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# استخدام عملية التسلسل الهرمي التحليلي الضبابي (FAHP) لتحديد قابلية انجراف التربة في الضفة الغربية – فلسطين

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**الملخص:**

أكثر من (80٪) من أراضي الضفة الغربية جبلية، تتراوح الارتفاعات فيها من حوالي (-421) مترًا تحت متوسط مستوى سطح البحر، بالقرب من البحر الميت في وادي الأردن، إلى حوالي (1020) مترًا فوق مستوى سطح البحر، في الجزء الجنوبي من الجبال الوسطى للضفة الغربية بالقرب من مدينة الخليل. ويؤثر هذا الوضع على توزيع الأمطار والغطاء النباتي؛ مما يخلق بيئة تساهم بشكل فاعل في عملية انجراف التربة في الضفة الغربية. وتبحث هذه الدراسة في استخدام عملية التسلسل الهرمي التحليلي الضبابي (FAHP) في بيئة نظم المعلومات الجغرافية؛ لتعيين المناطق المُعرّضة لانجراف التربة في الضفة الغربية. وتظهر نتائج الدراسة أن حوالي (72٪) من الضفة الغربية مُعرّضة بشكل معتدل لانجراف التربة، و(18٪) مُعرّضة للانجراف بشكل كبير، و(10٪) معرضة للانجراف بشكل ضعيف. وتتركز المناطق شديدة التعرض للانجراف على المنحدرات الغربية، والمرتفعات الغربية للضفة. جيوسياسيًا حوالي (65٪) من المنطقة مُعرّضة بشكل معتدل لانجراف التربة، وحوالي (54٪) من المنطقة المُعرّضة بشدّة للانجراف تقع في المنطقة (ج)، وتمثل المنطقة (ج) حوالي (62٪) من الضفة الغربية، وتخضع للسيطرة الكاملة من قبل سلطات الاحتلال الإسرائيلي، وهذا الوضع الجيوسياسي؛ يجعل من الصعب وضع برامج وخطط للمحافظة على التربة وحمايتها. وتوصي الدراسة بضرورة أن يكون هناك تدخّل سياسي دولي من أجل تمكين الفلسطينيين من إدارة أراضيهم، ووضع برنامج تنفيذي للحفاظ على التربة في منطقة الدراسة.

**الكلمات المفتاحية:** تعرية التربة، الضفة الغربية، فلسطين، FAHP، GIS.

# Using Fuzzy Analytic Hierarchy Process (FAHP) to Map Soil Erosion Vulnerability in the West Bank, Palestine

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**Abstract:**

More than 80% of the West Bank is mountainous, and their elevations range from around (421) m below the mean sea level near the Dead Sea in the Jordan Valley to around 1020 m above the mean sea level in the southern part of the central mountains of the West Bank near Hebron. This situation affects the rainfall and vegetation distribution, creating an environment that contributes effectively to the soil erosion process in the West Bank. This study investigates the use of the Fuzzy Analytic Hierarchy Process (FAHP) in the GIS environment to map the soil erosion vulnerability in the West Bank. The findings of the study reveal that approximately 72% of the West Bank exhibits moderate vulnerability to soil erosion, while 18% of the area is highly vulnerable, and the remaining 10% demonstrates low vulnerability.The highly vulnerable soil erosion areas are concentrated on the western slopes and highlands of the West Bank. Geopolitically, around 65% of the moderately vulnerable to soil erosion, and around 54% of the highly vulnerable area are in Area C. Area C represents around 62% of the West Bank and is under full control of the Israeli occupation authorities. This geopolitical situation makes it difficult to conduct soil conservation and development programs for the West Bank. This study recommends that international political intervention is a must to conduct a soil conservation program in the study area.

**Keywords:** Soil erosion, The West Bank, Palestine, FAHP, GIS

## Introduction:

Soil is a part of the earth's ecosystem. It is important because it is the medium on which plants grow (Robinson et al., 2017; Keestra, 2016). Most of the world's soil resources are in fair, poor, or very poor condition (FAO & ITPS, 2015). Water erosion of soil is a global environmental problem that reduces soil productivity and water quality, causes sedimentation, and increases the likelihood of flooding (Zhou et al., 2008). Accelerated soil erosion is a major threat to soil (Oldeman, 1994). Many human factors cause soil erosion, mainly deforestation, overgrazing and tillage (Pimentel and Burgess, 2013), and unsuitable agricultural practices (Montgomery, 2007).

The impacts of soil erosion can be severe, not only through land degradation and fertility loss, but through a conspicuous number of off-side effects, such as sediment, siltation, and eutrophication of waterways or enhanced flooding (Boardman, 2006). Climate might have an impact through erosion-induced changes in the soil. Carbon cycling remains poorly quantified because erosion may increase or decrease $CO_2$ emissions through enhanced mineralization and sediment burial (Lal, 2004).

Technological improvements and a more rigorous and increased use of fertilizers, which increased the production rates of the most common crops by 13% between 2001 and 2012, might have masked the ongoing degradation of soils and their ecosystem delivery capacity (Montanarella, 2015).

The FAO-led Global Soil Partnership (GSP, 2017) reports that 75 billion tons of soil are eroded yearly from arable lands worldwide, equalling an estimated financial loss of USD 400 billion per year. This estimate dates back to 1993. Simple empirical methods for predicting soil erosion, such as the Reversed Universal Soil Loss Equation (RUSLE), provide reasonably accurate estimates for most practical purposes (Renard, 1997). This applies to wide spatial applications when prediction errors do not exceed a factor of two or three (Bagarello, 2012). Also, the RUSLE approach works well in topographically homogeneous regions that do not involve complex slopes (Oliveira, 2013).

