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Developing an active tool in GIS to determine gully erosion levels depending on the Bergsma method

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الملخص

Gully erosion is the most significant environmental threat in the field of natural resource management. Recently, one of the complexities of soil erosion studies in Iraq is the lack of information on the location of gullies, As well as relying on traditional methods in studying this type of erosion. The objective of this paper is to develop an adaptive tool for estimating gully erosion levels based on Python and modular building in ArcGIS environment. This tool can be used for dealing with the stream network and calculate the length of the valley, as well as divide the lengths of the Stream into squares of grid and then determine and mapping the levels of gully erosion. The proposed methodology with the adaptive developed tool has been applied to compute the gully erosion levels in a Duhok basin which is located northeastern of Dohuk governorate-Kurdistan region and covers about (404.8) km2. To estimate erosion levels, the study area was divided into equal squares using the fishnet tool, then the Bergsma equation was applied after extracting streams and calculating areas. The developed tool was created based on the two factors, the one related to stream network density, while the second depends on the cell size. To achieve that, multi-threshold values were tested for each factor. The finding revealed that there are levels of gully erosion, which were classified into seven classes. Also, the results also supported the control of the geological and topographic factors on these levels. The developed tool also gave high efficiency in classifying erosion levels, and the possibility of applying it in other areas.

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1. Introduction:

Soil erosion is a natural process formed , in general, by global climate changes, and can be controlled by the following factors such as water, wind, and ice (Ritchie, 2000), (Valentin et al., 2005). Gully or Soil erosion caused by water is common land degradation because of its destructive on-site landform impacts for example loss of soil productivity and quality and off-site impacts for example rivers sedimentation. (Dwivedi et al., 1997); (Eswaran et al., 2001). Although soil erosion represents a natural process, at the same time, it may be accelerated by human processes or activities, and this can be made by the clearing of vegetation or overgrazing (Snyman, 1999). Soil erosion is created from the water impact, which depends on the interactive and

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combined effects of multi erosion control factors, which are: rainfall erosion, soil erodibility, slope steepness, slope length. There are three main types of soil erosion created by water effects, these types include sheet, rill, and gully erosion. In this context, Sheet erosion is the segregation and transportation of soil particles that exist as a result of rain-splash and terrestrial flow (Garland et al., 2000). Rill erosion works to remove the soil in small channels, while gully erosion removes the soil in large channels and being the most severe type. Gully erosion mapping is important to identify areas, improved distribution, and capabilities, define the magnitude of erosion, quantify the process size, estimate changing rates in the soil as well as predict environmental characteristics in the soil (Taruvinga, 2009), (Korzeniowska & Korup, 2016). Most of the previous studies focus in the gully erosion and works to design mapping approaches by using remotely sensed data and GIS. For example, (Bergsma, 1982) was used aerial photography as an essential tool in drawing gully erosion maps. Other researchers based on satellite imagery to detect gully erosion and prepared related maps of this type of erosion (Giordano & Marchisio, 1991). Soil erosion can be estimated using simple empirical methods like universal Soil Loss Equation (USLE) and physically based models like the European Soil Erosion Model (EUROSEM). In addition, modern technologies can help to detect and monitoring soil erosion like Remote Sensing and Geographical Information System as examples (Gull & Shah, 2020); (Chuenchum et al., 2020); (Senanayake et al., 2020)). In large areas, the integration of remote sensing and geographic information system techniques consider as good application for estimating soil erosion and its spatial distribution taking into account reasonable time, costs and accuracy (Gunawan et al., 2013); (Alexakis et al., 2013)). For example, soil erosion risk was assessed based on a simplified version of Revised Universal Soil Loss Equation (RUSLE) where the digital elevation model (DEM) data were used as supplementary remote sensing data (Boggs et al., 2001). Also, (G. Wang et al., 2003) used Thematic Mapper (TM) images and DEM data supported with ground dataset samples, to predict soil erosion where geostatistical methods were developed. The aim of this study is to develop a tool that has the ability to detect and classify gully erosion in the basin under study. This tool was developed based on the Bergsma equation. Furthermore, this tool can be engaged in Arc Gis software.

2. Study area description

The area under investigation represents a watershed located northeastern of Dohuk governorate- Kurdistan region and covers about (404.8) km^2. This watershed is called the Dohuk basin and lying between (36° 58' 30" to 36° 45' 00" N) and (42° 49' 30" to 43° 07' 30" E) Fig.1. The climate of this area is semi-arid and characterized by hot weather in summer and highly cold in winter.

