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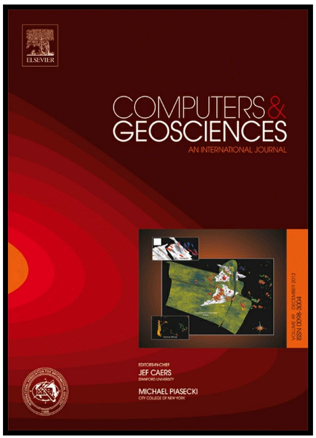

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New ArcGIS tools developed for stream network extraction and basin delineations using Python and Java Script

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Abstract

Damages caused by flash floods hazards are an increasing phenomenon, especially in arid and semi-arid areas. Thus, the need to evaluate these areas based on their flash flood risk using maps and hydrological models is also becoming more important. For ungauged watersheds a tentative analysis can be carried out based on the geomorphometric characteristics of the terrain. To process regions with larger watersheds, where perhaps hundreds of watersheds have to be delineated, processed and classified, the overall process need to be automated. GIS packages such as ESRI’s ArcGIS offer a number of sophisticated tools that help regarding such analysis. Yet there are still gaps and pitfalls that need to be considered if the tools are combined into a geoprocessing model to automate the complete assessment workflow. These gaps include issues such as i) assigning stream order according to Strahler theory, ii) calculating the threshold value for the stream network extraction, and iii) determining the pour points for each of the nodes of the Strahler ordered stream network. In this study a complete automated workflow based on ArcGIS Model Builder using standard tools will be introduced and discussed. Some additional tools have been implemented to complete the overall workflow. These tools have been programmed using Python and Java in the context of ArcObjects. The workflow has been applied to digital data from the southwestern Sinai Peninsula, Egypt. An optimum threshold value has been selected to optimize drainage configuration by statistically comparing all of the extracted stream configuration results from DEM with the available reference data from a topographic map. The code has succeeded in estimating the correct ranking of specific stream orders in an automatic manner without additional manual steps. As a result, this saves time and effort, and hence, is a very useful function for large catchment basins.

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1- Introduction

The evolution of a drainage system over space and time is affected by many variables such as lithology, tectonic lineaments, geomorphology, soil and the area's landcover. Many of these variables are mirrored in the landscape topography, which can be quantified and classified using concepts of geomorphometry.The measurement of shapes or geometries of any natural geomorphological features is termed as geomorphometry (Pike et. al., 2008; Selvan et. al., 2011). A detailed morphometric analysis of a basin greatly helps to characterize the impact of drainage morphometry on landforms and their features (Chandrashekar et al., 2015). Morphometric analyses are important in the context of the estimation of flash flood risk levels of watersheds. They can be used as an attempt to elucidate the surface water potentialities of basins in order to describe the basin's hydrological behavior (Angillieri, 2012; Omran, 2013) and to quantify the hydrological characteristics. Thus, the results of morphometric analysis will be a useful input for a comprehensive water resource management plan (Jawahar raj et al., 1998; Kumaraswami et al., 1998; Sreedeviet al., 2001). Hydrological models that are mainly based on morphometrical analytical results include the Instantaneous Unit Hydrograph (Nash, 2009), the Geomorphoclimatic Unit Hydrographs (Gupta et al., 1980) and the Geomorphic Unit Hydrograph (Rodriguez-Iturbe and Valdes, 1979).These models have been applied over ungauged basins in arid and semi-arid regions. The study of morphometric parameters mainly requires the delineation of both the drainage networks and the watershed line.

Therefore, today's state-of-the-art techniques should be applied. These include Remote Sensing (RS) data and processing using Geographic Information Systems (GIS), with the added availability of high resolution digital elevation models (DEM) from earth observation satellites and the progress made in computer science. Due to the increased power to process these large amounts of data even on PCs or laptops and the progress statistical and mathematical methods, many difficulties have been resolved and new problems can be tackled (Evans et al., 2003). This leads to a renaissance of concepts that were already introduced 70 years ago. At that time several studies focused on mapping of drainage networks

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and their watersheds for hydrological studies (Horton, 1945; Strahler, 1964; Shreve, 1974). Tracing techniques were used in these studies to extract drainage network and delineate boundaries of basins for studying the characteristics of basins and their relationship to the geometriesof those basins. Using classical approaches for delineation the drainage network, these studies need to measure linear features directly in the field or retrieve from secondary sources, (e.g., digitized from topographic maps, aerial photographs and stereo images). In many areas of the world, topographic maps are still the basic traditional reference for drainage network analysis because of their availability, simplicity and affordability. However, the extraction of information, such as delineation of drainage and watershed from topographic maps, requires much time and expertise in cartography, resulting in subjective decisions. Moreover, the results of manual procedures such as tracing methods still have to be transferred to digital data for further processing. Limitations and subjectivity of manual procedures in defining stream networks highlight the need for a more precise and efficient approach in depicting landscape dissection. The widespread availability of digital data including DEMs, radar images, stereo photogrammetry, and Light Detection and Ranging (LiDAR) point clouds has opened new gates for more objective approaches to the delineation of channel networks(Sekulin et al, 1992; Bertolo, 2000; Lin et al., 2005;Afana, 2011). In the 1980s computational technologies were developed to use DEMs for the extraction and numerical analysis of drainage networks (Mark, 1984; O'Callaghan and Mark, 1984; Jenson, 1985). Nowadays, many GIS like ESRI's ArcGIS, QGIS or Saga include in their toolboxes standard tools to extract the stream segments and basin watersheds from DEMs.In the recent years, with the availability of data and processing power, it is possible to process bigger datasets for larger catchment areas in a reasonable time and the extracted results were used to study the morphometrical parameters for mapping flooding risk areas (Rudriaiah et al., 2008; Al Saud, 2009;Nageswararao et al., 2010).

To apply the complete workflow from DEM preprocessing to the extraction of morphometric parameters to larger regions, where perhaps hundreds of watersheds have to be delineated and

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classified, the process has to be automated. Although the complete process can be implemented straight forward, the extracted results still create different problems with regard to their credibility in using the data in geomorphological and hydrological models (Omran, 2013). Additionally, depending on the software which is used, there are still some gaps in the automated workflow which until now have to be filled by manual work. For example, using ArcGIS' Spatial Analyst Hydrology tool set,the extracted stream segments are attributed with the correct Strahler order, but they have to be merged according to their order number as the watershed characteristics like drainage density or frequency are based on them. Omran et al. (2011) describe an algorithm for the merging of stream segments based on Strahler's theory. Another problem to be addressed is the determination of the pour points of the different sub basins according the merged segments.