Land management and related land use changes affect the spatial patterns and magnitude of accelerated soil erosion, which may affect land productivity and food security (Lal, 2004; Montanarella, 2015).

The benefits of rapid data processing, multi-criteria analysis, and Geographic Information System (GIS) have been successfully used in solving siting problems. According to Haidara (2019), a combination of GIS tools and the multi-criteria decision method (MCDM) can effectively assess erosion vulnerability.

Previous case studies demonstrated that using GIS tools and MCDM in the watershed and soil resource analysis/evaluation/vulnerability improves decision-making (Chitsaz and Malekian, 2016; Vulevic and Dragovic, 2017). Alexakis et al. (2013) used remote sensing data and GIS to investigate the soil erosion rate in the catchment area of Yialias in Cyprus. Their study compared two methods, i.e., the analytical hierarchy process (AHP) and RUSLE.

This study adopted a weighted FAHP using the GIS tool. The AHP multi-criteria decision-making methodology allows us to overcome one of the RUSLE method's major limitations, i.e., its inability to consider the interdependence between different factors (Alexakis et al., 2013).

## Aims of the Study

We aim to map areas at risk of soil erosion in the West Bank using a weighted FAHP and GIS tool. We also aim to help decision-makers and agricultural planners take measures to reduce the severity of soil erosion in the West Bank, characterized by mountainous environments and steep slopes.

## Previous Studies

Several researchers have investigated the use of GIS tools and the multi-criteria decision method to detect areas at risk of soil erosion. Eskandari et al. (2022) investigated the impact of land use/cover on soil erosion using Landsat satellite images and the 19 RUSLE models on plains around the Jarahi River and Shadegan International Wetlands in Iran. The study concluded that the change of land use/cover led to increased soil erosion in the study area. Dash et al. (2021) used AHP through weighted overlay analysis to conduct a site suitability analysis for conservation measures in the Altuma watershed of the Brahmani River Basin, Odisha, India. Because it is simple and less time-consuming, this study uses AHP and Boolean logic to estimate the optimal conservation locations. Tairi et al. (2019) used AHP and GIS to map areas at risk of soil erosion in the Tifnout-Askaoun Watershed, Southern Morocco. They found that about 48% of the study area is at a very high risk of soil erosion. Halefom and Teshome (2019) focused on mapping soil erosion-prone areas in the Alamata watershed in Ethiopia and concluded that the most effective soil conservation strategies should focus on that area. By integrating GIS and AHP, several factors were used to detect areas at risk of soil erosion. Das et al. (2020) integrated RUSLE and AHP with geospatial technology to model the soil erosion hazard zone of the West Kameng watershed in Arunachal Pradesh, Northeast India, and found AHP to be 84.90% accurate. Mihi et al. (2020) studied soil erosion vulnerability in parts of northern Algeria using different methods, including AHP. Factors such as precipitation, slope, land cover, and remote sensing data were incorporated in GIS to produce the map of soil erosion vulnerability. Pradeep et al. (2015) integrated AHP with RUSLE to determine critical soil erosion-prone areas of an upland agricultural sub-watershed in the Western Ghats of Kerala, India. They identified critical soil erosion-prone areas by combining geo-environmental variables.They reclassified the AHP's soil erosion probability map as a soil erosion severity map, displaying regions with varying erosion probability. Vulević et al. (2015) used AHP to identify areas at risk of soil erosion in the Topčiderska River Watershed, located in northern Serbia. They considered three criteria: land use, slope gradient, and vegetation cover. They recommended that areas at high erosion vulnerability be prioritized for conservation. Chen and Zha (2016) used AHP to assess soil erosion vulnerability in a coupled human-natural system to determine the proportions of factors in an index system contributing to southern China's soil erosion. According to the findings, areas vulnerable to soil erosion accounted for 57.98% of the watershed. Arabameri et al. (2018) studied the soil erosion vulnerability of the Neka Roud Watershed in northern Iran using multi-criteria decision-making techniques and GIS. Their study concluded that using satellite-based RS datasets in conjunction with MCDM models in a GIS environment to evaluate the influence of morphometric parameters and LU/LC classes on soil erosion susceptibility is a more appropriate and accurate framework than the conventional approach.

These studies showed that using remote sensing data and GIS technology facilitated conducting environmental studies including soil erosion studies efficiently with the minimum field work. This study used open source data, and this solved the problem of the inability to collect field data due to the Israeli occupation authorities' control over it.

## Materials and Methodology

### Study area

The West Bank of the Jordan River is located between latitudes 31° 20' and 32° 38' N, and longitudes 34° 53' and 35° 31' E. It has a surface area of around 5860 km², including the water area that is a part of the Dead Sea (210 km²) (Ghodieh, 2022) (Figure 1).

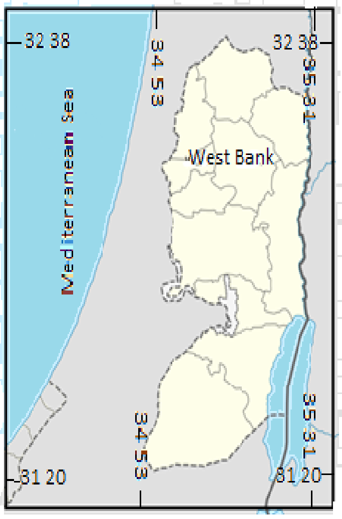


**Figure 1.** Map of the West Bank (Ghodieh, 2022)

The West Bank is characterized by high topographical, climatological, and land cover diversity. Elevations of the West Bank range from -430 m in the Dead Sea region to around 1021 m in the mountain region (Ghodieh, 2022) (Figure 2 d).