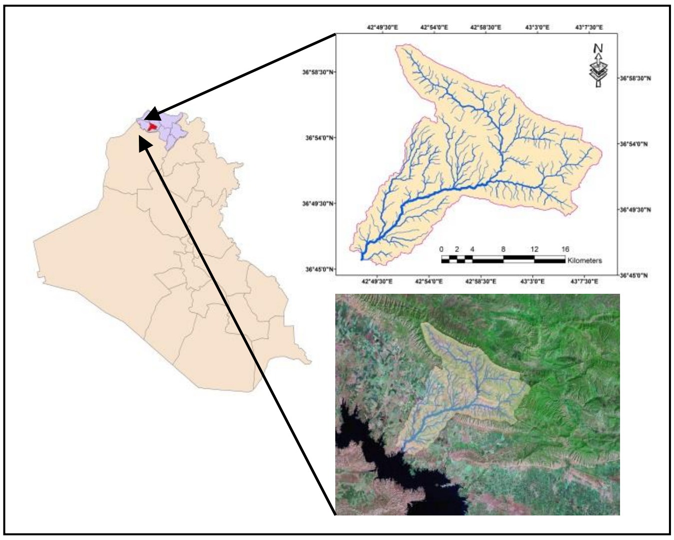

Figure 1. The location of the study area

Tectonically, the study area belongs to the High Folded Zone of Iraq and parallel to the Taurus extension. Generally, the most folds at this zone are characterized by its intensity, long extended, high amplitudes, as well as, vergent towards the south and southwestern parts. Related to structural geology, most parts of this watershed that bounded by Bekhair structure is a double plunging anticline, and the axis trends generally towards northwest-southeast. The structural framework of this anticline exhibit en-echelon and multi-dome along the fold axis. Geomorphologically, the main units within the watershed are the structural unit reflects the most anticlinal ridges which are well developed at the north and northeastern parts of the watershed which represents the core of the fold as well as some parts of the southwestern limb. In this context, denudational units among the structural units are the triangular facets or flat iron topography, cuestas and hogsback are appear clearly in the same parts. Fluvial units can be inferred by curved valleys, radial valleys, terraces, and valley filling. Stratigraphically, lithological units are briefly described as the following formations (from the older to younger) Fig2:

A. Bekhma formation: the outcrops of this formation are form the oldest units at the core of the Bekhir anticline and appear as a high terrain, which indicates its strong resistance to weathering and erosion. The lithology of this formation is composed of thickly and thinly bedded of dolomitic limestone and marly limestone.

B. Shiranish Formation: lithology of this formation includes limestone and marly limestone.

C. Kolosh Formation: The outcrops of this formation have variety in thickness at most parts of Bekhair anticline and contain black claystone, siltstone, and sandstone.

D. Khurmala Formation: The lithology of this formation is composed of dolomitic limestone and some beds of re-crystalline limestone.

E. Gercus Formation: The lithology of this formation is consists of reddish-brown fine clastics.

F: Avanah Formation: lithology of this formation is re-crystalline marly limestone interfingering with some lenses of marl.

G: Pilaspi Formation: This formation forms the structural carapace of the Bekhair anticline and is exposed in large areas. It consists of well-bedded limestone and dolostone.

H: Quaternary deposits: the materials of these deposits are represented by slope sediments, valley filling sediments, and flood plain deposits.

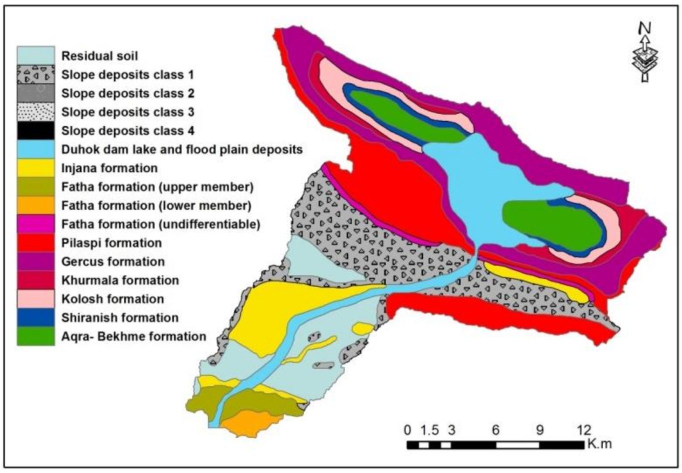

Figure 2. Geological map of the study area, Modified from (Sissakian et al., 1995)