Despite the validation of stream extraction from DEM has received considerable attention,the assessment of the achieved results still lags behind. The validation procedure for a drainage network should be done prior further processing, as in the case of hydrological models.Generally, thereare two main approaches for drainage network validation: quantitative and qualitative methods(Chorley et al., 1984).Quantitative method includes geomorphometrical parameters that describe structural properties of a stream network. These properties are extracted from different sources (e.g., digital maps or extracted drainage networks) and then compared statistically. The qualitative method depends on expert knowledge based on field visits, visual interpretation of the resulting data, comparison with other data sources, such as orthophotos and 3D structures (Afana, 2011). Field work still forms one of the most precise approaches to validate channel network. The exact stream network can be examined in the field, but time and efforts make it impractical to check for stream validity, especially in large-scale catchments. As a surrogate for own field work, topographic maps can be considered. Based on a geodetic field survey the drainage network has been captured accurately and has been mapped following the cartographic rules of generalization, depending on the scale of the map. A good compromise for the level of detail needed and cartographic generalization are topographic maps 1:25

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000. On the other hand, the details of the drainage network extracted from a DEM are closely related to the DEM's resolution. For this study, related to the availability of maps and the DEM resolution, mid-scale maps (e.g., 1:50,000 and 1:100,000) have been used for evaluation of the results. Stream network details are defined by a threshold value that determines where channels begin in the landscape, widely known as the "specific threshold area". This value represents the minimum drainage area required to drain to a point where a channel forms. It is the essence of stream extraction to select the appropriate threshold value. The choice of the appropriate value used to define the optimum channel network is highly related to the scale and resolution of the original data (Thompson et al., 2001).This value for channel initiation is usually specified arbitrarily although it is recognized that different threshold value will result in substantially different stream networks for the same basin (Helmlinger et. al., 1993). The smaller the chosen threshold value, the more detailed the obtained channel network, and more initial sub-watersheds will be generated. On the other hand, depending on the algorithm used for determining the flow direction, artifacts will be introduced which will not reflect the real world situation. Different suggestions have been made to find an optimal threshold value. Generally, using a constant value for stream network delineation is an accepted means of determining where channels begin in the landscape (e.g., O'Callaghan and Mark, 1984; Band, 1986; Montgomery and Dietrich, 1992). However, drainage density has been shown to vary between regions due to different climatic regimes, natural landscape characteristics, and land-use impacts (Gandolfi and Bischetti, 1997; Tucker and Bras, 1998). Additionally, assigning a constant threshold value neglects the spatial variability of headwater source areas and may lead to significant differences between field observations and predicted conditions (Willgoose and Perera, 2001). One common approach to define the threshold value is calculating 1% of the maximum flow accumulation, which is considered a default method for displaying the stream network (Band, 1986; Tribe, 1992; Merwade and Ruddell, 2012). Deilami et al. (2013) statistically determined the threshold value to be the first break value from the standard deviation classification method for a flow accumulation raster layer. Another method to

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select the threshold value was developed and implemented in the TauDEM software (Tarboton, 2001; Shrestha and Miyazaki, 2006). Ariza-Villaverde et al. (2013) suggest a multifractal analysis for determining an optimal threshold value.In many other studies, the value has been determined based on trial and error, using the visual similarity between the extracted network and the lines depicted on topographic maps. This paper describes a new automated approach for selecting the optimum threshold value and comparing the results with these extracted from topographic maps. This approach uses expert knowledge by defining the expected stream order of the main stream and not the threshold value itself, which is determined by iterating until the desired order is reached.

This paper presents a new implemented automated workflow based on an ArcGIS Spatial Analyst toolbox enriched by Python scripts and ArcObjects based Java code to extract stream network from DEM with stream segmentation according to Strahler's theory. The model runs in a batch to produce different drainage network configurations by iterating through a range of threshold values. The workflow includes selection of a threshold value to achieve the optimum drainage configuration by comparing the extracted network configuration results from DEM with the available reference data from a topographic map. The automated workflow delineates watershed sub-basins according the stream order. Evaluation of the results is done statistically by comparing the extracted stream number for each order with the results of the traced stream numbers from a topographic map sheet 1:50,000. The compared parameters include the number of streams for each order according to Strahler theory and the number of sub-watersheds for each order. The best match determines the optimum threshold value used for stream extraction and represents the most plausible stream configuration compared to the topographic map.

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2- Data and Study Area

The adapted workflow was applied to Wadi Feiran basin, which is one of the prominent drainage systems in the southern Sinai Peninsula. It is located at the southwestern part of Sinai between Latitude 28^o 30`& $28^o$ 55` N and Longitudes 33^o 20`& $34^o$ 03` E and covers an area of about 1790 km^2 (Fig.1).

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This basin represents one of the most rugged and elevated regions (2640 m a.s.l) of Egypt. The longest stream in the basin has a length of 120 km and a moderate slope gradient of about 39 m/km from Saint Catherine in the east, to the Gulf of Suez in the west (Geriesh et al., 2001).The main channel of WadiFeiran and its tributaries drain the surrounding high mountains and flow towards the Gulf of Suez towards the West (Kassem, 1981).The Wadi Feiran mega-basin is characterized by aridconditions and suffers from a shortage of water resources. Rainfall is rare and normally occurs as thunderstorms ofshort duration and high intensity. Lithologically, basement rocks including granite and volcanic outcrop most frequently in the basin, especially at higher elevations. Metamorphic and sedimentary rocks occupy the middle and lower reaches of the basin.

Fig. 1. The Location map of the study area.

In this study, a DEM was used to extract morphological data that were further translated into morphometric parameters for each sub-basin in the study area. The DEM is a digital representation of cartographic information in a raster form created from terrain elevation data. The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global DEM Version 2 (ASTER GDEM) data of Wadi Feiran Basin were collected from the Land Processes Distributed Active Archive Center (LP DAAC) established by National Aeronautics and Space Administration(NASA). The ASTER GDEM is available from the Earth Observing System Data and Information System (EOSDIS, 2015) in GeoTIFF format with geographic latitude/longitude coordinates at a 22 m resolution grid of elevation postings. The DEM was released for downloading in October, 2011. The GDEM data of the study area was re-projected to the Universal Transverse Mercator (UTM) zone 36 (WGS 84) projections.

The drainage network and the morphometric parameters (e.g., drainage frequency, drainage density and bifurcation ratio) were extracted using topographic maps of scale (1:50,000). The whole basin of Wadi Feiran is covered by 11 sheets of topographic maps and this scale corresponds to spatial resolution 25 m (Tobler, 1987).A generalized drainage map of the Wadi Feiran basin was traced from

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the relevant topographic maps to inspect the general morphology of the main channels and smoothly delineate the enclosed sub-basins (Fig. 2).The dissecting drainage lines are common landscapes that essentially modeled the shape and nature of Wadi Feiran basin.

Fig.2. Drainage networks of WadiFeiran basin (Abouelmagd, 2003).