Rainfall averages range from less than 200 mm in the southern part of the Jordan Valley to more than 700 mm per year in the mountains, and 500 mm in the semi-coastal region (Amr et al., 2018) (Figure 2 a).

The land cover of the West Bank is extremely affected by the topography and climate. The western slopes of the West Bank are characterized by moderate to dense vegetation cover, while the eastern slopes are characterized by low-density vegetation cover (Ghodieh, 2022). Figure 2g shows moderate to high dense cover values for the western part of the West Bank, while the eastern part records sparse vegetation cover.

Based on climatic diversity and topography, Ghattas et al. (2002) divide soils of the West Bank into four categories (Figure 2c):

- Mediterranean soils of uplands and mountains (mainly Terra Rosa and Rendzina soils),
- Mediterranean soils of plains and valleys (mainly Terra Rosa and Alluvial soils),
- Desert soils of uplands and mountains (mainly Grey Steppe soils), and
- Desert soils of plains and valleys (mainly Alluvial and Saline soils).

We consider the diversity of the study area characteristics when identifying areas at risk of soil erosion in the West Bank.

## Data Sources

For this study, we obtained GIS data, particularly maps of rainfall, land use, topography (slope, aspect, and elevation), and soil map, from various sources. Some of these maps were digitized and processed using ArcGIS 10.8 software. We generated other maps from 30 m digital elevation models (DEMs) of the study area obtained from the Shuttle Radar Topography Mission (SRTM), available at the website www.earthexplorer.com (n.d.).

The West Bank lies in 4 digital elevation models in the United States Geological Survey website (USGS), so these DEMs were mosaicked in the ArcGIS environment, then clipped to the West Bank boundaries map and georeferenced to the projected Palestinian coordinate system (Palestine 1923- Palestine Grid).

## Soil erosion vulnerability criteria

Developing a set of criteria to facilitate the decision-making process to detect areas vulnerable to soil erosion is necessary. There are many factors to consider, including the topographic properties of the study area, such as elevation, slope, surface curvature, and aspect. Other factors that we must also consider when assessing the soil erosion vulnerability classification are the climate properties of the area, particularly the distribution of rainfall, land use, and soil. These are the most common criteria that contribute to soil erosion.

## Analysis and Discussion

Analysis of the spatial criteria that contribute to soil erosion emphasizes measuring the properties and relationships while considering the spatial distribution of the phenomenon under study directly (Câmara et al., 2004). We carried out the spatial analysis of the area using the ArcGIS software. Using well-defined criteria, we used a Fuzzy AHP model.

## Model

We use ArcGIS geoprocessing tools to perform spatial analysis on an input dataset to generate a new output dataset. Analysis, data management, editing, and other operations are all part of geoprocessing tools. The four main factors contributing to soil erosion are rainfall, soil, topography, and vegetation (Meena and Datta, 2021). The proposed model considers seven criteria, representing the most effective factors in soil erosion at the study area (Table 1).

**Table 1. Main criteria used for building the model**

| No. | Criteria | Rank |
|---|---|---|
| 1 | Rainfall | 1 - 10 |
| 2 | Slope | 1 - 10 |
| 3 | Land use | 1 - 10 |
| 4 | Soil classification | 1 - 10 |
| 5 | Elevation | 1 - 10 |
| 6 | Aspect | 1 - 10 |
| 7 | Surface curvature | 1 - 10 |

Rank 1 represents the lowest and rank 10 represents the highest erosion vulnerability.

Figure 2 shows a schematic diagram of the methodology used for mapping the soil erosion vulnerability in the West Bank.