3. Gully erosion concept

Gully erosion is considered as the erosion process that affects the earth's surface whereby the accumulated surface runoff runs in straiten channels, over small periods, erodes the soil from this area to depths (Poesen et al., 2003), (Kirkby & Bracken, 2009). Once initiated, one of the gullies can develop into a network of landforms of active gullies that working significantly to soil loss in a basin or catchment (Martınez-Casasnovas, 2003). In this context, Gully erosion can develop as extended rills (Stout, 1965) but their genesis may be considered much more difficult (Morgan, 1979), and usually includes mutual relations between the following: 1. The susceptibility of the land cover to erosion, 2. The volume, type, and speed of runoff, 3. Changing in land cover as a result of landuse and conservation practices (Bocco, 1991). Generally, the mechanism which is led to sheet-rill and gully development is managed by a lot of factors. The study presented by (Le Roux & Sumner, 2012) clarified these factors, and hence the factors related to gully erosion will be summarized as follows.

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3.1 Rainfall

Gully erosion is the product of severe storms which can make more water on the soil surface than can be intercepted by plants or vegetation and then infiltrated into the soil leading to surface runoff. Also, Soil particles may be broken up by heavy raindrops leading to create smaller fragments. In addition, heavy raindrops can break up soil particles into smaller fragments, as a consequence, the pore spaces get blocked up and this will result in reduces infiltration capacity as well as lead to a lot of surface runoff which could further increase the risk of erosion (Valentin et al., 2005).

3.2 Lithological setting

Lithology has a major role in erosion through its control of erosional processes, as rock erodibility is based on it (Ali et al., 2016). gully erosion especially reliant on the lithology characteristics of the material close or exposed to the earth surface (Casalı et al., 1999); (El Maaoui et al., 2012); (Golestani et al., 2014). furthermore, lithological characteristics are related to the geomorphological landforms (Dai et al., 2001) (Zinck et al., 2001) (Gorum et al., 2008) (Zhu et al., 2014).

3.3 Topographic setting

The topography is controlling the gully erosion process and, thus, detect the spatial distribution of gullies (Zhu et al., 2014); (Conoscenti et al., 2014). The topography of the surface effects on the concentration of drainage flow and an evaluation of topography can be used to forecast the location and likelihood of gully erosion. In this context, topographic effects on gully erosion are dividedoned in the impacts of slope length. and slope steepness (Le Roux). Slope steepness led to the proportion of downslope movement (i.e. increase in the downslope movement). the slope is important when considering the overall transport of soil particles (T. Wang et al., 2014). As the slope steepens, the proportion of downslope movement increases as a consequence of respective increases in surface runoff velocity. On the other side, erosion is generally smaller on gentle slopes due to an existing lot of surface ponding and slower surface flow that protecting the soil from the effects of rain.

3.4 Landuse

Farming activities that decrease soil cover and expose the soil surface can largely increase erosion risk. According to (Martel & Mackenzie, 1980), Cultivation and stock stomping can degrade soil structure, causing loss of soil organic materials as well as compaction and reduced rainfall infiltration. Soil structure degradation also decreases the cohesion of soil particles or the tendency of soil particles to cohere.

4. Erosional stages down to the gully

Generally, erosional processes occur when the water, wind, and weight of soil powers, are significantly grater than the forces of adhesion that hold the soil particles together, resulting in separation of soil particles into sediment. Consequently, there are four main types of erosion processes composed of the following: splash, sheet, rill as well as gully erosion Fig. 3 (Sandipan et al., 2012), (Grigar et al., 2020), (Kumawat et al., 2020). All previous types of erosional stages can cause sediment erodability, transport and settling.

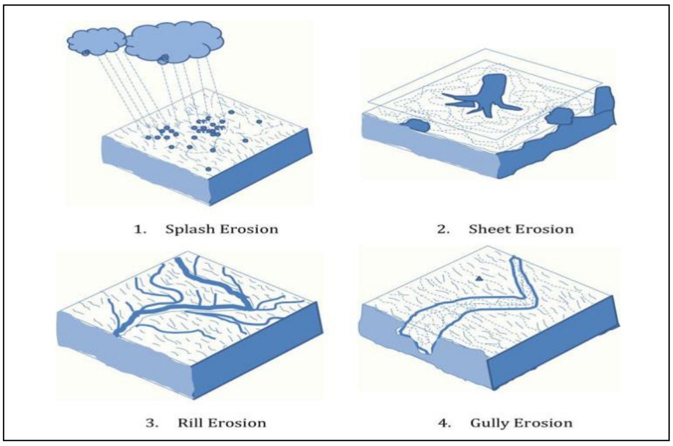

Figure 3. showing the four main types of soil erosion by water (Kumawat et al., 2020)

A brief description of these types of erosion as follows:

4.1 Splash erosion:

This type is considered the first stage of the erosion process. It forms when drops of rain hit the soil. The explosive effect by frittering soil material, so that particles of soil are 'splashed' gradually onto the soil surface. The splashed particles may reach high about (60 cm) above the earth's surface and shift up to 1.5 meters away from the effect point.