3- Methodology

This section presents the methodology to process a DEM in order to facilitate interactive watershed delineation and stream network extraction. Criteria and steps used to extract the stream network and basin delineation will be thoroughly illustrated. The workflow was based on tools available in the ArcGIS 10.1 toolbox; in particular tools from the Spatial Analyst extension were used (Fig.3). The individual tools were combined using the ArcGIS ModelBuilder for batch processing. As the ModelBuilder is still weak in implementing loops as an available tool in ArcGIS, the models have been supported with prepared scripts and enriched by Java and Python codes (Fig.4). This workflow was applied on the DEM of Wadi Feiran. The steps are indicated as follows.

3.1 Extraction of the stream network from the DEM

If the characteristics of the underlying objects are known (i.e., the number of streams and their length for each order of stream), the extraction of the stream network can be easily implemented in GIS (Schröder and Omran, 2013) as follows:

DEM generation (if not given) →filling of pits and depressions → calculation of local flow directions → calculation of flow accumulation → extraction of drainage network →Strahler order segmentation → vectorization of drainage network

Fig. 3. Overall process flow of the code which was implemented on DEM.

A common problem with drainage network delineation using DEM is the presence of sinks, particularly in flat areas and depressions. Therefore, sinks are commonly removed prior to DEM processing for drainage identification. Small sinks have been observed downstream in the basin, in

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addition to some small parts of the catchment areas. For this reason, a fill process was used to fill each depression in DEM with an appropriate limit. A filled DEM process should be iterated until all sinks are filled and the elevation raster is void of depressions. Therefore, sinks have to be removed from a DEM through the filled process.

Fig. 4. Model Builder diagram showing the iteration workflow to extract the drainage patterns through the threshold range values from the Digital Elevation Model.

The next step creates the flow direction raster. A flow direction raster shows the direction water will flow out of each cell of a filled DEM. A widely used method for deriving flow direction is the D8 method. This method is used by ArcGIS and assigns a cell’s flow direction to one of its eight surrounding cells either adjacent or diagonally, in the direction with steepest downward slope. The D8 method produces good results in high gradient slopes, but tends to result in parallel flow lines along less steep areas (Omran, 2013). Next, the flow accumulation is used. This tool aims to extract a flow accumulation raster, tabulating the number of cells from which surface water will flow for each cell. Thus, it records how many upstream cells are contributing to the drainage of each cell.

Stream network delineation is performed in the next steps. Most methods of stream delineation were developed for D8-based approaches, assuming that flow dispersal is limited from each cell to only one of eight principal directions separated by π/4 (450) (Jasiewicz and Metz, 2011). A stream network raster is derived from the flow accumulation raster where each cell is assigned a value equal to the number of cells that drain to it. This step is based on a defined threshold value applied to the grid flow accumulation layer (O'Callaghan and Mark, 1984). Streams and channel start points are delineated as those grid cells where the contribution area threshold is exceeded. If this threshold is reached or exceeded, grid cells are then defined as stream cells, and all grid cells with flow accumulation below this threshold are defined as non-stream cells. In this study, several drainage network configurations have been extracted by defining different threshold values. The key question is, what is the optimum threshold value to use?

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Though the workflow is well known and applied in many research projects, it is worthwhile to have a closer look at some of the basic steps. The focus of the discussion is to combine the tools to an automated workflow, which may be implemented using ArcGIS Model Builder, for example. Two main issues have been addressed in the stream extraction process; the first one was updating the algorithm related to the Strahler order. For re-ordering the segmented streams, a tool based on Python has been implemented. The second issue was implementing an iteration loop for the determination of an optimal threshold value. For each iteration, the stream network has been extracted. The configuration of stream networks for each threshold value should be created with a difference not only in the stream number for each order, but also reaching in the order of the stream.

A workflow is implemented to generate several drainage networks depending on a given maximum stream order as input value(i.e., the order of the main stream as an expert guess based on previous studies or evaluation of topographic maps). Starting with an initial threshold value (input value) which will generate a main stream with lower order than the specified maximum one, the algorithm will iterate by decreasing the threshold value in each loop by a specified step size until the given order for the main stream is reached. The threshold value obtained is the starting value for a more detailed evaluation to determine the optimum value. Given a range of threshold values and a step size, the model given in Fig.4 will create a stream network configuration for each threshold with respect to the Strahler order system.

Generally, the stream ordering process is a method of assigning a numeric order to links or segments in a drainage network. The order systems supported by ESRI’s Stream Order tool were proposed by Strahler (1957) and Shreve (1966), where the Strahler method is more commonly used. In this method, all links without any tributaries are assigned an order of 1 and are referred to as first order. The stream order increases when streams of the same order intersect. Therefore, the intersection of two first-order links will create a second-order link; the intersection of two second-order links will create a third-order link, and so on. Since the Strahler method only increases in order at intersections of

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the same order, it does not account for all links and can be sensitive to the addition or removal of links (Tarboton et al., 1991). The Strahler order tool of ArcGIS assigns the order number to the stream segments according to the topological structure of the network, i.e., at each node a new link will start regardless of whether the stream order number changes or not. Thus, based on the topology and the Strahler order numbers, merging of the stream links is necessary. The algorithm to achieve this was implemented as a Python script so it can be used as a tool in the Model Builder. The algorithm itself is explained in Omran et al. (2011).

The next issue to be discussed in the workflow is the determination of the pour points for each node of the Strahler ordered stream network. Pour points are indicated by the location where water would flow out of the cell. Thus, a pour point should be located within an area of high flow accumulation because it is used to calculate the total contributing water flow to that given point. As the pour points have to be aligned with the flow accumulation layer for the automatic extraction of the watersheds, the manipulation of raster cells is necessary. Accessing raster cells using Python is not possible in a straightforward manner, thus the necessary algorithm has been implemented in Java using the ArcObjects API. The algorithm uses Strahler re-ordered streams, as well as Strahler raster, as input. As output of the algorithm a new raster with pour points is created. The resulting pour points are based on the confluence locations of the stream segments, but are moved one pixel upstream for each segment of lower or same order than the order of the confluence point. The algorithm is given in pseudo code in figure 5.

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Fig. 5. Pour point algorithm in pseudo-code notation.

3.2 Delineation of subwatersheds

A drainage basin acts like a funnel, collecting all the water within the basin area and channeling it into a waterway. The drainage basin includes both the streams that convey the water, as well as the land surfaces from which water drains into those channels. Each drainage basin is separated

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topographically from adjacent basins by a ridge, hill or mountain, known as a water divide. Watersheds or basins draining into one another area found in the form of a nested hierarchy. The topography helps to determine where and how water flows from one area to the next. However, each large drainage basin can be broken into smaller drainage basins with its own topographic and hydrologic characteristics; these are called sub-watersheds, or sub-basins for short. Delineation of a watershed entails determining the boundary of the watershed, i.e., the ridgeline. The ridgeline joins the highest elevation points, and thus becomes the boundary of the watershed. The most important aspect for defining and delineating a watershed is to fix the outlet of the drainage course. Basically, the location of the outlet defines the area of the watershed.