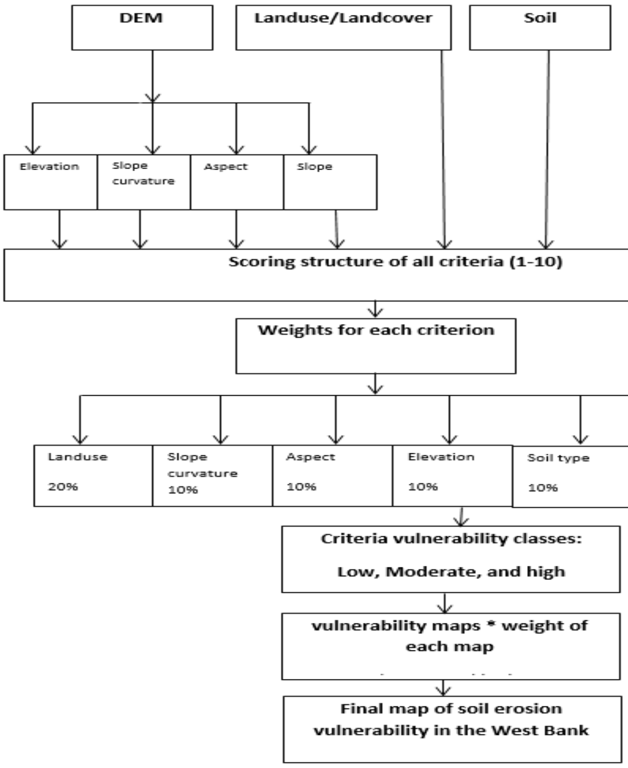


**Figure 2.** Schematic diagram of the methodology used for mapping soil erosion vulnerability in the West Bank

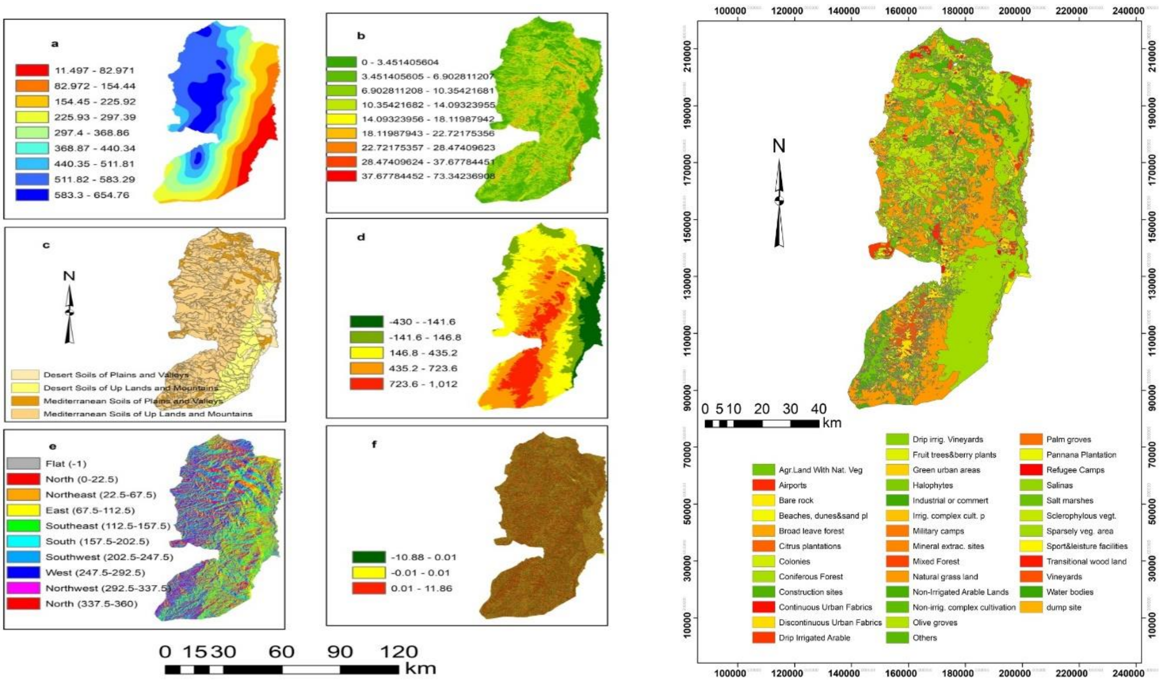


**Figure 3.** a) Rainfall (Source: Amr, Z.S., et. Al 2018) b) Slope c) Soil classification (Source:Palestinian Ministry of Local Government, GIS section, (2018)) d) Elevation (Source: https://earthexplorer.usgs.gov/ ) e) Aspect f) Curvature g) Land use (Source: Palestinian Ministry of Local Government, GIS section, (2018)

## An Overview of Model Criteria

Soil erosion vulnerability mapping is one of the main GIS applications for facing land degradation. GIS-based soil erosion analysis is used in various situations, including geomorphology, environmental concerns, agricultural activities, flood risk, and landslides. The goal of using FAHP is to maximize the use of the area's various characteristics that contribute to soil erosion vulnerability.

A cartographic modelling approach to soil erosion analysis entails pre-processing spatial data sets relevant to a specific soil erosion analysis, creating a plan to spatially represent the soil erosion vulnerability model, and running the model through GIS. Because data for soil erosion applications typically comes from multiple sources, the pre-processing stage is required. They are frequently saved in various formats (e.g., raster and vector models). When combining data from various sources, all spatial data must be geo-referenced in the same coordinate system. The next step is to define the evaluation criteria that will be used to score the potential erosion sites.

**Rainfall**: Rainfall is the most important factor contributing to soil erosion in the area. Soil erosion has a direct positive relationship with slope gradient. Fang and Tang (2015) conducted rainfall simulation experiments in two neighbouring plots (scale: 1 m by 5 m) with four varying slopes (17.6%, 26.8%, 36.4%, and 46.6%), and discovered that the 46.6% slope value produced the highest runoff. The West Bank's barren lands are subject to gully erosion, which occurs when water is channelled across unprotected land and washes away the soil along drainage lines (Arabameri and Pourghasemi, 2019). The rainfall map was classified into nine equal classes starting from less than 50 mm in the southern part of the Jordan Valley up to around 650 mm at the mountain tops and western slopes (Figure 3a). The map was reclassified and the least rainfall areas were given rank 1, while the highest rainfall areas were given rank 10 (Figure 4a and Table 2).

**Table 2. Scoring structure for rainfall of the West Bank**

| Rainfall (mm) | Score |
|---|---|
| 11.5 - 83 | 1 |
| 83.0 – 154.4 | 2 |
| 154.4 – 225.9 | 3 |
| 225.9 – 297.4 | 4 |
| 297.4 – 368.9 | 5 |
| 368.9 – 440.3 | 6 |
| 440.3 – 511.8 | 7 |
| 511.8 – 583.3 | 9 |
| 583.3 – 654.8 | 10 |

**Slope**: Slope is one of the most effective factors contributing to soil erosion when studied at long timescales. Perreault et al. (2017) found that the observed gradient-erosive relationship is likely to be more complex or stochastic than often described theoretically, particularly over relatively short timescales (60-100 years). The slope gradient of the West Bank was generated from the available DEM at 30 m spatial resolution. The slope gradient of the area ranges from 0° representing the flat areas in the Jordan Valley and intermediate plains within the mountainous and hilly areas, and up to around 73° in the mountainous areas and refractive valleys (Figure 3b).We reclassified the slope map, and the flat and gentle slope areas were given low ranks, while the steep slope areas were given higher ranks (Figure 4b and Table 3).

