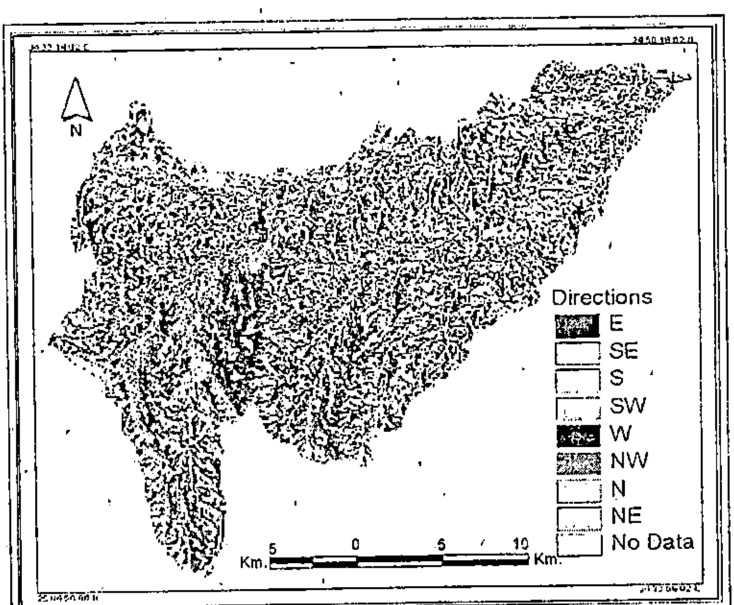

Fig. 4 Flow Direction of Wadi Alam

ridges. Because all cells in a depressionless digital elevation data set have a path to the data set edge, the pattern formed by highlighting cells with values higher than some threshold value delineates a fully connected drainage network. As the threshold value is increased, the density of the drainage network decreases. Another complimentary step can help that called "flow delta value" this procedure produces a difference value data set. Delta value is the amount of increase in flow accumulation value in the flow direction. This data set is useful for automatic seed generation and pour point table calculation. (P.Venkatachalam et al, 2001)

2-6 The Automatic Extraction of Drainage Network:

The pattern formed as a result of Wadi Alam Flow accumulation mapping and the highlighting cells method with values higher than some threshold value delineates a fully connected 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. 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.

Stream links are the sections of a stream channel connecting two successive junctions, a junction and the outlet, or a junction and the drainage divide.

The numbering of stream junction nodes and the ordering of the stream network has been carried out using Shreve – Strahler stream ordering System.

2-7 The Automatic Extraction of Watershed:

A drainage basin is an area that drains water and other substances to a common outlet. Other common terms for a drainage basin are watershed, basin, catchment, or contributing area. This area is normally defined as the total area flowing to a given outlet, or pour point. An outlet, or pour point, is the point at which water flows out of an area.

This is usually the lowest point along the boundary of the drainage basin. The boundary between two basins is referred to as a drainage divide or watershed boundary (Arc info 7.2 1998, P 7-16.). The pattern formed as a result of Wadi Alam Drainage Basin mapping and the highlighting cells method with values higher than some threshold value delineates a fully connected drainage Basin, as Wadi Alam Watershed illustrated in figure(4).

3-The Morphometric Characteristics and Accuracy Assessment:

Automated delineation of drainage network and watershed using digital elevation model has been described above but here the paper focused on the selected parameters (Morphometric Characteristics) used to measure and compare both the automated and manual networks and watersheds which are listed in table (1).

The GIS software packages which are dealing with the Hydrogeomorphological Modeling have many results discrepancy, meanwhile its function similarity, so the performance of Arcview GIS Add-on software Module namely BASIN1, Arcinfo, and Arcgis are evaluated by comparing the generated watershed, channel network. and other derived parameters to those obtained by traditional evaluation methods using 1 : 50

000 topographic scale sheets. The Accuracy Assessment performed through the deviation calculations by subtracting of automatic values from manual ones, then dividing the result on the manual value as a validation base. then multiply all by 100 to get the deviation percentage.

