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Integrated Evaluation of Soil Erosion-prone Areas Based on the GIS Technique and the Analytic Hierarchy Process on Hillside Slopes, Northwest of Jordan

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Abstract

This study aimed to create maps of areas at risk of soil erosion by integration between GIS and the analytic hierarchy process on hillside slopes, northwest of Jordan. For that, it relied on five factors, which included soil erosion contributing ones; thus, slope degree, land use/land cover, soil texture, rainfall, and stream power index (SPI) were integrated into ArcGIS 10.4.1 tools for identifying the areas affected by the risk of soil erosion. Multi-criteria decision analysis (MCDA) method is used to create maps risk of soil erosion. The results of the study showed, based on the erosion risk map classified into five risk levels, including very high, high, medium, low, and very low, that the areas with high and very high erosion risk represented about 8.5% and 16.3%, respectively. The areas with low and very low soil erosion risk formed about 36.6% and 8.9%, respectively, of the total area of the study area. The findings of this study will help decision-makers to plan and carry out effective soil and soil conservation practices in

Areas were highly vulnerable to soil erosion.

Keywords: *Soil Erosion, GIS, Jordan, AHP, MCDA. SPI.*

1. Introduction

Soil erosion is related to human activities and natural problems, such as irresponsible land-use practices, inappropriate soil conservation methods, overgrazing, severe rainstorms, significant slope...etc. It also affects the degradation and desertification of the lands on the slopes of sloping hills, (Mhiret et al. 2018., Andualem et al. 2020). It equally affects the storage, filtering, and cleaning of water. (Zhu et al. 2014., Addis and Klik. 2015). Water erosion in the world is intensified because of different climatic conditions and land use impacting various natural conditions, (Garc´ıa et al. 2021).

The MCDA method depends on multiple factors for effective decision-making for natural resource management, land-use planning, and identification of environmental hazards. (Aher et al. 2013). The analytic hierarchy process (AHP) is considered one of the most important methods that are relied upon in making important decisions due to the efficiency of its use. Also, this method includes multiple levels of spatial decision-making, where the factors related to the suitability of the site are weighted to prepare a pairwise comparison matrix that depends on the relative importance scale. (Al Raisi et al.2014, Chaudhary et al.2016., Yasser et al.2013., Al-Sababhah 2022). The AHP is studied extensively and used in applications where problems related to multiple criteria decision-making are fateful. Many researchers have widely used the AHP method to make critical decisions regarding soil erosion, which saved time and effort in preparing these environmental studies. (Saaty 2008., Aikhuele et al, 2014., Ribeiro, 1996).

Finally, erosion is a natural and/or anthropogenic phenomenon affecting all regions of the world; it is very accentuated, especially in regions with arid and semi-arid climates like the Mediterranean zone, of which Jordan is a part. In the current study, the MCDA method was used to analyze a series of criteria to be ranked from the most preferable to the least preferable using a structured approach. Often the result of the MCDA is several weights related to the various alternatives. The weights express the importance of the different alternatives to each other. The selected factors that govern the fit of the site are weighted using AHP assisted by a pairwise comparison matrix that uses a relative importance scale.

2. Methods and Materials:

In Jordan, as everywhere in the world, soil erosion is the result of various natural and human factors and has many environmental impacts with social, economic, and environmental consequences.

2.1 Study area:

The study area is located in the northwestern district of Jordan and geographically lies between 35°88’ E and 35°54’ E longitude and 32°26’ N and 32°66’N latitude covering an area of 1077.6 km² from the total area of Jordan. The study area can be subdivided into five drainage basins including Al-Arab, Ziqlab, Al-Rayan, Al-taybeh, and Kufr Anja

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valleys. Figure 1a. In terms of geomorphology, the study area watershed is a complex relief. Indeed, all the rivers have their source in the high mountains on the east bank of the northern Jordan Valley at elevations reaching 1226 m. It ends up below sea level in the Jordan River at elevation (- 332) m. Figure 1b. In the northern Jordan Valley sub-catchment, six slope classes are identified, and calculated in degrees. Drainage basins for the study area are considered permanent water sources to supply the northern regions of Jordan for agricultural and other domestic purposes. Hydrologically, there are three main dams and 177 groundwater wells in the study area. Figure 1c. Climatologically, the long-term temperature analysis showed that the area's average temperature was approximately 19.6°C, with a mean annual minimum and maximum temperature between 14.6 °C and 23 °C, respectively. Figure 1d. Also, the long-term analysis observed a regional rainfall average of 431 mm per year (i.e., approximately 245 mm minimum to 580 mm maximum). Figure 1e. Finally, the study area can be subdivided into three climate regions, including the semi-arid, semi-humid, and humid regions. Figure 1f. The study area also includes 12 soil units according to the USDA classification. Figure 1g. Also, chert-limestone and sand-limestone dominated about 53% of the area of the study area. Figure 1h.