**Table 3. Scoring structure for slopes of the West Bank**

| Slope (°) | Score |
|---|---|
| 0 – 3.45 | 1 |
| 3.45 – 6.90 | 2 |
| 6.90 – 10.35 | 3 |
| 10.35 – 14.09 | 4 |
| 14.09 – 18.12 | 5 |
| 18.12 – 22.72 | 6 |
| 22.72 – 28.47 | 7 |
| 28.47 – 37.68 | 9 |
| 37.68 – 73.34 | 10 |

Soil: In this study, we adopted soil types based on climate. Soils are divided into four classes: Mediterranean soils (Terra Rosa soil) of the uplands and mountains and Mediterranean soils (Terra Rosa soil) of plains and valleys. These soils are fertile and suitable for crop and citrus cultivation (Verheye and De La Rosa, 2009). Figure 2c shows the desert soils of uplands and mountains, and the desert soils of plains and valleys. Desert soils are common in regions of exposed bedrock, salt-encrusted basins, and badlands (Watson, 1992). Desert soils in the West Bank are mainly in the Jordan Valley and on the eastern slopes of the mountain's region (Dudeen et al., 2001). The soil map was reclassified, and the lowest rank was given to desert soils of the plains and valleys with a score of 4 because it is the least vulnerable to water erosion. The desert soils of uplands and mountains came in the second rank with a score of 6, the Mediterranean soils of plains and valleys were given a score of 6, and the Mediterranean soils of uplands and mountains got the highest rank with a score of 10 because this type of soil is the most vulnerable to water erosion (Figure 4c and Table 4).

**Table 4.Scoring structure for soil types of the West Bank**

| Soil type | Score |
|---|---|
| Desert soils of plains and valleys | 4 |
| Desert soils of uplands and mountains | 6 |
| Mediterranean soils of plains and valleys | 8 |
| Mediterranean soils of uplands and mountains | 10 |

**Elevation**: The elevation map of the West Bank is produced from DEM. The elevation is included in the erosion criteria because it is directly related to other factors contributing to West Bank soil erosion, such as rainfall, slope, soil, and vegetal land cover. Elevations of the study area range between -430 m in the Dead Sea area (the lowest area in the world) and 1021 m in the mountains' region to the north of Hebron (Figure 3d). We reclassified the elevation map into five classes. The lowest lands were given the least rank with a score of 2, while the highest lands were given the highest rank with a score of 10 (Figure 4d and Table 5).

**Table 5. Scoring structure for elevations of the West Bank**

| Elevation (m) | Score |
|---|---|
| -430 - -141.6 | 2 |
| -141.6 – 146.8 | 4 |
| 146.8 – 435.2 | 6 |

| | |
|---|---|
| 435.2 – 723.6 | 8 |
| 723.6 - 1012 | 10 |

**Aspect**: The slope aspect is an important factor that affects soil erosion in the West Bank. The western slopes of the Palestinian mountains in the West Bank are directly affected by the Mediterranean cyclones in winter and receive a higher amount of rainfall (500-700 mm/ year) and create a denser vegetal cover. The eastern slopes are in the rainfall shadow, receive a lower amount of rainfall (200- 400 mm), and create a sparse vegetal cover. This situation, in turn, makes the western slopes more vulnerable to soil erosion. An aspect map is produced from the digital elevation model, including nine directions (Figure 3e). The west and north aspects were given the highest scores, while the lowest scores were given to the flat lands, in addition to the east and south aspects (Figure 4e and Table 6).

**Table 6.Scoring structure for aspects of the West Bank**

| Aspect | Score |
|---|---|
| Flat | 1 |
| North | 7 |
| Northeast | 6 |
| East | 3 |
| Southeast | 4 |
| South | 3 |
| Southwest | 6 |
| West | 10 |
| Northwest | 8 |

**Surface Curvature**: Most slopes are not regular but consist of convex, concave, and regular segments. The erosion rate varies along the slope, and erosion affects the slope shape as it progresses (Stefano et al., 2000). A curvature map of the West Bank is created from DEM, including three types of curvature (convex, concave, and uniform). The values of the West Bank slope curvature range from -10.88 to 11.86 (Figure 3f). Negative values refer to concave slopes, positive values refer to convex slopes, and value 0 refers to uniform segments. The convex slope represents 41.87% area, the concave slope represents 41.51% area, and the uniform segments represent 16.62% area. Convex slopes are more vulnerable to soil erosion than the other two types. The curvature map was reclassified and each type was given a score value. The convex slope areas were given the highest score of 8, the uniform segments were given a score of 5, and the concave slope areas were given the lowest score of 3 (Figure 4f and Table 7).

**Table 7. Scoring structure for slope curvatures of the West Bank**

| Slope curvature | Score |
|---|---|
| Concave slopes | 3 |
| Uniform segments | 5 |
| Convex slopes | 8 |

**Land use**: A detailed land use/cover map is used to evaluate the effect of different types of land use on soil erosion. This map was generated from high-resolution aerial photographs (10 cm resolution) by the Palestinian Ministry of Local Government and is available on its website for public use (https://geomolg.ps/L5/index.html?viewer=A3.V1). The map includes 38 land use classes (Figure 3g). We reclassified the map and gave each type of land use a score. We gave barren lands and rocks the highest score, while the densely vegetated lands were given the lowest score (Figure 4g and Table 8).