4.2 Sheet erosion

The mechanism of this type of erosion includes soil removal in thin layers by the impact of shallow surface flow and raindrop. It is usually located evenly over an equal slope terrain And it remains unnoticed until much of the valuable topsoil has been lost, and then eroded soil deposition occurs at the slope bottom.

4.3 Rill erosion

Rill erosion results when surface water runoff concentrates, and then create tiny yet well-dentified channels. These discernable channels where the soil has been eroded away are small enough to not affect field machinery operations.

4.4 Gully erosion

This type of erosion can be considered as an advanced level of rill erosion. In this context, if rills are not handled, they will become larger gullies. The depth of gully channels about more than (30cm).

5. Methodology

The methods used for calculating gully erosion are based on the DEM –analysis which is providing a practical procedure for erosion identifying over a large area. To apply that, a tool was developed in Python using modular builder in ArcGis program. The methods used in this study consist of three main steps described below and as illustrated in Fig. 4

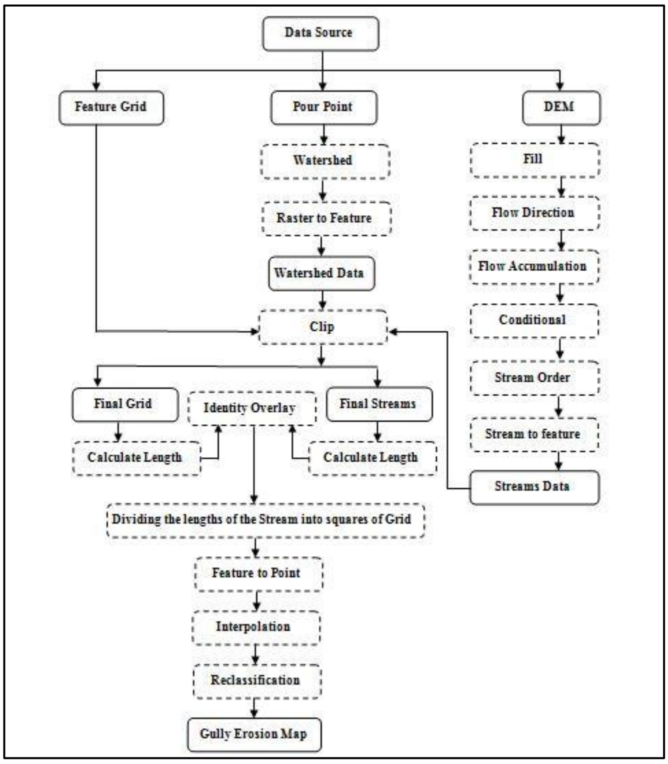

Figure 4. Flow chart (with details) of the methodology

5.1 Conceptual model builder of gully erosion

Generally, The conceptual model in geographic information systems (GIS) is expressed diagram to describe the quantitative and qualitative procedures of executive processes on the data. The system diagram is considered one of the most common conceptual models used in (GIS), which uses symbols and words to describe the main components and links of the model (Ian, 2010). This model defines how data is organized for use by (GIS), and the procedures that take place during the input, analysis, and output phases (Alberto Giordano et al., 1994). In this context, the conceptual model formalizes the variables identified in the proposed knowledge tabulation of the diagram structure (Car & Frank, 1995). Conceptual modeling has several advantages for designing scientific applications, the most important of which is allowing users to express their knowledge of the application without the need to use mathematical expressions or detailed procedures in the use of functions (Lisboa-Filho et al., 2010). Recently, some conceptual models are