Fig. 6. ModelBuilder diagram showing the workflow to delineate watershed from extracted pourpoints and flow direction layer

The delineation of drainage basins can be done manually based on the contour lines of topographic maps. On the other hand, the widespread availability of elevation data in digital format has bolstered the development of automated tools that can be used to delineate drainage basins and their associated stream networks. The traditional manual method of basin delineation starts by digitizing the pour point. By comparing the results of the stream network with the topographic map visually, pour points are identified and digitized. The snap pour point tool is used to ensure that the digitized points are dragged to the point of highest accumulated flow. In the final step the watershed tool is used, which requires the input of flow direction (raster layer) and pour point (vector or raster layer).As in the extraction of a stream network, it is important not to use the simplification option while converting the raster map to vector features. Otherwise, the delineated stream network and basins will not match exactly, which is a prerequisite for the following steps to automate counting and join the drainage network. Identifying and digitizing pour point for a large number of sub-basins is a time consuming labor. Therefore, an automated workflow was implemented. The suggested tool is divided into two parts. The first part aims to input the extracted pour points files that originated from Java script as explained before. The second part implements the delineation of the watersheds using the watershed

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tool. This tool needs the flow direction layer as input data and converts them to vector format (Fig. 6).The dissolved tool was used to aggregate the watershed line for each basin order in one vector file format.

4- Results and Discussion

The analysis for Wadi Feiran was implemented based on manual evaluation of a topographic map 1:50,000 by Abouelmagd, 2003. The tracing method was applied on nine topographic map sheets, and the numbering of streams and the delineation of sub-basins were done manually. The highest stream order determined was 7, with a basin area of about 1790 km^2 (Table1). Based on this evaluation, this order was used as input in the automated workflow to determine the threshold value and create a stream configuration with order 7, with an arbitrary initial threshold value of 600, and a step size of 10. The result of the first batch run showed that threshold values ranging from 500 to 160 resulted in stream networks with the highest order 6, in the range from 150 to 40 in stream configurations with the highest order 7, and in highest order 8 lower than 40 (Fig. 7).Thus, a value of 150 pixels was chosen as the starting threshold value to build the stream network with order 7. In the second step, a number of stream networks were created in the range of 150 to 40 pixels using a smaller step size to find the optimum value compared to the topographic map. Here only the results near the optimum threshold value are shown in table (1).

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Fig. 7. The results of maximum stream order regarding to threshold values range

The results show that there is an increase in the number of streams with decreasing threshold values, especially at stream order 1, 2, 3 and 4 (Table 1). The numbering of streams at orders 7 and 6 for all threshold values matches the evaluation of the topographic map by Abouelmagd, 2003. The number of order 5 streams corresponds with the data from the topographic map at threshold values between140 and 128, while differences were observed at values of 135, 126 and 125 (Fig.8 & Table1). The number of streams at threshold values of 130 and 129 for order 4 to 7matches very well with the data extracted from the topographic map, but there are discrepancies for order 1 to 3.The pattern of the numbers of streams for the different orders is similar for threshold values 136 and 135, especially for stream order 1 to 3. Here also the total number of streams at matches with the number counted on the topographic map.

Fig. 8. Different configurations of stream networks around the optimum threshold value were extracted from DEM by new tool.

The Root Mean Square Distance (RMSD) method was used to examine the difference between the results from the automated process and the data from topographic map sheets. The results show that the least total difference is observed at threshold values between 137 and 134 (Table 1).The analysis shows that the optimum threshold values were 136 and 135,both of which fit best with the evaluation of the topographic map. Compared to e.g. the 1% method mentioned in the introduction, which would result in a threshold value of about 2400 pixels for the study area, the results found in this study suggest using a much smaller value.

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Table 1 Results of stream number for each order regarding to different threshold value; with Comparison between the results of a new tool (Modeled data) and results from topographic maps (traced data) using Root Mean Square Distance (RMSD).

Stream Order	**Threshold Values**																**R.D. ***
	140	**139**	**138**	**137**	**136**	**135**	**134**	**133**	**132**	**131**	**130**	**129**	**128**	**127**	**126**	**125**	
1st	4519	4552	4598	4635	4664	4699	4752	4788	4834	4861	4893	4947	4974	5030	5077	5116	**4720**
2nd	1036	1047	1059	1064	1073	1079	1091	1097	1113	1117	1119	1131	1139	1148	1157	1166	**1007**
3rd	234	239	241	241	243	243	247	251	254	258	255	258	263	265	269	270	**242**
4th	42	42	42	42	42	42	43	43	44	44	44	45	48	49	50	52	**45**
5th	8	8	8	8	8	8	8	8	8	8	8	8	8	9	10	10	**8**

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6 th	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	**2**
7 th	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**1**
Total	5842	5891	5951	5993	6033	6074	6144	6190	6256	6291	6322	6392	6435	6504	6566	6617	**6025**
RMSD	76.82	65.29	50.14	38.77	32.77	28.44	34	42.77	59.01	67.86	78.05	97.95	108.55	129.02	146.72	161.65	

*** Referenced Data(number of stream regarding to topographic map 1:50.000) after (Abouelmagd, 2003)**

After extracting the drainage network, the corresponding watersheds have to be delineated. Basically, the location of the outlet defines the area of the watershed. Thus the most important aspect for defining and delineating a watershed is to fix the outlet of the drainage course. It should be mentioned that the total number of streams for each order should have the same number of delineated basins. The classification of sub-watershed was based on their nested hierarchy up to the main stream represented by the downstream of basin (Omran, 2013). Here, the code can be performed as a basin classification based on the stream order relating to the Strahler theory (Fig.9). The delineation of the smallest basins as order 1, 2and 3 is automatically considered as an important part of the code, but it is difficult to implement this step using topographic maps. Additionally, the parameters “small basins as basin area” and “perimeter” could be useful in hydrological models.

Fig. 9. Different configurations of Basins delineation with different threshold values.

5- Conclusions

GIS techniques were used to delineate hydrographic basins and extract stream network based on a DEM, with emphasis on stream segmentation according to Strahler’s theory using an automated workflow. An algorithm implemented in Python enabled the correct and accurate counting of the stream segments for each order , whereas a pour point tool programmed based on ArcObjects in Java helped to delineate the watersheds for each stream order. The former tool was developed to find an

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optimal threshold value for modeling the raster layer of the drainage network automatically starting from some initial values. The intermediate results of the iteration provide a chance to evaluate the extracted stream networks against topographic maps. The implementation of the adopted tools on range of different DEM sources (e.g., SRTM and Tandem x) has not been applied here to present its effect on the number of extracted stream order at different resolutions. Thus, it would be recommended as future work to apply this tool on different DEM source for evaluating the optimal threshold value with different resolutions.

The results of the automated workflow can be used to calculate all morphometric parameters for each sub-basin (e.g., stream frequency, stream density, overland flow, bifurcation ratio, length ratio) based on the stream order number, stream length and basin areas. The new tool was developed to delineate the hydrographic basin area for each stream order through the smallest basin order, which is useful in hydrological applications such as geomorphological unit hydrographs and rainfall runoff models. It saves time and effort by automatically estimating the correct number streams for each stream order without additional manual steps, especially useful for large catchment basins.