**Table 8. Scoring structure for land use in the West Bank**

| Land use | Score | Land use | Score | Land use | Score |
|---|---|---|---|---|---|
| Agricultural land with natural vegetation | 3 | Drip irrigated vineyards | 2 | Others | 5 |
| Airports | 1 | Fruit tree berry plants | 1 | Palm groves | 2 |
| Bare rock | 10 | Green urban areas | 2 | banana plantation | 1 |
| Beaches, dunes and ploughed land | 7 | Halophytes | 5 | Palestinian refugee camps | 1 |
| Broad leaf forest | 3 | Industrial or commercial | 2 | Salinas | 3 |
| Citrus plantations | 1 | Irrigated complex cultivated plants | 2 | Salt marshes | 3 |
| Israeli colonies | 2 | Israeli military camps | 3 | Sclerophyllous vegetation | 2 |
| Coniferous forest | 1 | Mineral extraction sites | 7 | Sparsely vegetated areas | 10 |
| Construction sites | 3 | Mixed forest | 3 | Sport leisure facilities | 2 |
| Continuous urban fabrics | 2 | Natural grassland | 10 | Transitional woodland | 4 |
| Discontinuous urban fabrics | 5 | Non-irrigated arable land | 3 | Vineyards | 2 |
| Drip irrigated arable | 2 | Olive groves | 3 | Water bodies | 1 |
| | | | | Dump sites | 2 |

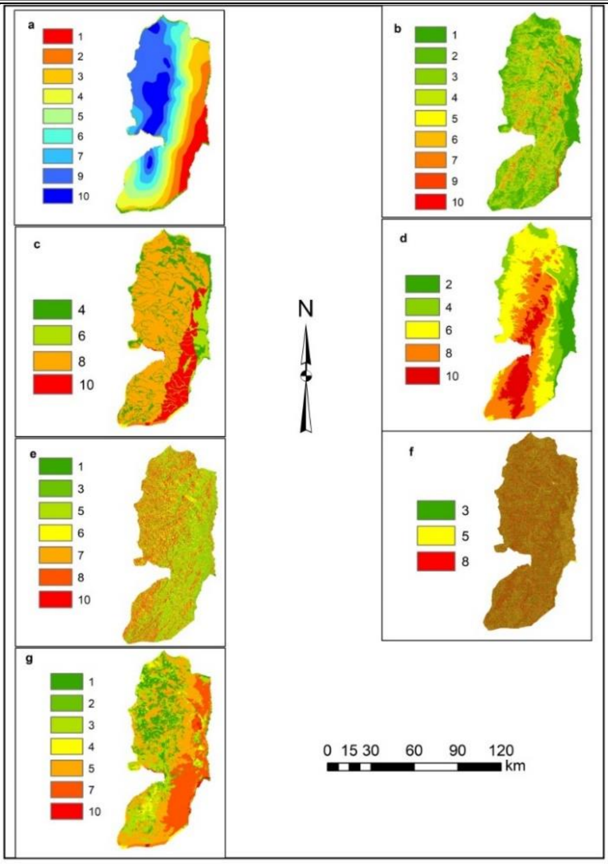


**Figure 4. a: rainfall, b: slope, c: soil types, d: elevation, e: aspect, f: curvature, g: land use**

## Weights of Model Criteria

We used FAHP to detect the levels of soil erosion vulnerability in the West Bank. Each criterion was given a percentage weight according to its effect on soil erosion. We decided the weight of each criterion based on our understanding of the study area and the consultation with experts in the field. The total weight is 100%. Rainfall, slope, and land use were given the highest weight of 20%, and the remaining 40% were distributed equally between the other four criteria (soil, aspect, slope curvature, and elevation) (Table 9).

**Table 9.Weights for soil erosion vulnerability criteria**

| No. | Criteria | Weight % |
|---|---|---|
| 1 | Rainfall | 20 |
| 2 | Slope | 20 |
| 3 | Soil type | 10 |
| 4 | Elevation | 10 |
| 5 | Aspect | 10 |
| 6 | Slope curvature | 10 |
| 7 | Land use | 20 |
| | Total | 100 |

Most of these criteria are used in previous studies because they are the most effective factors in soil erosion vulnerability studies. To a great extent, the topographic characteristics of the study area, mainly the two opposite slope directions (west and east) and its geographical location close to the Mediterranean Sea, decided the geographical distribution of rainfall and vegetation cover. Western slopes receive the marine effects directly and enjoy plenty of rainfall and denser vegetation cover. On the other hand, the eastern slopes lie in the rainfall shadow and are affected by the desert. Therefore, it receives a small amount of rain, resulting in a desert environment with sparse vegetation. All weighted criteria were overlaid in the ArcGIS 10.8 software to produce the soil erosion vulnerability map (Figure 5).

## Detection of Soil Erosion Vulnerability Levels

We considered seven criteria when building the soil erosion vulnerability model in the West Bank. We adopted the weighted overlay model, where we give each criterion a weight value according to its effectiveness on soil erosion (Table 9). It is clear from Figure 5 and Table 10 that there are three levels of soil erosion vulnerability in the West Bank: low soil erosion vulnerability, moderate soil erosion vulnerability, and high soil erosion vulnerability. Areas at low risk of soil erosion represent around 10% of the surface area of the West Bank and are concentrated in the Jordan Valley. Areas at moderate risk of soil erosion cover around 72% of the West Bank and spread across most areas, except the Jordan Valley. 18% of areas at high risk of soil erosion are concentrated on the western slopes of the West Bank, in addition to the mountains and hills. Areas at high risk of soil erosion require more attention and conservation plans to reduce the severity of soil erosion and its negative impact on agricultural lands.