There are many traditional methods for channel network mapping such as contour crenulations and slope analysis , but they have limitations , so The Blue- Line Method (Morisawa, 1957) was selected because it is the

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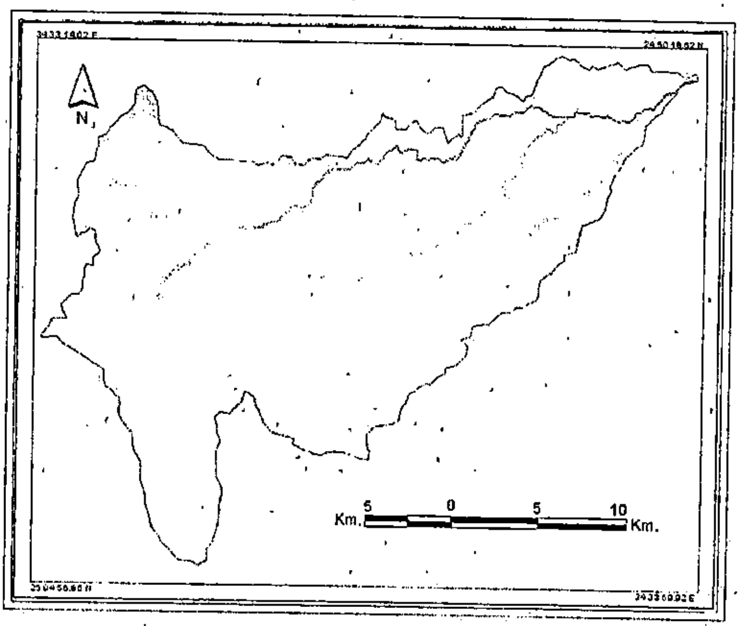

Fig. 5 Flow Accumulation of Wadi Alam

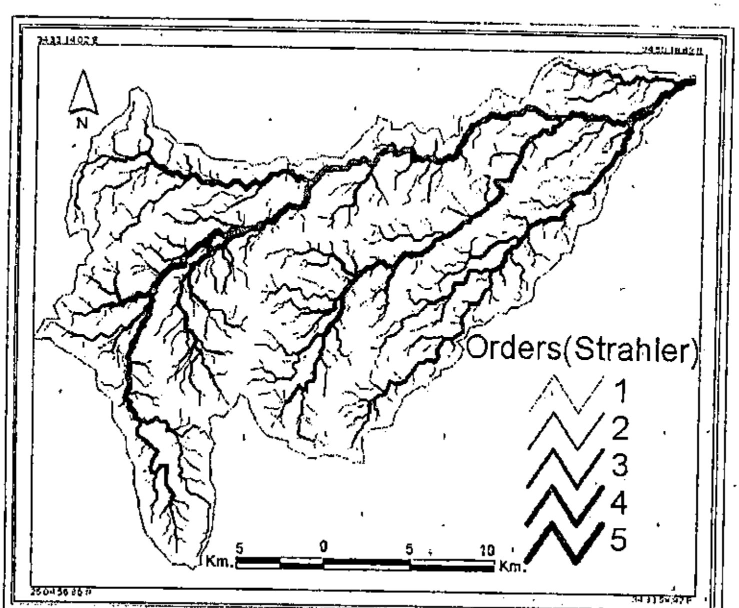

Fig. 6 Drainage Network of Wadi Alam

simplest and the most familiar with the geomorphologist work, and despite The Blue- Line Method limitations, it is a standard that is readily available for most Egypt's watersheds, extending over several topographic sheets which are surveyed with the following standard scales 1:100000, 1:50000, 1:25000 respectively.

However, the final results interpreted from table' (1) reporting that there are three main comparison and accuracy outputs represented as follow:

a- Manual Advantage: this category comprising all parameters that have got negative difference values which are varied internally in order to, the largest negative difference is found for Hypsometric Integral with value (-6.2), and the smallest negative differences are found for Drainage density, basin maximum length, Basin perimeter, Ruggedness value, Basin Area, with values (-2.6), (-1.8), (-1.36), (-1), (-0.3) respectively, the last deviation value means that the Basin area is Automated extracted as accurate as 99.7% . This close agreement shows the power of GIS accuracy analysis, automation, and simulation modeling in hydrogeomorphology.

b-Fully Matching: this category comprising all parameters that have got Zero difference values which are found for Network maximum length, Network minimum length, Network bifurcation ratio for order 2,3, and4, the higher Stream Order, Basin Area.