Furthermore, this research is intended to point a way forward to update the topographic maps of the southern Sinai Peninsula, as well as for the geologically similar regions of Egypt’s eastern desert and the western part of Saudi Arabia. The automated workflow can be used on different DEM resolutions and can additionally be applied on different areas in the world experimentally. The code can be used in the future for generating hydrological models, especially models related to topographic parameters like geomorphic unit hydrographs and instantaneous unit hydrographs. The code succeeds in obtaining data about the smallest basin order1 and 2, which cannot be easily derived from topographic maps. These data (i.e., stream length, stream number and basin area of smallest basin order) should be used as important factors in hydrological models.

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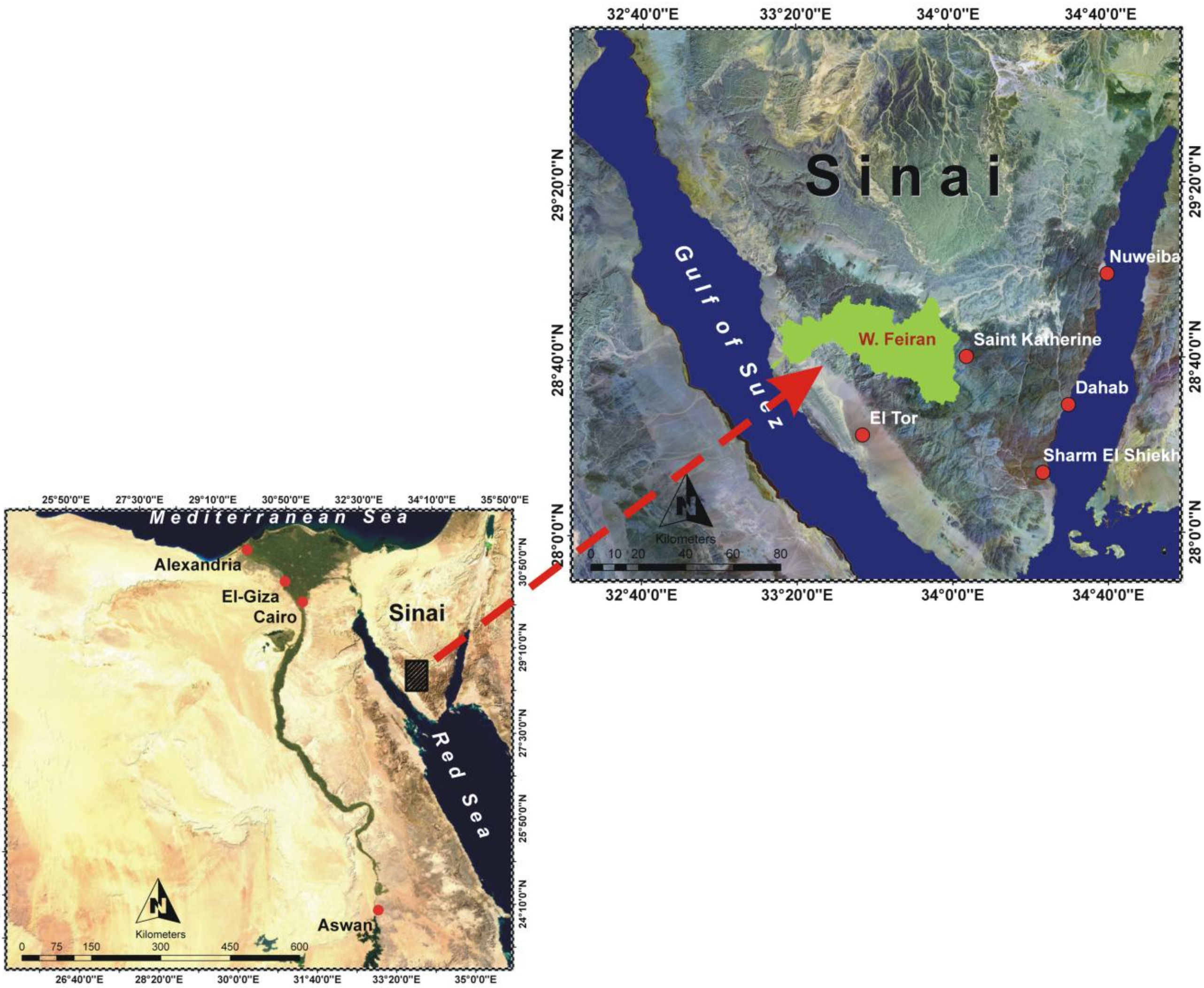

Fig. 1.The Location map of the study area.

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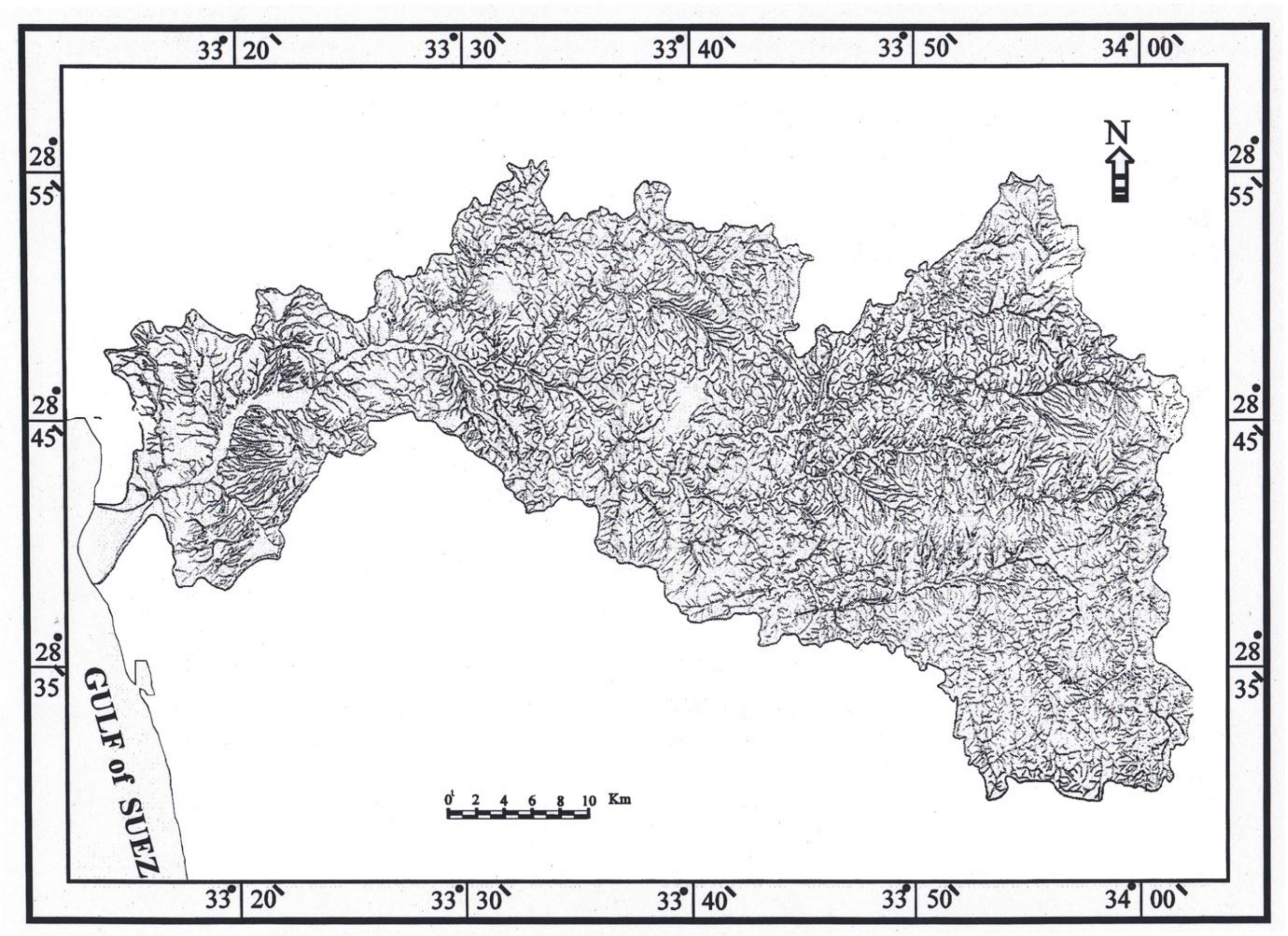