**Table 10. Soil erosion vulnerability classes of the West Bank**

| Class value | Class description | Area (km²) | % |
|---|---|---|---|
| 1.80 – 3.99 | Low vulnerability | 556.55 | 9.84 |
| 3.99 – 5.99 | Moderate vulnerability | 4092.97 | 72.39 |
| 5.99 – 8.40 | High vulnerability | 1004.96 | 17.77 |
| | Total | 5654.48 | 100 |

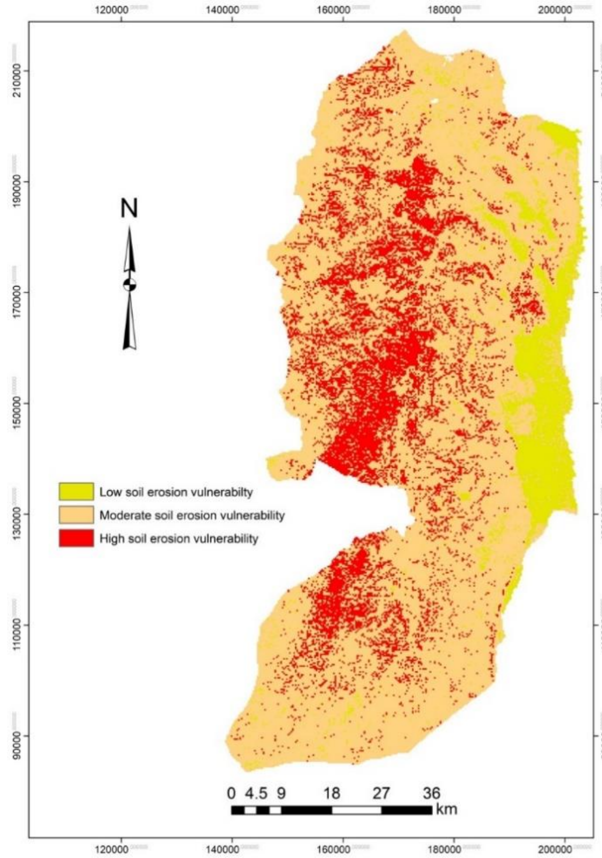


**Figure 5. The final Map of soil erosion vulnerability in the West Bank**

## Relationship of agricultural land value to soil erosion vulnerability

To determine the impact of soil erosion risk on agricultural lands, the maps of soil erosion vulnerability and the agricultural value (Figure 6) were overlaid in ArcGIS 10.8 software. The intersection geoprocessing function was used to calculate levels of soil erosion risk for each agricultural land value class.

Figure 6 shows the agricultural land values in four categories: high agricultural value, high agricultural value with an area of more than 250 dunums), moderate agricultural value, and low agricultural value. Table 11 shows the area for each category. The two high agricultural value categories were merged into one category. In addition to urban centers, areas of agricultural land of low value represent 63.91% of the West Bank and are mainly on the barren eastern slopes and the badlands of Jordan Valley. The agricultural lands of moderate value represent 25.65% of land and are in mountainous areas, mainly covered with olive and fruit trees. The last category, the lands of high agricultural value, represents 10.44% of land and are in the Mediterranean and the Desert alluvial plains, which are mainly covered with vegetables, field crops, and greenhouses

**Table 11. Agricultural value for lands of the West Bank**

| Agricultural land value | Area (km²) | % |
|---|---|---|
| Low agricultural value | 3614.03 | 63.91 |
| Moderate agricultural value | 1450.36 | 25.65 |
| High agricultural value | 590.09 | 10.44 |
| Total | 5654.48 | 100 |

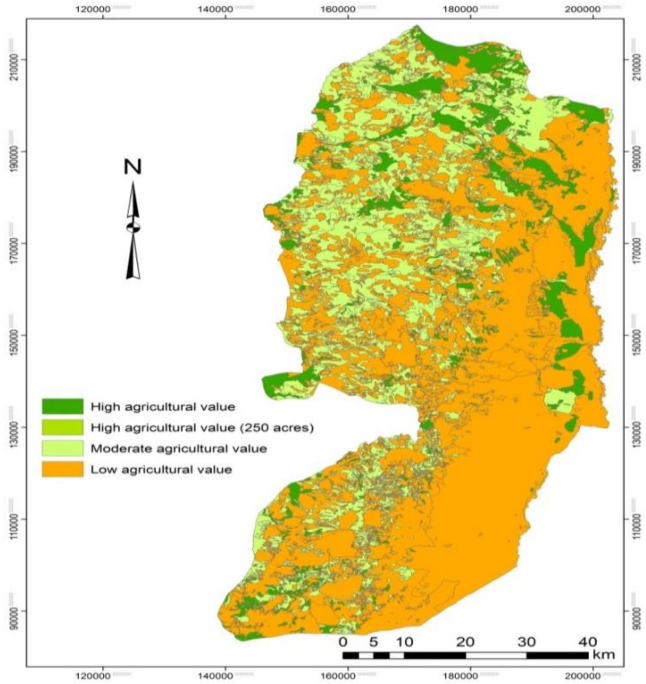


**Figure 6. The agricultural value of the West Bank lands**

Source: Palestinian Ministry of Local Government, GIS section, (2018)

Table 12 shows the results of the intersection geoprocessing of the soil erosion vulnerability map and the agricultural value map.