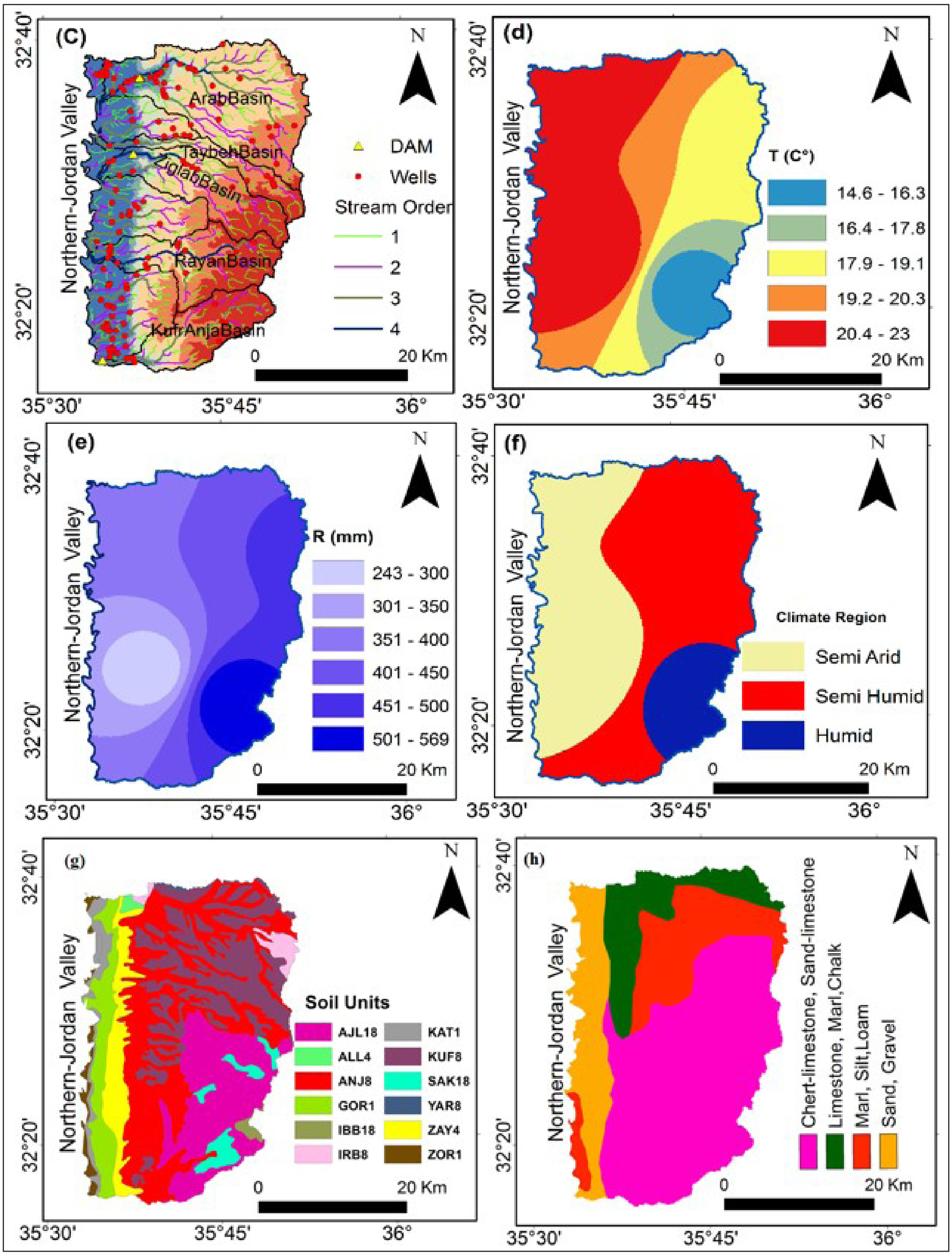

Figure 1. (a) Study Area Location, (b) Elevation (m), (c) Hydrological Properties, (d) Temperature (C°), (e) Rainfall (mm), (f) Climate Regions, (g) Soil Units, (h) Geology Texture.

Also, the study area includes the parts of the eastern bank of the Jordan River, which are: The first is ZOR, which is the narrow range of the flood plain of the Jordan River. The second section is Katar which occurs as a thin stream running along the channel of the Jordan River; its characteristics are generally moderate to high salinity, difficulty in leaching salts, very low permeability, and high erosivity along margins. The third section is Gor, which extends along the eastern edge of the Jordanian river, is highly suitable for irrigation, and is already intensively used for irrigated production of orchard crops and horticultural crops. The fourth part is the escarpments of Jordan Valley; the escarpments are in calcareous rocks, very steep, rocky slopes with rock faces. The major limitations to agrarian culture in this area are the very steep slopes and the stony, often shallow soils that occupy the upper part of the area. Figure 2.