The fully matching is shows agreement hundred percent 100% and proves that the Automatic Extraction of Watershed, Network, morphometric characteristics utilizing GIS **is efficiently** hundred percent.

F – 7 F 8

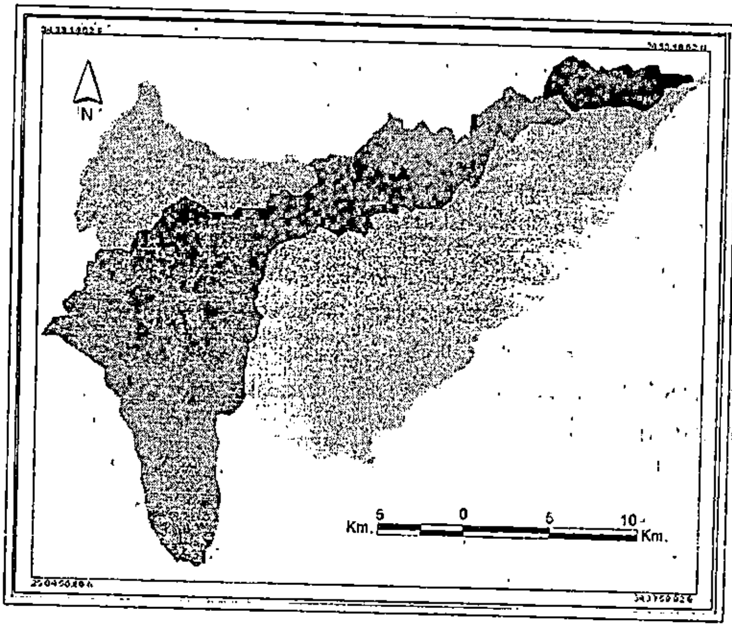

Fig. 7 Watersheds of Wadi Alam

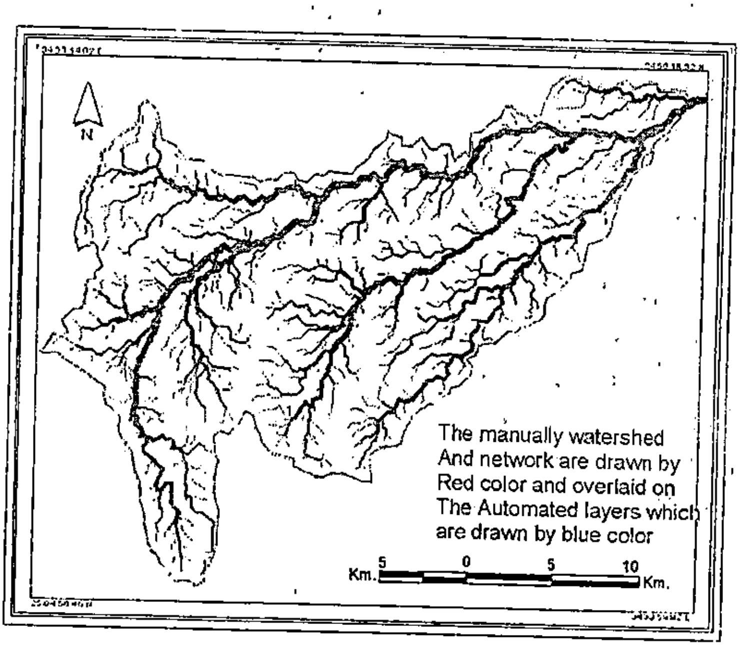

Fig. 8 Comparison of Automatic and Manual Extractions of Wadi Alam

Table(1) The Morphometric Parameters Measured by Manual and Automated Extractions

