

GIS to Create Maps Based on the Bergsma Model for Gully Erosion Estimation Using DEM: A Case Study for Qarahanjeer, Kirkuk, Iraq

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Abstract

Gully erosion is a serious environmental problem that threatens soil sustainability, especially in arid and semi-arid regions like Qarahanjeer in Kirkuk, which spans an area of 676 km². The main research problem is the lack of studies and effective methods to determine the extent of gully erosion. To meet this challenge, this study used the Bergsma (1986) model and GIS techniques to estimate gully erosion based on digital elevation model (DEM) data from the ALOS PALSAR program. The main objective of the study is to evaluate the applicability of the Bergsma model in mapping gully erosion risk areas in the Qarahanjeer region and to verify its effectiveness using field observations. The results revealed the levels of gully erosion. High erosion was the predominant category, comprising 54.692% of the research area, represented by categories from 1501 to 2700. Moderate erosion (21%) occurred in transitional zones, characterized by augmented fluvial energy and vegetative cover (1001 to 1500). Despite very limited areas (12.47%) categorized (2701 to 3700), severe erosion (0.69 %) categories (3701 to 4700) assessments signify significant degradation, as these operations disrupt natural drainage patterns. Also, recommended that depressions be dug in the basin estuaries to collect water, particularly surface runoff for use, and to utilize high-resolution spatial data to estimate erosion. Applying research and recording geomorphological changes with GIS and remote sensing.

Keywords:

Digital Elevation Model Dem, Bergsma Model, Gully Erosion, Qarahanjeer.

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1. Introduction

Landforms are subject to change over time, and erosion is one of the most important aspects affecting these morphological changes on the Earth's surface (Kirkby and Bracken, 2009). One of the complexities of soil erosion studies in Kirkuk is the lack of information on the location of gullies and the reliance on traditional methods to study this type of erosion. The study is limited to the Qarahanjeer area in the north-eastern Governorate of Kirkuk. It focuses on a specific time frame for the digital elevation model (DEM) and analysis using GIS techniques. Streams are formed from the confluence of minor watercourses, making them wider and longer.

Therefore, the amount of running water increases, which increases the likelihood of their ability to erode, which works to deepen and widen these streams, which makes the running water capable of carrying boulders and small pieces of rock (Wang et al., 2014).

Gullies, in general, are active in the absence of plants on the sides that work to stabilize them. Gully or water-induced soil erosion is a prevalent kind of land degradation due to its detrimental on-site effects on landforms, such as the reduction of soil productivity and quality, as well as off-site cumulative impacts from several erosion control elements, including rainfall erosion, soil erodibility, and slope (Ismaeel et al., 2021). Soil is also one of the basic factors that provide the basic needs of humans. Unfortunately, every year,

millions of tons of soil are exposed to environmental hazards and human activities (Zhang et al., 2015). Water erosion contributes about 56% of these sediments. During the past two decades, many methods have been used to estimate the area of erosion in water basins. These methods are also tools for estimating sediments in water basins. Among the methods used to estimate erosion are those related to land use changes and how to employ this to determine sedimentation volume (Feng et al., 2010). The study successfully utilized Geographic Information Systems (GIS) and Remote Sensing (RS) technologies to map the areas most susceptible to gully erosion within the Mamran Basin. This mapping is crucial for understanding the spatial distribution of erosion risks (Jawad and Baqer, 2024). Other researchers utilized satellite data to identify gully erosion and created corresponding maps of this erosion type (Giordano and Marchisio, 1991). Gully erosion is considered one of the problems that all regions suffer from, especially the eastern region of Misan. It is the most dangerous type of erosion and is widespread due to its impact on fertile lands. Suitable for crops, the Bergsma method is employed to assess soil erosion rates in the Wadi Al-Rahba basin located in the East Governorate of Misan, where it quantified erosion levels from extremely low to moderate, ranging from 750 to 1400 m²/km². (Al-Saadi, 2023). Recently, the Kalar District of Sulaymaniyah Governorate covers the 314,746 km² Mamran Basin, a watershed with numerous streams. Their analysis used 1990–2020 Sulaymaniyah station rainfall data. The northwest and southeast of the research area have 0.6% moderately active erosion, whereas 15.3% has considerable erosion in dispersed areas. Basin erosion is severe in 3.6% and high in 80.5% (Jawad and Baqer, 2024). The study's importance lies in highlighting geomorphology's role in revealing the extent of erosion in Qarahanjeer and identifying active gully erosion sites, measuring erosion intensity, and assessing associated risks through spatial analysis and mapping to support land management decisions and mitigate environmental degradation. Due to the effect of the study area on the effectiveness of water erosion, which results in geomorphological risks, we will therefore address the forms of water erosion as follows:

Rain erosion: It is the process resulting from the sudden and heavy collision of raindrops with

soil and rock fragments, especially those concentrated on steep slopes, which causes the fragments to fly into the air due to the rain. They then descend to a new position due to the force of gravity, where the drops work to separate the soil particles and fine detrital materials through the pressure resulting from the direct collision of these raindrops with the particles, causing quantities of soil to be scattered in the air. Some of it moves many times, leading to the erosion of sediments from their original locations. The activity of rain depends on its kinetic energy, the duration of rain, the quality of vegetation cover, and the cohesion of soil particles (Almashhadani and Al-Hasanay, 2023).

Sheet erosion: The mechanism of this type of erosion involves the thin-layer removal of soil by the action of shallow surface flow and raindrops. It is usually evenly distributed on an even slope and remains unnoticeable until a significant portion of valuable topsoil is lost, and then deposition of soil occurs at the slope bottom (Ismaeel et al., 2021).

Rill's erosion: Stream erosion develops due to the accumulation of runoff as the laminar flow transforms from a diffuse flow into a concentrated flow that moves along slopes with varying slopes. It is the stage that follows the laminar flow stage, as it takes the form of a fine network of streams resulting from heavy rainfall, as they form strips of flow that have an excellent capacity for surface erosion and appear parallel to the sides of the slopes. Their depth does not exceed a few centimeters. Their appearance coincides with the rainy season, and their features become clearer in areas where grooves, depressions, and gaps are widespread, as their activity increases with the increase in the slope and the amount of water (Li et al., 2025), as shown in Figure (1).



Fig. 1: Field investigation of stream erosion (20/06/2025).

Gully erosion: Gully erosion is one of the geomorphological processes caused by surface running water through erosion processes, when certain conditions are available in terms of depth, slope, and suitable rock. Gully erosion is an advanced stage of torrent erosion, and the underlying energy of running water in the gullies increases with increasing distance from the watershed line and increasing slope. The gradual deepening of the streams forms gully erosion, as the gullies take on different shapes and sizes, and their cross-section takes the shape of the Latin letter (V), as shown in Figure (2). These are narrow channels, whose edges often have very steep sides reflecting the action of vertical erosion. As for the transverse ridges, the shape of their course resembles the letter (U), where horizontal erosion is superior to vertical erosion (Almashhadani and Al-Hasanay, 2023).



Fig. 2: Gully erosion morphology: Field study conducted on June 20, 2025, at Coordinates (E 467237, N 3927907).

2. Study Area

Qarahanjeer district, located in Kirkuk City, northern Iraq, occupies an area of about 676 km² and consists of 30 small towns. Qarahanjeer district lies between longitudes (44° 30' - 44° 50' E) and latitudes (35° 23' - 35° 41' N). Sulaymaniyah City borders it to the east, while Markaz Kirkuk, Shawn, and Laylan districts

border Qarahanjeer to the west, north, and south, respectively (Fig. 3). The climate of Qarahanjeer is part of the Kirkuk climate, which is warm and semi-arid, with an intensive increase in temperature in summer and rainy with low temperatures in winter (Shareef et al., 2019). A wavy topography characterizes Qarahanjeer, with the lowest and highest points being about 395 m and 991 m, respectively. The Khassa River passes through Qarahanjeer from east to west and ends at Khassa Lake.

The study aims to highlight the role of geomorphology in revealing the extent of erosion and assessing hazards through spatial analysis and mapping to inform land management decisions and reduce environmental degradation effects in Qarahanjeer, focusing on the Muqdadiya and Bai Hassan formations, which cover the area of study.