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working interactively in GIS software. The most important of these models are generated by ArcGIS desktop software by a sub-program called the model builder, which is an application used to create, edit and manage conceptual models. Model builder enables the visualization of the workflow (by the graphic flowcharts) and the creation and automation of Geoprocessing tasks that are typically performed in one step. Once the automation model is successful, it can be relied upon for tool development. Consequently, the conceptual model of gully erosion was constructed by the Bergsma method, which included the merging of a set of tools relevant to different applications in GIS. The conceptual model builder of gully erosion consisted of two parts. The first part included the merging of the following tolls: Fishnet, Clip, Identity, Feature to point, Spline, Reclassify, and Raster to Polygon tools. The Fishnet tool creates a grid of squares with a vector file, then switches the results to the Clip tool, which cuts the grid of squares based on the study area boundaries, then switches the results again to the Identify tool that works spatial identification between streams and the square networks. Consequently, each square calculates the stream length involved in it (in meters). After that, the squares are converted into feature points and then processed through a spatial interpolation process to be converted into a Raster Surface. Finally, the raster surface is reclassified according to the Bergsma method and transformed to the vector format again. The second part of the conceptual builder model contains a set of tools that deal with attribute data. These tools are: Add Field, Select by Attribute, as well as Field Calculator. These fields are added to save information about erosion levels using the Bergsma method so that each level is selected by the tool of Select by Attribute, and then the information related to each class is entered in the Field Calculator tool until the added fields are filled with the information Fig.5.

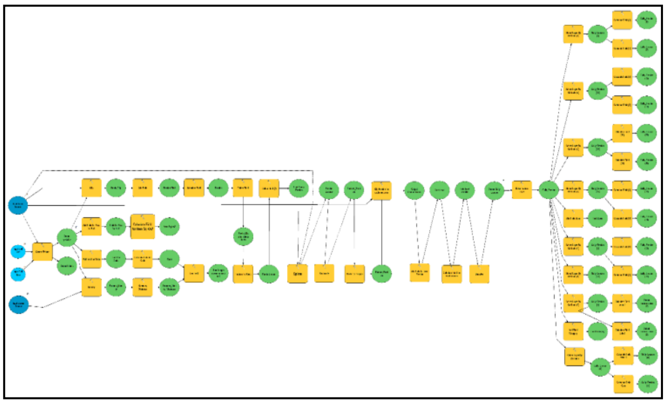

Figure 5. Diagrame of model builder showing the elements used in programming, designing and implementing the tool for gully erosion extracting

5.2 Transform the Conceptual Model To ArcGIS Desktop Tool

Conceptual model transformation to the adaptive ArcGIS tool requires knowledge of the necessary parameters that must be available in the user to control the modeled process in a comprehensive manner. Therefore, the developed tool based on its functionality was named Gully Erosion by Bergsma Method, and it contains 6 parameters Fig. 6 , through which the user can control the modeling of the gully erosion. These parameters are as follows:

1. Input Stream Feature parameter, from which the stream file is entered in the feature class or shapefile format.
2. Input Basin Feature parameter, from which the water basin file is entered, in a storage format feature class or shapefile.
3. Input Cell Size Width parameter, from which the width of the box is specified in meters.
4. Input Cell Size Height parameter, from which, the height of the square is specified in meters.
5. Output Grid parameter, from which the squares grid file is saved in Shapefile format, on which it will be relied upon to derive Gully erosion.
6. Output Gully Erosion parameter, from which the Gully Erosion file is stored in the computer's memory, in a Shapefile format.

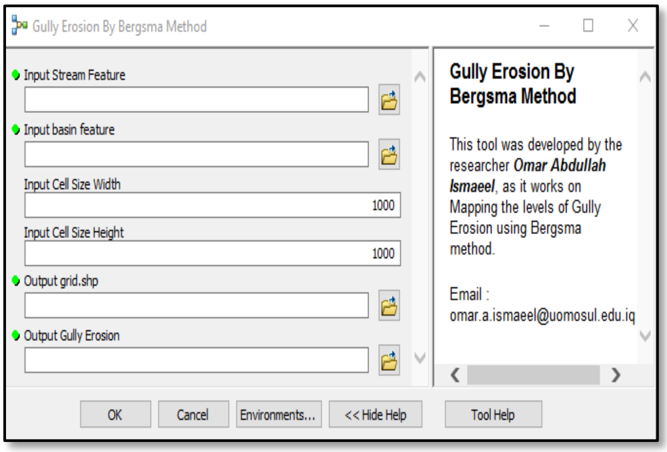

Figure 6. Window interface of input layers and factors used in the execution of gully erosion

5.3 Automatic delineation of streams

To extract stream networks and watershed, several steps were previously mentioned in the methodology Fig. 4, as they were explained in detail in Fig. 7, it is noted that the DEM data has been processed from the sink & pit filling, and this is an important procedure to obtain accurate results. To test the operation of the developed tool with different data details, four data models of streams were designed, which were derived from the digital elevation model. The details of DEM derived streams are controlled by the Con tool in the ArcGIS program, and then a threshold value is chosen for cells carrying aggregate values in DEM. In this context, four models were chosen from the selection that controls the details of streams, which are (Value> 1500), (Value> 1000), (Value> 500) and (Value> 250). However, this will result in a set of streams with different details. It is also noted that the stream's bifurcation will increase as the specified threshold value decreases. As shown in Fig. 8, auto-extracting of stream networks from the DEM using multi-different thresholds reflects the entire view of stream networks of the area under investigation. Furthermore, it can be noticed that the water from this area drains in all directions.