**Table 12. Cross matrix of soil erosion vulnerability and land agricultural value areas (km²)**

| | Low agricultural value | Moderate agricultural value | High agricultural value | Total |
|---|---|---|---|---|
| Low soil erosion vulnerability | 343.84<br>9.50% | 49.26<br>3.40% | 163.45<br>27.70% | 556.55 |
| Moderate soil erosion vulnerability | 2609.17<br>72.20% | 1088.03<br>75.02% | 395.77<br>z67.07% | 4092.97 |
| High soil erosion vulnerability | 661.02<br>18.30% | 313.07<br>21.58% | 30.87<br>5.23% | 1004.96 |
| Total | 3614.03<br>100% | 1450.36<br>100% | 590.09<br>100% | 5654.48 |

Table 12 shows that 5.23% of the agricultural lands of high value (alluvial plains), 21.58% of the agricultural lands of moderate value (mountainous lands of the western slopes), and 18.30% of the agricultural lands of low value (barren lands of the eastern slopes), are highly vulnerable to soil erosion.

## Land conservation difficulties

Conservation priority should be given to areas highly vulnerable to soil erosion. Access to these areas is subject to their geopolitical status because Israel occupies the West Bank. According to the Oslo Interim Agreement between Israel and the Palestinian Liberation Organisation (PLO) in 1993, the West Bank is geopolitically divided into three areas: Area A, Area B, and Area C (Figure 7). The Palestinian Authority controls Areas A and B while Israeli authorities control Area C. Areas A and B represent around 38% of the West Bank, while Area C accounts for 62%.

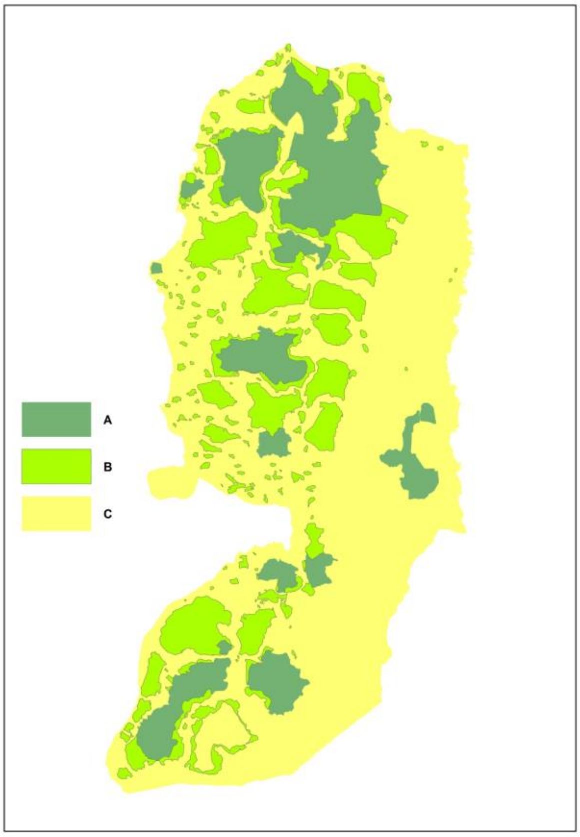


**Figure 7.** Geopolitical division of the West Bank (Hamada and Ghodieh, 2021)

To detect the possibility of land conservation for areas highly vulnerable to soil erosion, we did an overlay analysis using the intersection geoprocessing function on the soil erosion vulnerability map and the geopolitical map of the West Bank using ArcGIS 10.8 software. Table 13 shows the intersection results.

**Table 13. Cross matrix of soil erosion vulnerability map and geopolitical status map of the West Bank (km²)**

| | Area A | Area B | Area C | Total |
|---|---|---|---|---|
| Low soil erosion vulnerability | 61.32<br>11.02% | 21.18<br>3.81% | 474.05<br>85.17 | 556.55<br>100% |
| Moderate soil erosion vulnerability | 691.67<br>16.90 | 735.23<br>17.96% | 2666.07<br>65.14% | 4092.97<br>100% |
| High soil erosion vulnerability | 185.83<br>18.49% | 274.11<br>27.28% | 545.02<br>54.23% | 1004.96<br>100% |
| Total | 938.82 | 1030.52 | 3685.14 | 5654.48 |

Table 13 shows that 54.23% of the high soil erosion vulnerability areas are in Area C, meaning that any conservation plan needs the approval of the Israeli military occupation authorities in the West Bank, which rarely permits Palestinians to work freely there. Moreover, the Palestinian Authority is in a serious financial crisis, especially after the Israeli occupation authorities began to withhold the Palestinian tax revenues, which represent about 50% of the Palestinian Authority's financial resources. This geopolitical situation does not allow Palestinians to conduct a conservation plan for soils in most parts of the West Bank.

## Conclusion

This study found that 72.39% of the West Bank area, which are mostly planted with olive and fruit trees, are moderately vulnerable to soil erosion. Around 65.14% of these areas are in Area C. Also, 17.77% of the study area is highly vulnerable to severe soil erosion, of which 54.23% are in Area C on the Western slopes of the central mountains of the West Bank. Only the Jordan Valley recorded low soil erosion vulnerability values because it represents flat areas with low rainfall averages. The geopolitical status of the West Bank creates serious obstacles and difficulties for Palestinians to conduct an effective soil conservation program.

The study recommended that an international intervention, especially from the United Nations, European Union, and the United States, is required to reduce the obstacles and difficulties to allow Palestinians to conserve and develop areas most vulnerable to soil erosion, especially in area C. It also recommended that the Ministry of Agriculture to provide farmers with instructions and guides to tackle the problem of soil erosion.

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