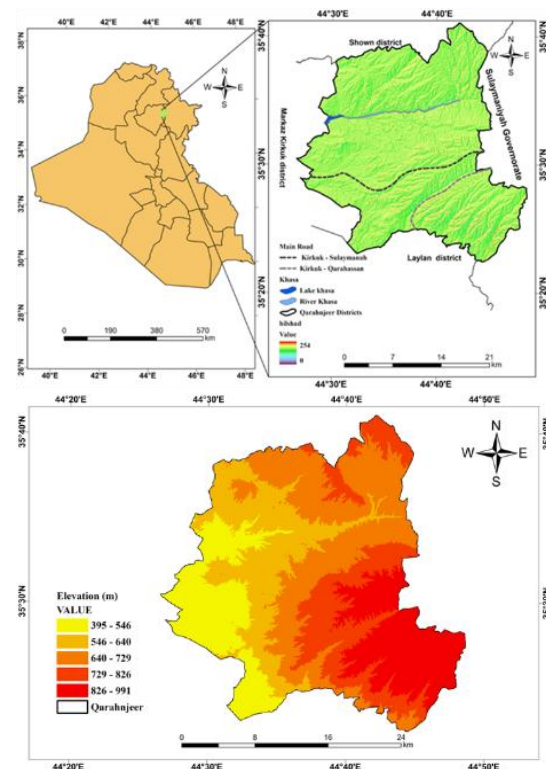


Fig. 3: Location of the study area (Qarahanjeer).

3. Geological and soil data

Soil types and their distribution are essential for regulating the infiltration of surface runoff. Soil with low infiltration rates rapidly accumulates water, increasing soil degradation. Consequently, it is essential to comprehend both the distribution of soil types and the geological and lithological distribution of sediments within the studied area. Geological factors significantly influence erosion

as they govern erosional processes (Ali et al., 2016). The lithological properties of land are crucial in gully erosion (Casalí et al., 1999; El Maoui et al., 2012; Golestani et al., 2014). Lithological features are associated with geomorphological landforms (Dai et al., 2001; Zinck et al., 2001; Gorum et al., 2008; Zhu et al., 2014). To achieve this objective, theme layer maps were used to provide a comprehensive overview of the soil distribution and types within the research region, and the initial geology map (GM) illustrates the predominant lithology of the strata, revealing two formations present in the research area (Mukdadiya and Bai Hassan formations) (Fig. 4a). Mukdadiya is composed of pebbly sandstone, sandstone, and mudstone deposits, whereas Bai Hassan consists of conglomerate, sandstone, and claystone. Furthermore, alluvial deposits consist of sediments including sand, silt, and clay. The second thematic map is the soil type map (ST) (Fig. 4b). Only limited sections of the research region comprise soil containing sand and gypsum.

4. Gully Erosion according to the Bergsma method

The tool is named ‘Gully Erosion’ by the Bergsma method, which contains six parameters (Input stream feature, input basin feature, input cell size width, input cell size height, output grid parameter, and output gully erosion), through which the user can control the modeling of gully erosion.

Two essential key layers need to be acquired to apply gully erosion (the stream feature and the basin feature of the study area). This study has implemented an adaptive method for measuring

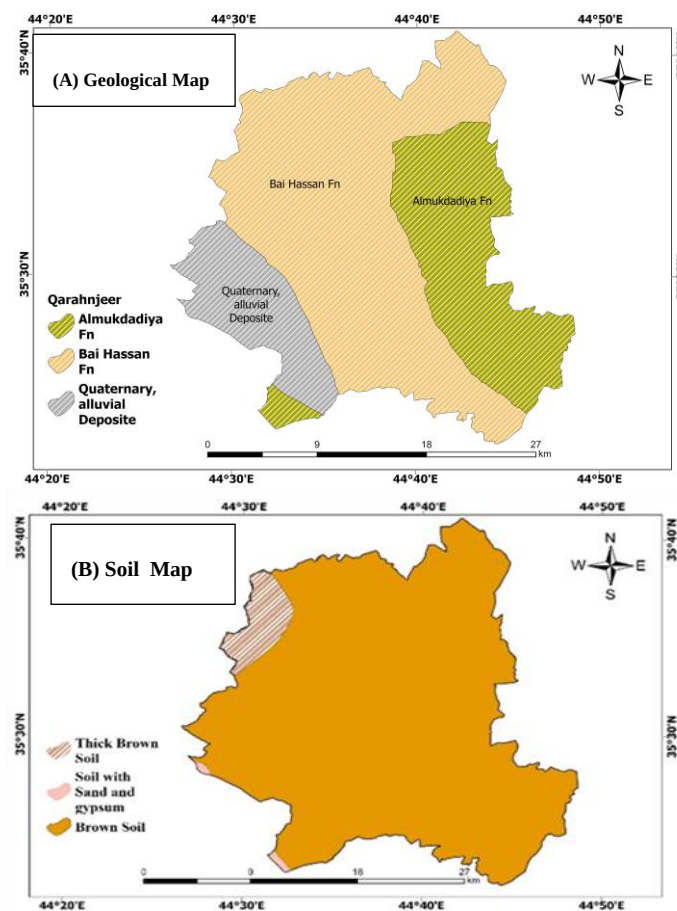


Fig. 4. (A) Geological map and (B) Soil map.