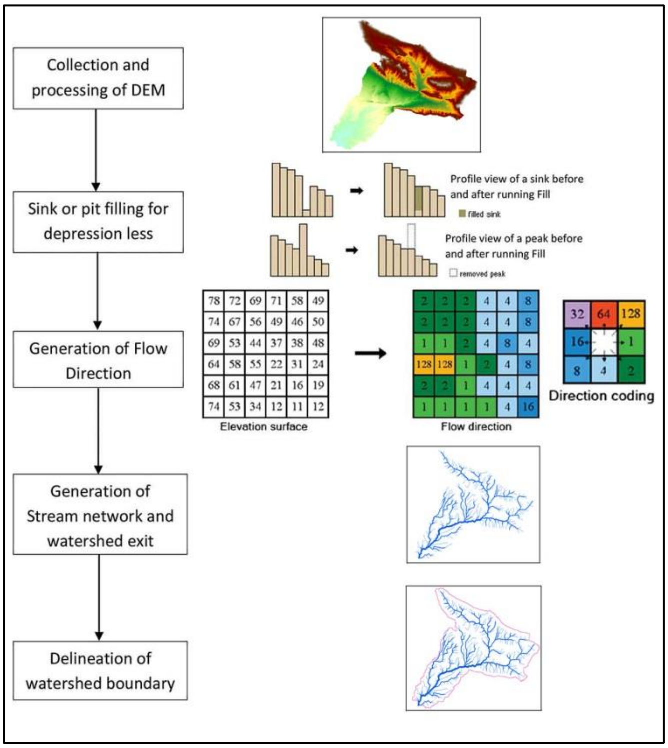

Figure 7. watershed delineation steps modified from (Ray, 2018)

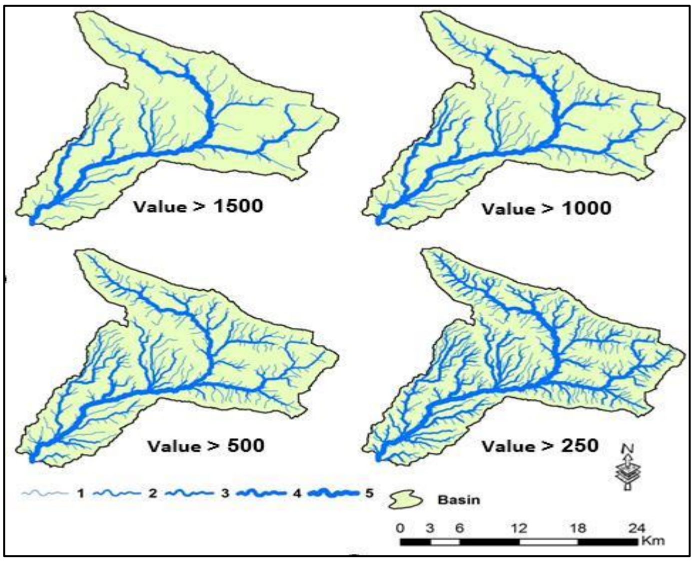

Figure 8. Different criteria of stream networks around the selected threshold value were determined from DEM by the developed tool

6. Results and discussions

The Bergsma method was used to estimate the gully erosion of the watershed under investigation. The use of this equation with a stream network can give important results. The stream network map was prepared based on the automated extraction process, according to varying values of threshold limits, allowing for accurate estimation of erosion values. After that, the study area was divided into equal squares using the fishnet tool. After extracting streams and calculating areas, the Bergsma equation was applied as follow:

$$AE = \sum L / A$$

Where AE is the rate of erosion per square, L is the stream length in each square, and A is the area of one square in km^2. To estimate gulley erosion of the study area by relying on the Bergsma method, two scenarios were used as the following:

6.1 Erosion levels estimation based on stream network density

Four threshold values were tested to derive stream and then calculate erosion levels at each threshold. As shown in Table 1, seven erosion zones can be identified in the area and each zone is distinguished from the other by the degree of erosion effectiveness. The amount of erosion varies depending on the threshold value.