Method	Manual	Automatic	Deviation	
Network	man.		**ratio=D/man*100**	**difference(D)**
a- Network length				
-١total length	٦٢٨,٢٢٥	٦٥٠,٢٥	%٣,٥٠	٢٢,٠٢
-٢link numbers stream counts	٨٠٩,٠٠٠	٨٧٣,٠٠	%٧,٩١	٦٤,٠٠
-٣maximum	٤,٠١٠	٤,٠١	%٠,٠٠	٠,٠٠
-٤minimum	٠,٠٩٠	٠,٠٩	%٠,٠٠	٠,٠٠
-٥range	٣,٩٠٠	٣,٩٠	%٠,٠٠	٠,٠٠
-٦variance	٠,٣٤٤	٠,٣٤	%٢,٠٣-	٠,٠١-
-٧standard deviation	٠,٥٩٠	٠,٥٨	%١,٥٢-	٠,٠١-
b- bifurication ratio				
Order 1/2	١,٨٧٧	٢,١٩	%١٦,٦٨	٠,٣١
order 1/3	٢,١٧٠	٢,١٧٠	%٠,٠٠	٠,٠٠
order 1/4	١,٠٨٠	١,٠٨٠	%٠,٠٠	٠,٠٠
order 1/5	١,٦٥٠	١,٦٥٠	%٠,٠٠	٠,٠٠
c- remaining parameters				
-١strahler order	٥,٠٠٠	٥,٠٠	%٠,٠٠	٠,٠٠
-٢shreve magnitude	٣٩٥,٠٠٠	٤٢٦,٠٠	%٧,٨٥	٣١,٠٠
-٣stream frequency	١,٩٥٩	٢,١٢	%٨,٢٢	٠,١٦
-٤drainage density KM / KM2	١,٥٧٠	١,٥٣	%٢,٥٥-	٠,٠٤-
Watershed				
a- Geometric parameters				
AREA_KM2	٤١٢,٩٤	٤١١,٧١	%٠,٣٠-	١,٢٣-
PERIMET_KM	١٢٤,٢٧٨	١٢٢,٥٩١	%١,٣٦-	١,٦٩-
Maximum Length	٥٩,٠٠٢	٥٧,٩١٦	%١,٨٤-	١,٠٩-
width	٦,٩٩٩	٧,١٠٩	%١,٥٧	٠,١١
b- Form & Relief parameters				
Form_Factor	٠,١١٨٦	٠,١٢٢٨	%٣,٥٤	٠,٠٠
Circularity	٣,٣٦١	٣,٤٤٤	%٢,٤٧	٠,٠٨
Max_Relief	٢٤٢,٠٠	٢٤٧,٠٠٠	%٢,٠٧	٥,٠٠
Relief Ratio	٠,٠٠٤	٠,٠٠٤	%٠,٠٠	٠,٠٠
Relative Relief	٠,٠٠٢	٠,٠٠٢	%٠,٠٠	٠,٠٠
c- Morphometric parameters				
Texture_Ratio	٧,٠٢٥	٧,١٢١	%١,٣٧	٠,١٠
Hipsometric Integral	١,٧٠٦	١,٦٠٠	%٦,٢١-	٠,١١-
Ruggedness	٠,٢٨٢	٠,٢٧٨	%١,٠٥-	٠,٠٠

c- Automatic Advantage: this category comprising all parameters that have got positive difference values in order to, the sorted positive differences are beginning from Bifurcation ratio order 1, Stream Frequency, Shreve Magnitude, Link Numbers(Stream account), Form Factor, Total Link lengths , Circularity, Maximum Relief, Basin Width, Basin Texture Ratio, with values (16.7), (8.2), (7.85), (7.9), (3.54) (3.51), (2.47), (2.1), (1.6), (1.37) respectively. This close agreement shows that the general character of a system of channels and Watershed is reproduced by the Automated Extraction, and all of these category parameters have only obtained by GIS simulation modeling and automation, so no one can find these parameters on 1:50 000 topographic maps or less, but can do it by more fine resolution, field work, or by GIS hydrogeomorphological modeling and Automatic Extraction.

4- Conclusion :

After conducting the study on Wadi Alam using the Digital Elevation Model, the Automatic Extraction Algorithms, and the selected Morphometric Parameters, the study reveals that the Utilization of GIS in Automatic Extraction is proving to be very valuable tools for saving time, raising accuracy, quantifying and computerizing huge geomorphological projects.

The visual appearances of the automated and map-based watershed and channel networks are very similar, and so are the watershed and channel network composition parameters which display an average discrepancy of less than 3%. The Manually Watersheds and Network are drawn by red color and overlaid on the automated ones which are drawn by blue color (fig.8) for serving the comparison purpose of Automatic and Manual Extractions of Wadi Alam. both of visual check and quantitative assessment are pointing out that the extraction accuracy was more than 97.4%, except for the hypsometric integral that carried out with 93.8 accuracy, whereas the Basin area is accurate to 99.7%.