Fig. 2.Drainage networks of Wadi Feiran basin (Abouelmagd, 2003).

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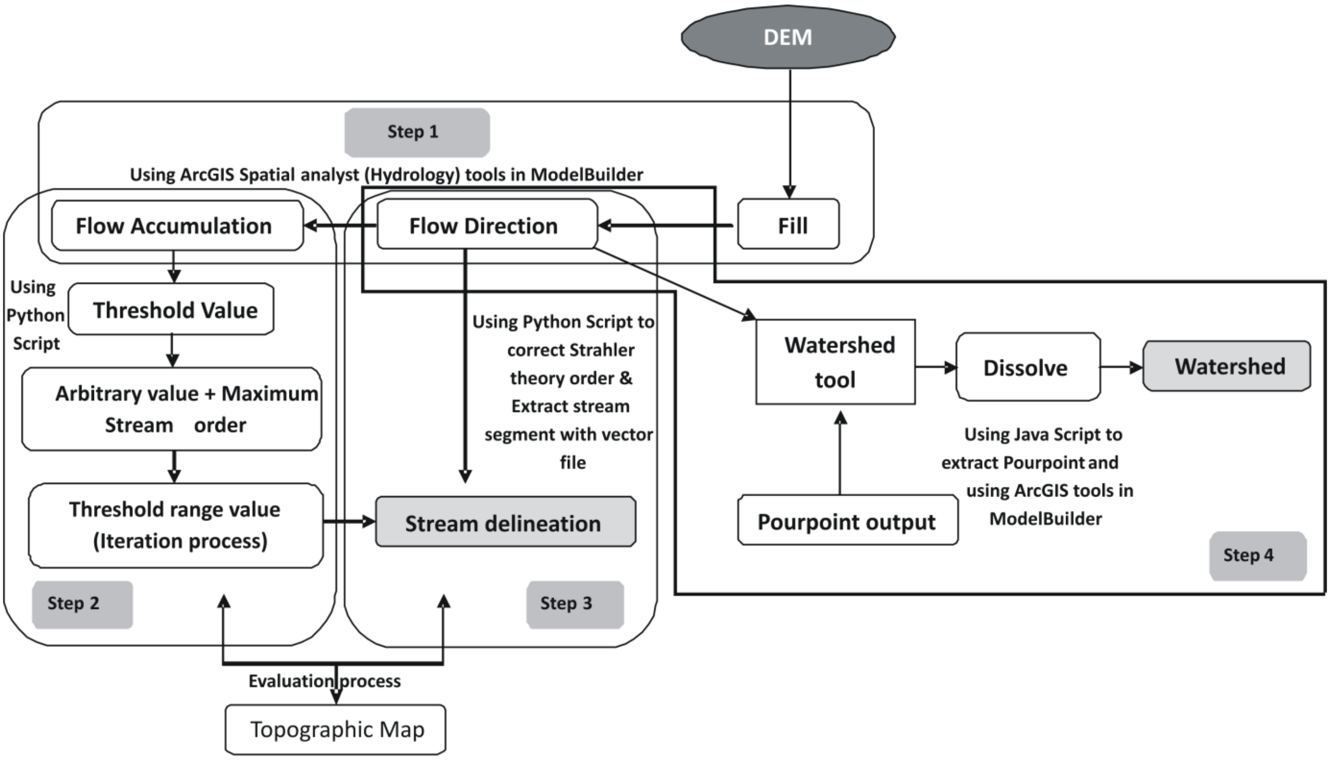

Fig. 3. Overall process flow of the code which was implemented on DEM.

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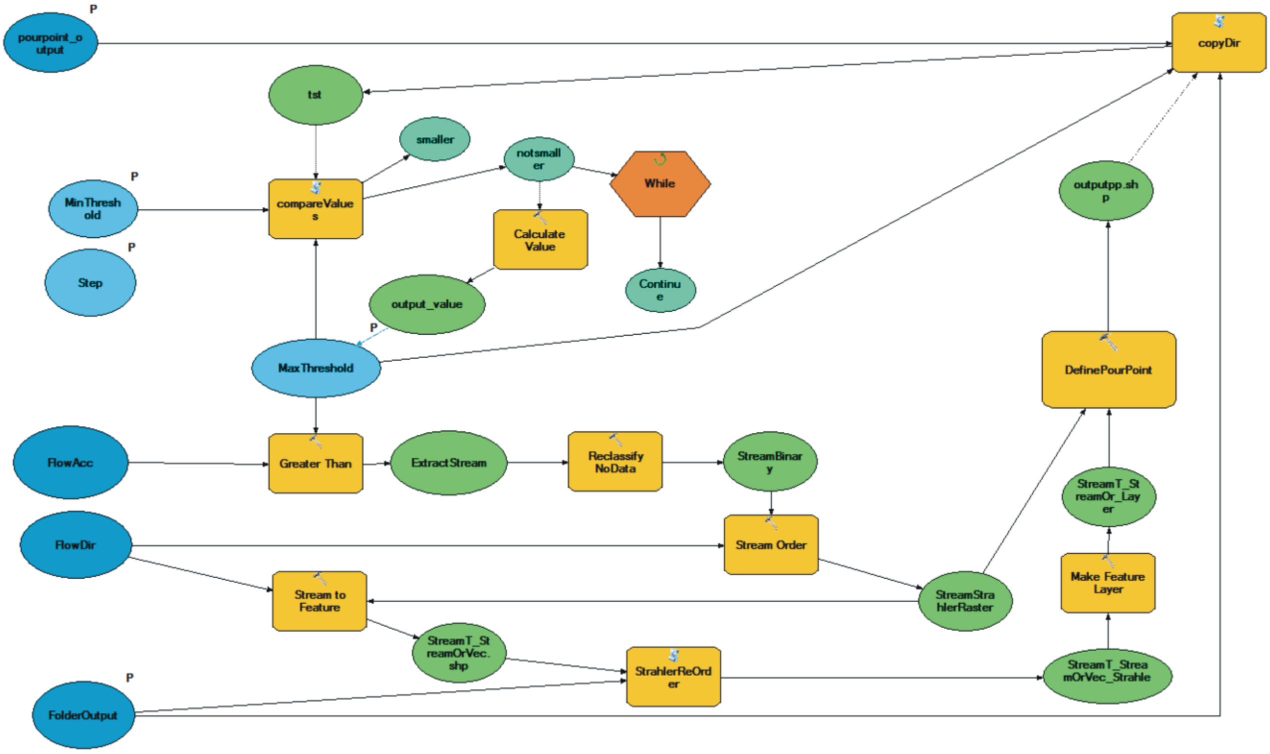