Table 1. Erosion level classes extracted from stream density based on the selected threshold values

Erosion Level / Streams details	Very light	Light	Moderate	High	Very high	severe	Very severe
Value > 1500	89.1	132.1	126.6	56	0.9	0	0
Value > 1000	71.3	131.3	120.6	79.7	2	0	0
Value > 500	46.9	94.7	112.8	140.4	9.9	0	0
Value > 250	27.9	61.1	79.1	193.8	41.5	1.4	0

The table shows that there are seven regions of the gully erosion levels inferred from the developed tool based on the variation in drainage density. It is noticed that with the increase of stream density, as a result of reducing the threshold values to less than 250, there will be a possibility of reaching extreme erosion, and this has already been indicated. The value of an area of 14 km^2 of gully erosion was recorded at an extreme level. On the other hand, this level did not appear in the other values of the threshold. Furthermore, The highest level of gully erosion was recorded at a threshold below 250 with a value of 193 km2 and an extreme level. Referring to the same table, it can be concluded that with the increase of a threshold value, areas of gully erosion will increase also at higher values, specifically in the area classified under very light, light, and moderate. However, this does not correspond to the areas classified under the high, very high, and severe levels. The principal reason for this is that the increase in the threshold value will lead to the removal of high order streams (i.e. first and second orders) and that will be reflected in the areas related to erosion levels. Based on the foregoing, the following question can be concluded: What is the appropriate threshold value in the evaluation of gully erosion through the tool that was developed in the current study? To illustrate that, Fig. 9 can be observed which includes four scenarios for gully erosion levels in the area under investigation using different values of threshold values. By comparing these scenarios with the geological map in Fig. 2, it can be concluded that the threshold value (500) gave good results based on the following reasons:

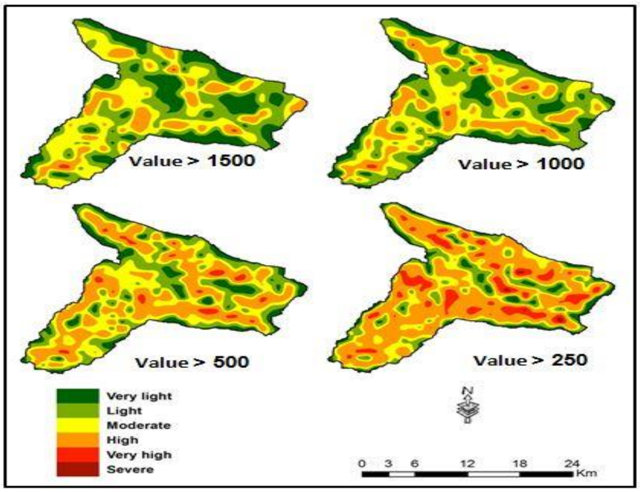

Figure 9. Different scenario of Basins delineation based on the different threshold values

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1. The Bekhma formation exists in the very light erosion zone because of consisting of hard limestone rocks that are resistant to erosion processes and the appearance of the formation in an elliptical structure is compatible with its structural pattern in the northeastern parts of the Bekhair anticline.

2. The formations containing brittle rocks that are not resistant to erosion processes, such as Shiranish, Kolosh, Khurmala, and Gercus, have been classified as having high and very high erosion. In this context, these formations surround the Bekhma formation and are characterized by a topographical depression as a result of being affected by erosion processes.

3. The rocks of the Pilaspi Formation, which form the carapace of Bekhair anticline, are characterized by light and very light erosion levels due to limestone rocks that are resistant to erosion.

4. Towards the south and southwestern parts of the study area, an increase in the intensity of erosion is observed as a result of the decrease in the rock outcrops, as well as the presence of recent sediments of the Quaternary deposits.

6.2 Erosion levels estimation based on cell size effect

The developed tool used two parameters which are: input cell size, and cell size hight. These two factors determine the effect of the square grid size on the gully erosion scenario outputs. For testing the values of the previous parameters, four model squares grid with side lengths of 2000, 1500, 1000, 500 meters were selected. Table 2, refers to several values of the grid squares size. The very severe erosion zone was reported in the cell size (500), while the very severe, severe, and very high erosion levels did not appear in the cell size (2000), This reflects the effect of the square or cell size factor on the erosion output levels. the distributions of the erosion zone on the study area, several values of the square size were tested, and then four erosion zone scenarios were prepared Fig. 10, each of these scenarios reflects a specific value of the square side length. After comparing the previous scenarios with the geological map of the study area Fig. 2, it was concluded that the side length value of (500) gave a good agreement with the geology and topography of the area. As well as, the formations containing hard rocks were represented by very light and light erosion levels, while the formations containing brittle rocks contained higher levels of erosion varieties. Depending on the foregoing, the developed tool can represent the levels of gully erosion with good results depending on the selection of the appropriate values.