Gully erosion was assessed using a Python method published by Ismaeel et al. (2021), as shown in Figure 5. This tool helps to make figuring out erosion in the study area faster and more accurate.

The design of the tool highlights the specifications for data input and output, along with the geomorphological principles it utilizes. It evaluates gully erosion via the Bergsma approach, examining stream capacity and density, and it accepts Shapefile inputs and stores Feature Class outputs in a Geodatabase, shown as an isopleth map that changes depending on the research area's representation and on whether erosion levels are increasing or decreasing

5. Materials and Methods

The method employed for calculating gully erosion through digital elevation model analysis is a procedure for finding erosion across extensive areas.

Stream network extraction in GIS relies on hydrologic analysis of Digital Elevation Models (DEMs) through systematic geospatial processing. First, the DEM undergoes preprocessing to fill sinks and ensure seamless flow direction calculations. Using GIS hydrology tools (Flow

Direction), flow paths are calculated for the steepest downward slope of each cell. Subsequently, a Flow Accumulation raster quantifies upstream contributing areas, where higher cell values indicate concentrated flow. Stream channels are then delineated using a user-defined threshold (value >1,000 cells) to distinguish active streams from intermittent flows. The resulting binary raster is converted to vector polylines using tools like Stream to Feature, generating a topological stream network as shown in Figure (6). Optional steps include stream ordering (Strahler method) to classify channel hierarchies and smoothing to enhance cartographic representation. This method is widely applied in erosion modeling, as demonstrated in studies like the Bergsma model for gully erosion prediction.

After extracting streams and calculating areas, the Bergsma equation is as follows:

$$AE = \sum \frac{L}{A}$$

Where: AE is the erosion rate per square, L is the stream length in each square, and A is the area of one square in km².

Consequently, due to its functionality, the instrument was designated as Gully Erosion by the Bergsma Method, which includes input stream feature, input basin feature, input cell size width, input cell size height, output grid parameter, and output gully erosion. It comprises six factors that enable the user to regulate the modelling of gully erosion. These parameters are crucial for its functionality within the ArcGIS Desktop environment and enable comprehensive control over the gully erosion modeling process, allowing for detailed analysis and mapping. The parameters are:

1. Input the study area as a shapefile or feature class.
2. Input a stream of a shape file or feature class.
3. Input the cell size width. The default value for the length of a quarter of a square rib is 1000 square meters, meaning that the tool sets 1000 square meters according to what Bergsma saw when dividing the lengths of waterways by the area of the squares.
4. Input Cell Size Height parameter, from which the height of the square is specified in meters.
5. The output grid parameter generates a square grid file in Shapefile format, which is then used to calculate gully erosion.
6. Finally, Output Gully Erosion saves the Gully Erosion file as a Shapefile in the computer's memory, as shown in Figure 7.

6. Results and Discussion

The Qarahanjeer area is a dynamic geological model for examining the effects of accelerated erosion processes on sedimentary deposits. The Muqdadiya and Bai Hassan Formations are in danger of quickly falling apart due to water infiltration and a weak geological structure with faults and folds that cause soil subsidence and gullies.

The majority of the research region is brown soil. The timeframe for this study is 2024.

Gully erosion stages are classified using the Bergsma method of natural geomorphic factors (steepness of slopes and hydrology). The Bergsma method ensures the classification of gully erosion at levels in a study area according to gully length per unit area. The results show that a 2.301% area of (15573607.408 m²) is affected by very minor erosion, followed by light erosion (8.83%) area of (59752225.981m²), moderate erosion (21.000%)

area of (142159214.599 m²), high erosion (54.692 %), very high erosion (12.47%) area of (84412599.999 m²), and severe erosion (4.678,400.00 m²), at a density of 2701 to 3700 m/km².