Finally, it is recommended in the near future application projects specially in such GIS Automation to rely on fine and very fine DEM spatial resolution, sink filling, and a narrow grid cell size for optimizing the automatic extraction to simulate and match with the real field morphology like that have done on Wadi Alam.

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أتمتة نظم المعلومات الجغرافية لحوض تصريف وادي علم-البحر الأحمر-مصر

د.أحمد محرم البهنساوي

باتت نظم المعلومات الجغرافية متعاظمة الأهمية كأدوات غير مسبوقة تخدم العديد من الحقول العلمية والتطبيقات الجغرافية والبيئية والجيمورفولوجية مثل الاستنتاج الآلي لأحواض التصريف وشبكاتها وكذلك اشتقاق خصائصها المورفومترية يمثل حوض التصريف الوحدة الأساسية والهدف الرئيسي في هذه الدراسة حيث يتم رسم حدوده المكانية إما من لوحات الخرائط الطبوغرافية بشكل يدوى أو اشتقاق واستنتاج هذه الحدود نموذج الارتفاع الرقمي D E M بتطبيق الطرق الرياضية.

يعرض هذا البحث للأسس المنهجية والتقنية اللازمة لاشتقاق حوض التصريف وشبكته وخصائصه الجيمورفولوجية بداية بإنتاج نماذج الارتفاع الرقمية ونهاية بإنتاج خرائط حوض التصريف وشبكة التصريف لوادي علم.

تبلغ مساحة حوض وادي علم ٤١٢كم مربع تقريبا، وتنتشر بهذه الرقعة المساحية العديد من النطاقات قليلة الإرتفاع تتناوبها نطاقات بسيطة مغلقة على نفسها تمثل عيوبا في نموذج الارتفاع الرقمي ويطلق عليها البالوعات أو المنخفضات وهى تترامى في معظمها على طول قاع الوادي ومجراه، وقد عولجت هذه العيوب برفع قيم خلايا الديم في مناطق المنخفضات لما يساوى الحدود الخارجية الأعلى للخلية الحدودية الخارجية المتجهة صوب المصب.

فضلاً عن الاستخلاص الآلي لحوض وشبكة التصريف لوادي علم الذي أنجزه البحث كأحد أهم أهدافه إلا أنه قد تعرض أيضا لعملية التقييم الكمي والبصري لحدود دقة هذا الاستخلاص الآلي باستخدام تقنيات نظم المعلومات الجغرافية من خلال حساب نسبة الانحراف والاختلاف بين النتائج المستخلصة آليا وتلك التي تم رسمها من الخرائط الطبوغرافية ذات مقياس ١: ٥٠٠٠٠ بغرض

المقارنة، وتمخض إجراء كل من التقييم الكمي والمراجعة البصرية عن بلوغ دقة الاستخلاص الآلي نسبة ٩٩,٧% لمساحة حوض التصريف، وأن حدود دقة الاستخلاص الخاصة بباقي الخصائص الجيمورفولوجية بشكل عام تتجاوز نسبة ٩٧,٤%.

GIS Automation of Drainage Basin of Wadi Alam, Red Sea_Egypt

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Geographical information systems (GIS) are extremely important tools in many Geographical, Environmental, and Geomorphological applications such as The Automated Drainage Network and Watershed Extraction . 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.

This paper, present a general methodology for the generation of Automated Watershed and Drainage Extraction (AWDE) starting from producing digital elevation models (DEMs), and ending to producing drainage watershed and drainage network maps from depression less DEM. The selected watershed - wadi Alam - is about 412Km^2. and including flat areas and depressions along the valley bottom, and flat areas near drainage divides. The depressions are usually artifacts of the DEM and have been removed by raising the elevation of the cells within the depression to the elevation of the lowest outlet cell of the outside edge of the depression.

The paper also have assessed the accuracy of the Automated Extraction of Watershed, Drainage Network, and Morphometric Parameters of Wadi Alam red sea Egypt, using the calculated deviation percentage of the automated parameters and the one defined by the blue-line method on the Egyptian topographic map sheets. Both of visual check and quantitative assessment are pointing out that the extraction accuracy was more than 97.4%, and the Automated Basin area is accurate to 99.7%.