Fig. 4. ModelBuilder diagram showing the iteration workflow to extract the drainage patterns through the threshold range values from the Digital Elevation Model.

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```
Input:
    Strahler order streams (vector)
    Strahler order streams (raster)

AlgorithmPourPoint:
    listIntersectionPoints = list[ ]
    listPourPoints = list [ ]
    separate stream segments according to their Strahler order
    for loop iOrder = 1 to maxOrder:
        intersectstream segments of iOrder with the stream segments of iOrder to maxOrder
        convert the intersection points to raster
        for each pixel
            if pixel is intersection point: add the pixel location to listIntersectionPoints
        foreach item in listIntersectionPoints
            for each of the 8 neighbors of the item's location in the Strahler stream raster
            if the pixel's value is of iOrder add the pixels to listPourPoints
    create a new raster for the items in listPourPoints
```

Fig. 5.Pour point algorithm in pseudo-code notation.

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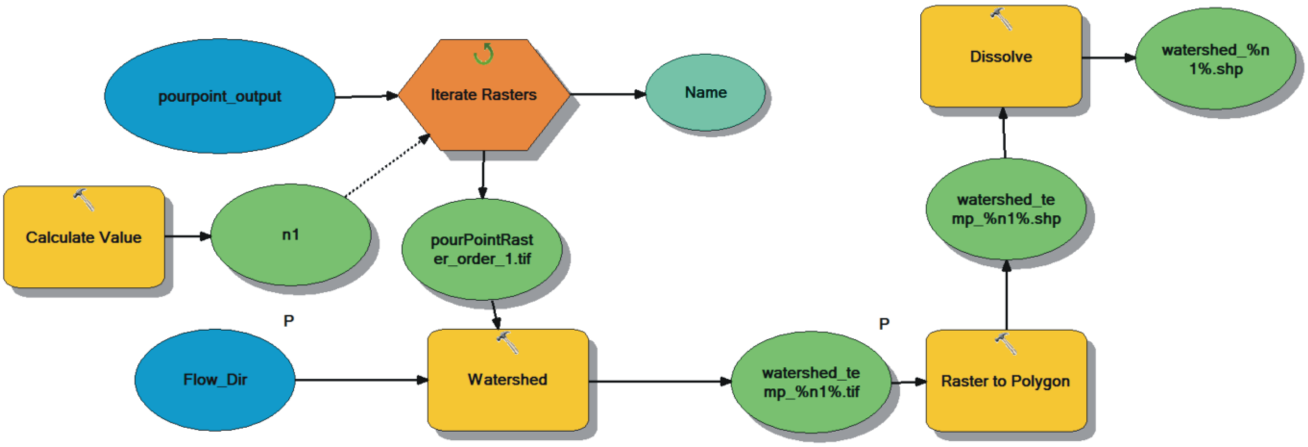

Fig. 6. ModelBuilder diagram showing the workflow to delineate watershed from extracted pourpoints and flow direction layer.

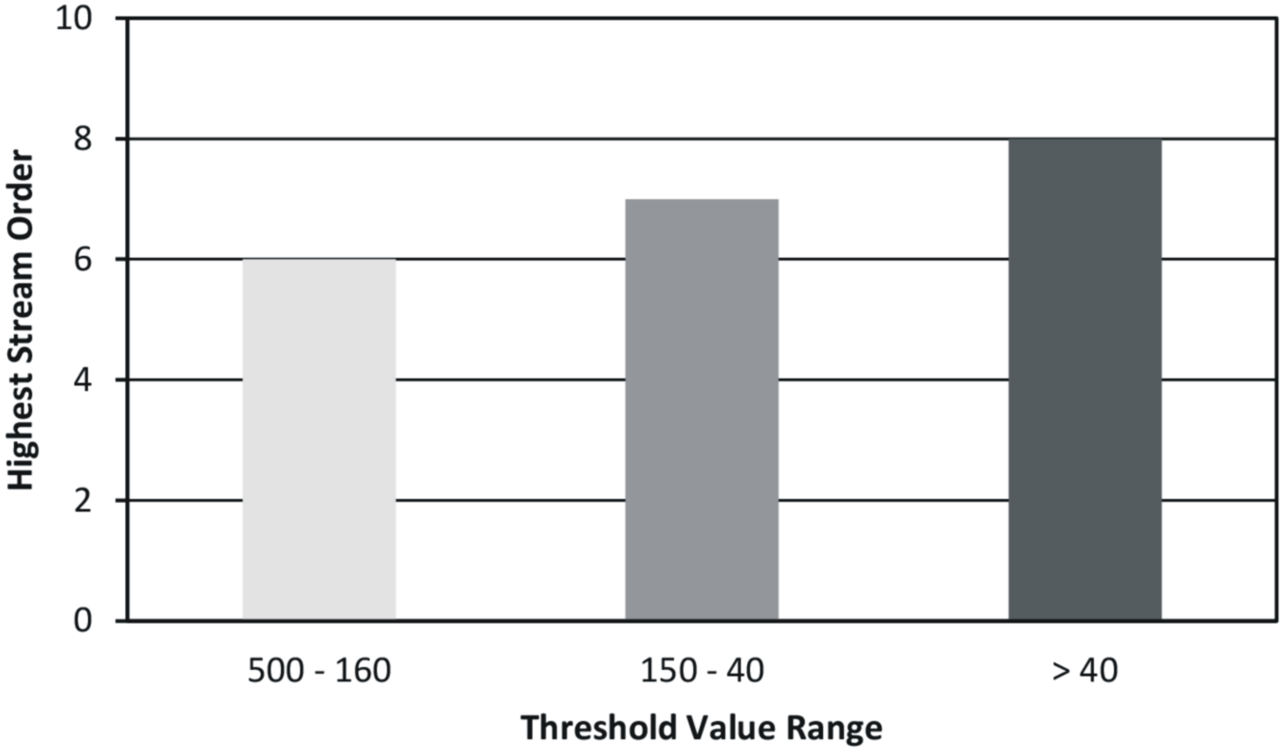

Fig. 7.The results of maximum stream order regarding to threshold values range.

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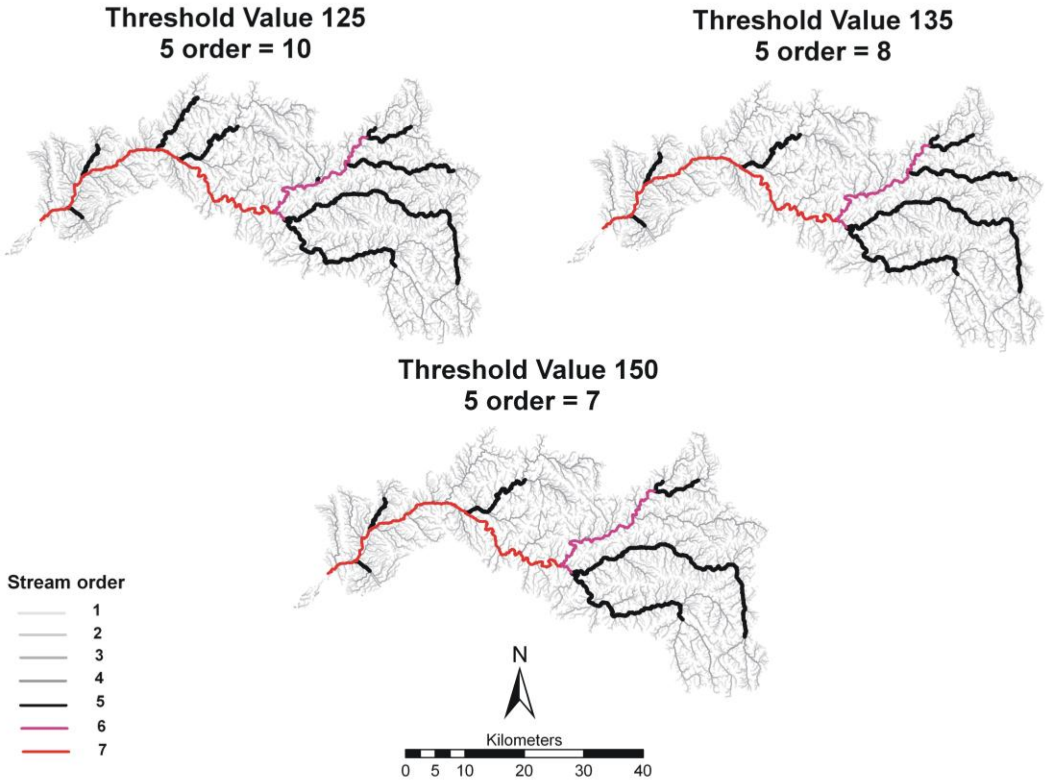

Fig. 8. Different configurations of stream networksaround the optimum threshold value were extracted from DEM by new tool.

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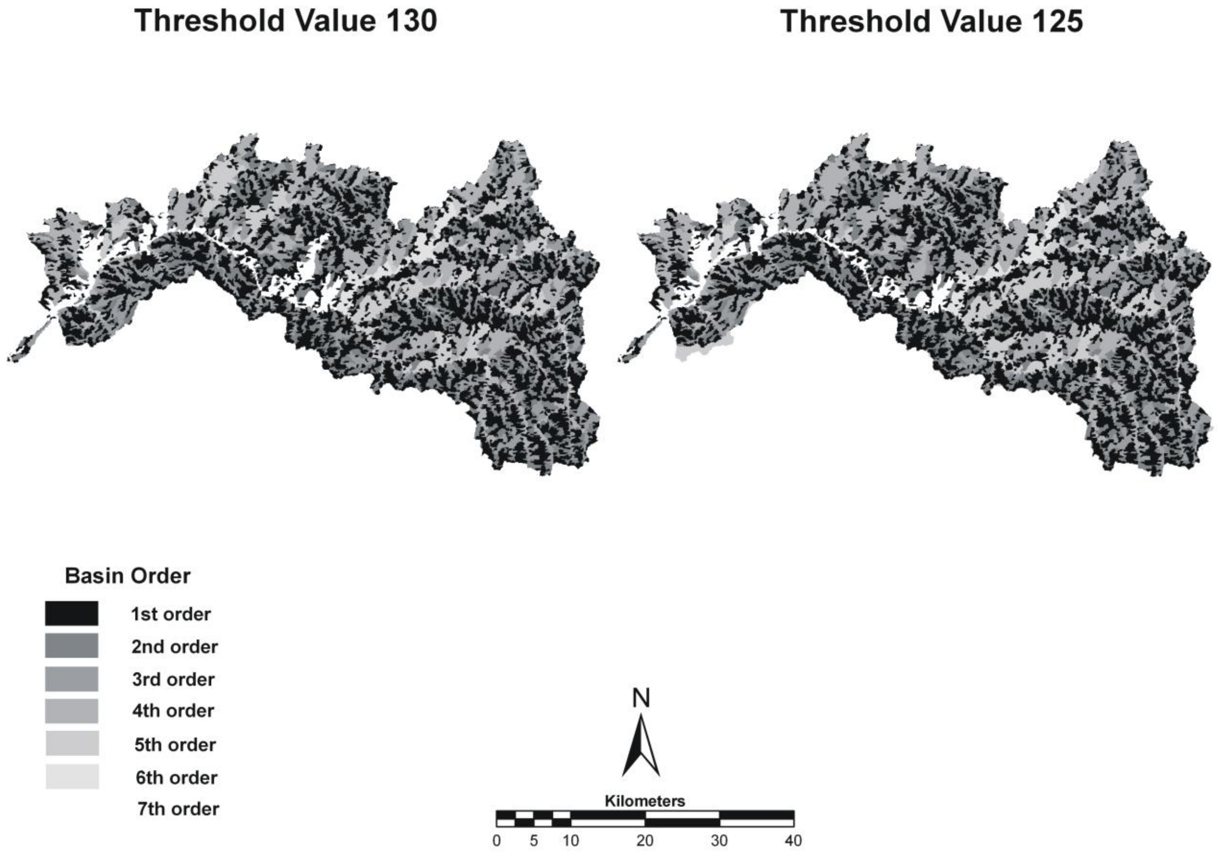

Fig. 9.Different configurations of Basins delineation with different threshold values.

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