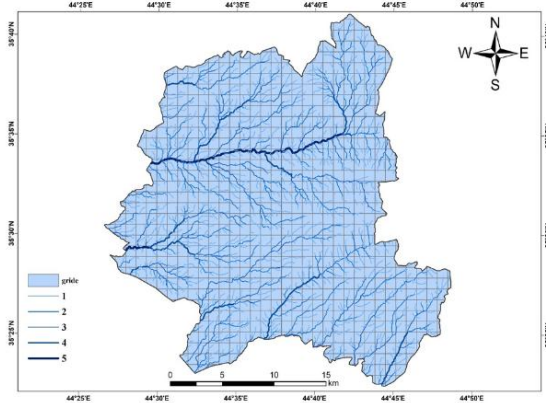


Fig. 6: Stream network of the study area generated by the researcher using ArcGIS 10.8

High erosion is the dominant class, covering (370,082,414.60 m²) of the area. The spatial distribution of gully erosion in the study area is primarily attributed to the spatial heterogeneity of geomorphological and hydrological dynamics, as illustrated in Figure 7 and Table 1.

Table 1: Classification of intensity of gully erosion according to Bergsma equation

Class gully erosion levels	Area (km ²)	Area (m ²)	Percentage %	category
Very light erosion	15.573607	15573607.408	2.301	0 - 400
light erosion	59.752226	59752225.981	8.830	401 - 1000
Moderate erosion	142.159215	142159214.599	21.000	1001 - 1500
High erosion	370.082415	370082414.603	54.692	1501 - 2700
Very high erosion	84.4126	84412599.999	12.47	2701 - 3700
Severe erosion	4.6784	4678400.000	0.6913	3701 - 4700
Total area	676.639	676658462.4	100.000	

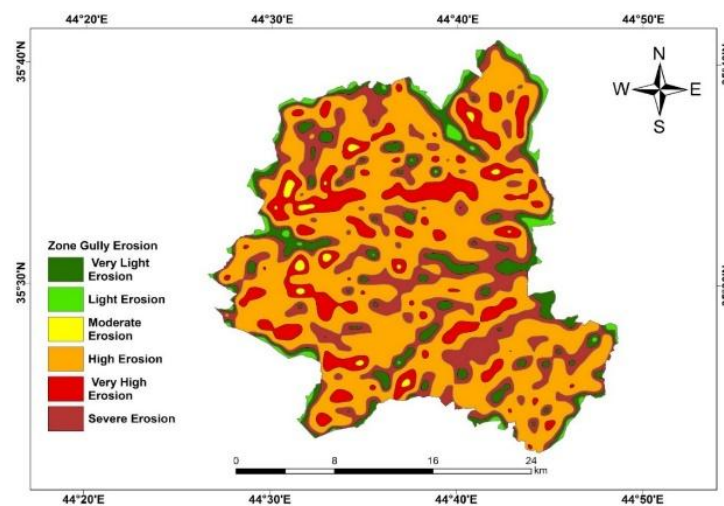


Fig. 7: Results of gully erosion levels in the study area

More than half (54%) are centered in low-lying areas or along stream valleys, which have high fluvial forces and are prone to erosion. Also, a chart shows the variations in areas (Fig. 8). This deep incision and lengthening of gullies cause them to become denser and yield more sediment. High elevational or watershed-divide areas experience low erosivity in response to slope

steepness, water concentration, and landscape resistance. The lowest risk areas are classified as no erosion zones covering 40% of the area, followed by moderate risk areas.

Erosion zones (21%) represent transitional zones with increasing fluvial energy but are buffered due to high vegetation cover reducing the

impact and preventing excessive gully development.

Other erosion classes show only degraded processes, such as extreme erosion, which occupy 12.47% and 0.691% (very high value), respectively, indicating a very advanced erosion process. Validation of field data ensures accuracy. Gully erosion by human activity, such as agriculture, road construction, and quarrying, disrupts natural drainage patterns and removes vegetation cover. These processes become even more important with the increasing susceptibility of soil and steep headwaters and a disproportionate increase in produced sediment for the high erosion zones. Mitigation relies on enhancing water drainage and stabilizing inclines.

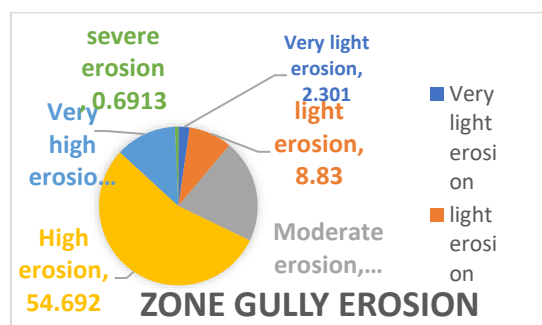


Fig. 8: Shows the area of Gully erosion

7. Conclusion

This study employed GIS tools to analyze gully erosion in Qarahanjeer utilizing DEM data. A new GIS tool is called Gully Erosion by Bergsma, which has six parameters

(input stream feature, input basin feature, input cell size width, input cell size height, output grid parameter, and output gully erosion).