Table 1. Erosion level classes extracted from stream density based on the selected cell size threshold values

Erosion Level / Cell Size	Very light	Light	Moderate	High	Very high	Severe	Very severe
2000 m	38.8	112	155.8	98.3	0	0	0
1500 m	45.6	105.9	135.4	117	1	0	0
1000 m	46.9	94.7	112.8	140.4	9.9	0	0
500 m	68.1	58.9	63.1	150.6	52	10.7	1.3

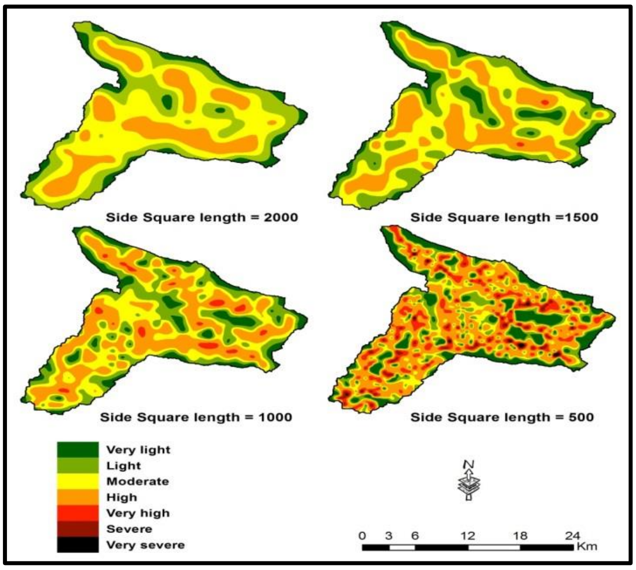

Figure 10. Different scenario of Basins delineation based on the different threshold values

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7. Conclusions

In this study, GIS techniques were used to study gully erosion in the Duhok basin based on a DEM. The new GIS tool has been developed named a Gully Erosion by Bergsma Method and includes six parameters which are: Input stream feature, input basin feature, input cell size width, input cell size height, output grid parameter, and output gully erosion. The outputs of this tool can be used to prepare a gully map for any area. To determine erosion level, multi-threshold values were tested when using the tool. The optimum value of the thresholds was determined to be appropriate for the geological environment of the area under investigation. Therefore, the current study recommends the necessity of comparing the tool outputs with the geological and topographic maps in order to select the appropriate threshold value which, determines the efficiency of inferred gully erosion levels.

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الملخص

تعد التعرية الاخدودية Gully Erosion من أهم التهديدات البيئية في مجال إدارة الموارد الطبيعية. في الوقت الحالي، أحد الصعوبات التي ترافق دراسات تعرية هي في كيفية تقدير مستوياتها بطريقة آلية بالكامل.

يهدف البحث الحالي الى تطوير أداة فعالة لتقدير مستويات التعرية الأخدودية بناءً على اللغة البرمجية (Python) وبناء الأنموذج المفاهيمي Conceptual Model في بيئة برنامج ArcGIS Desktop، اذ يمكن للأداة المطورة أن تتعامل مع المجاري المائية بصيغة حفظ من نوع Shapefile و Geodatabase ، وكذلك تقسيم المنطقة المدروسة إلى شبكة مربعات، ومن ثم تقدير مستويات التعرية الاخدودية على سطح الخريطة.

تم تطبيق المنهجية المقترحة باستخدام الأداة المطورة لحساب مستويات التعرية الاخدودية في حوض دهوك الذي يقع شمال شرق محافظة دهوك - إقليم كردستان ويغطي حوالي (404.8) كم^2.

كما صممت الأداة المطورة بناءً على عاملين، أحدهما يتعلق بحساب اطوال المجاري المائية، بينما يعتمد الثاني على حجم المربع. لتحقيق ذلك ، تم اختبار القيم متعددة العتبات لكل عامل. اسفرت النتائج عن وجود مستويات من التعرية الاخدودية التي تم تصنيفها إلى سبع فئات. اعطت النتائج دليلا واضحا لسيطرة العوامل الجيولوجية والطبوغرافية على مستويات التعرية. كما أعطت الأداة المطورة كفاءة عالية في تقدير مستويات التعرية مع إمكانية تداولها بين الباحثين و تطبيقها في مناطق أخرى.