Using the results of this tool is needed to make a gully map for any area. The research results show that most of the study area was affected by erosion, with an area forming approximately 54.692% of the total area in the study region, specifically within the categories of 1501 – 2700. The study concludes that the results match the researcher's findings from the field study and his observations of the impact of gully erosion on the study area. It becomes clear that the slope factor and the study area's geology directly impact the extent of erosion through their effect on surface runoff, and hydrological processes dominated the regional variability of gully erosion, highlighting the need for targeted mitigation measures.

Intensive and accelerated development outcomes should include restoration management, the configuration of a new and advanced drainage system, slope stabilization techniques, and significant vegetation restoration to reduce the impact of erosion and ensure a positive impact on the developed landscape.

The following suggestions are important for future research:

1. Benefit from the water quantities, especially surface runoff, through the process of water harvesting by creating depressions in the basin estuaries.
2. Investing in the area due to its proximity to the Khassa Dam by encouraging residents to engage in ecotourism in the study area.
3. Investing in the area for industry, which is characterized by a high percentage of gravel.

8. Conflict of Interest

The authors declare that they have no conflict of interest.

9. Funding Statement

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10. Author Contributions

Suzan I. Baez, draft writing, methodology, data collecting, analysis

Fawzi M. Omar, Supervising, Revising, Grammarian Reviewing

Mustafa R. Mezaal, Supervising, Revising, Grammarian Reviewing

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نظم المعلومات الجغرافية لإنشاء خرائط بناء على طريقة Bergsma لتقدير تآكل

الاخايد باستخدام نموذج الارتفاع الرقمي: دراسة حالة في قره هنجير، كركوك، العراق

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الملخص

يُعد تآكل الأخاديد مشكلة بيئية خطيرة تهدد استدامة التربة، لا سيما في المناطق القاحلة وشبه القاحلة مثل منطقة قره هنجير في كركوك التي تبلغ مساحتها 676 كم². وتكمن المشكلة البحثية الرئيسية في نقص الدراسات وعدم توفر طرق فعالة لتحديد معدلات تآكل الأخاديد بدقة. لمواجهة هذا التحدي، اعتمدت هذه الدراسة على نموذج Bergsma وتقنيات نظم المعلومات الجغرافية لتقدير تآكل الأخاديد باستخدام بيانات النموذج الرقمي للارتفاعات. وتهدف الدراسة بشكل أساسي إلى تقييم مدى فعالية نموذج Bergsma في رسم خرائط مناطق خطر تآكل الأخاديد في قره هنجير، مع التحقق من دقة النتائج من خلال الملاحظات الميدانية. وأظهرت النتائج تصنيف تآكل الأخاديد إلى عدة مستويات، حيث كان التآكل العالي هو الفئة السائدة، حيث شمل 54.692% من منطقة الدراسة، وذلك ضمن نطاق قيم تتراوح ما بين 1501 و2700. أما التآكل المتوسط (21%)، والذي يقع ضمن فئة 1001 إلى 1500، فقد ظهر في المناطق الانتقالية حيث تقلل الغطاءات النباتية جزئياً من تأثير طاقة التدفق المائي. وعلى الرغم من محدودية المساحات المتأثرة بالتآكل الشديد جداً (12.47%) ضمن فئة 2701 إلى 3700، إلا أن المناطق التي تعاني من تآكل حاد (0.69%) ضمن فئة 3701 إلى 4700 تشير إلى تدهور بيئي كبير، حيث تعمل هذه العمليات على تعطيل أنماط التصريف الطبيعي. كما أوصت الدراسة بحفر منخفضات في مصبات الأحواض لتجميع المياه، وخاصة الجريان السطحي، للاستفادة منها في ري الأراضي. بالإضافة إلى ذلك، شددت على أهمية استخدام بيانات مكانية عالية الدقة لتحسين تقديرات التآكل، وتطبيق البحوث وتسجيل التغيرات الجيومورفولوجية باستخدام نظم المعلومات الجغرافية والاستشعار عن بعد...

الكلمات المفتاحية:

النموذج الارتفاع الرقمي، طريقة Bergsma، التعرية الأخدودية، قره هنجير.

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