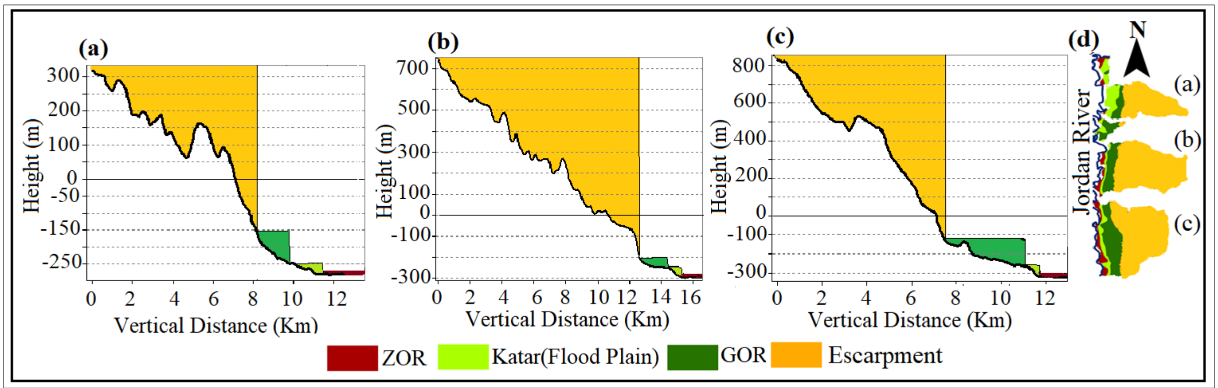

Figure 2. Vertical profile showing the distribution of the parts of the eastern bank of the Jordan Valley according to the change in elevation: (a) the northern part, (b) the middle part, (c) the southern part, (d) a map of the parts of the eastern bank of the Jordan River

2.2 Study Data:

This work is also based on two remote sensing datasets that were obtained: (i) Landsat-8 surface reflectance data freely available from the United States Geological Survey ((USGS (http://www.usgs.gov/)) during the period 2017-2021; and (ii) ASTER GDEM (https://asterweb.jpl.nasa.gov/gdem.asp) data freely available from NASA. As for the soil texture data, it was obtained from the soil survey records of the Jordanian Ministry of Agriculture for the period from 1993 – 2020. The spline interpolation method in GIS has been selected because it is the most appropriate one for studies involving a small number of cases. Also, the long-term (1990-2021) climatic data used in this assessment constitute the monthly and annual rates of rainfall rates for 11 climatic stations. Table 1.

Table 1. Table 1. List of Climatic stations used in this study.

Climate Station	Lat (N)	Long (E)	Ele (m)	Climate Station	Lat (N)	Long (E)	Ele (m)
Kufr Anjah	35°39’	32°16’	190	Taybeh	35°42’	32°32’	360
Wahadna	35°38’	32°19’	560	Dir Abi Saeed	35°40’	32°30’	310
Ruhaba	35°47’	32°25’	970	Kufr Asad	35°42’	32°35’	330
Kufryouba	35°48’	32°32’	570	Rayan	35°35’	32°23’	(-230)
Mazar	35°47’	32°28’	800	Baqura	35°37’	32°39’	(-228)
Irbid	35°51’	32°33’	560				

2.3 Measurement of Stream Power Index (SPI):

The SPI index is one of the most important factors controlling slope erosion processes. Since the erosive power of running water directly influences river cutting and slope toe erosion, (Nefeslioglu et al. 2008., Al-Sababhah 2018) the areas with high stream power indices have an excessive potential for erosion because it represents the potential energy procurable to entrain sediment, (Kakembo et al. 2009). Assuming that discharge is associated with the specific catchment area, the erosive power of water flow can be measured by the stream power index) SPI (, (Moore et al. 1991), as follows:

$$\mathbf{SPI} = \mathbf{As} \times \mathbf{tan\sigma} \quad (1)$$

where, As represents the specific catchment area in meters and σ is the slope gradient in degrees. Also, ArcGis can be used to measure SPI by the equation:

$$\mathbf{SPI} = \mathbf{Ln}\,((\text{"facc\_dem"} + 0.001) * ((\text{"slope\_dem"} / 100) + 0.001)) \quad (2)$$

By following these steps: Launch the Raster Calculator by clicking on click on Spatial Analyst Tools -Map Algebra - Raster Calculator, and Enter the formula, the result looks exactly like the formula above, Output Raster, thumb-drive\terrain\spi, and click ok to run the calculation. For more details, please refer to the website: https://www.wrc.umn.edu/randpe/agandwq/tsp/lidar

2.4 The Analytic hierarchy process (AHP) Method:

The AHP continues to be one of the most popular analytical techniques for complex decision-making problems and is widely used due to its flexibility and ease to use. An AHP hierarchy can have many levels to characterize a decision condition. The selected factors governing the suitability of the site’s suitability are weighted using the AHP which is aided by a pairwise comparison matrix that uses a scale of relative importance, (Al Raisi et al. 2014, Chaudhary et al. 2016, Yasser et al. 2013., Al-Adamat et al.2010). This method consists of a weighting of the factors adopted by a comparison. In pairs of factors that control erosion in this area, (Tairi et al. 2013) the main factors considered in this study are slope, land use/land cover, soil texture, rainfall, and SPI. The AHP process may be subdivided into three steps Including standardization, weight assignment, and weighted linear combination. Figure 3 indicates the overall procedures employed to create a model that enables us to identify zones of erosion risk.

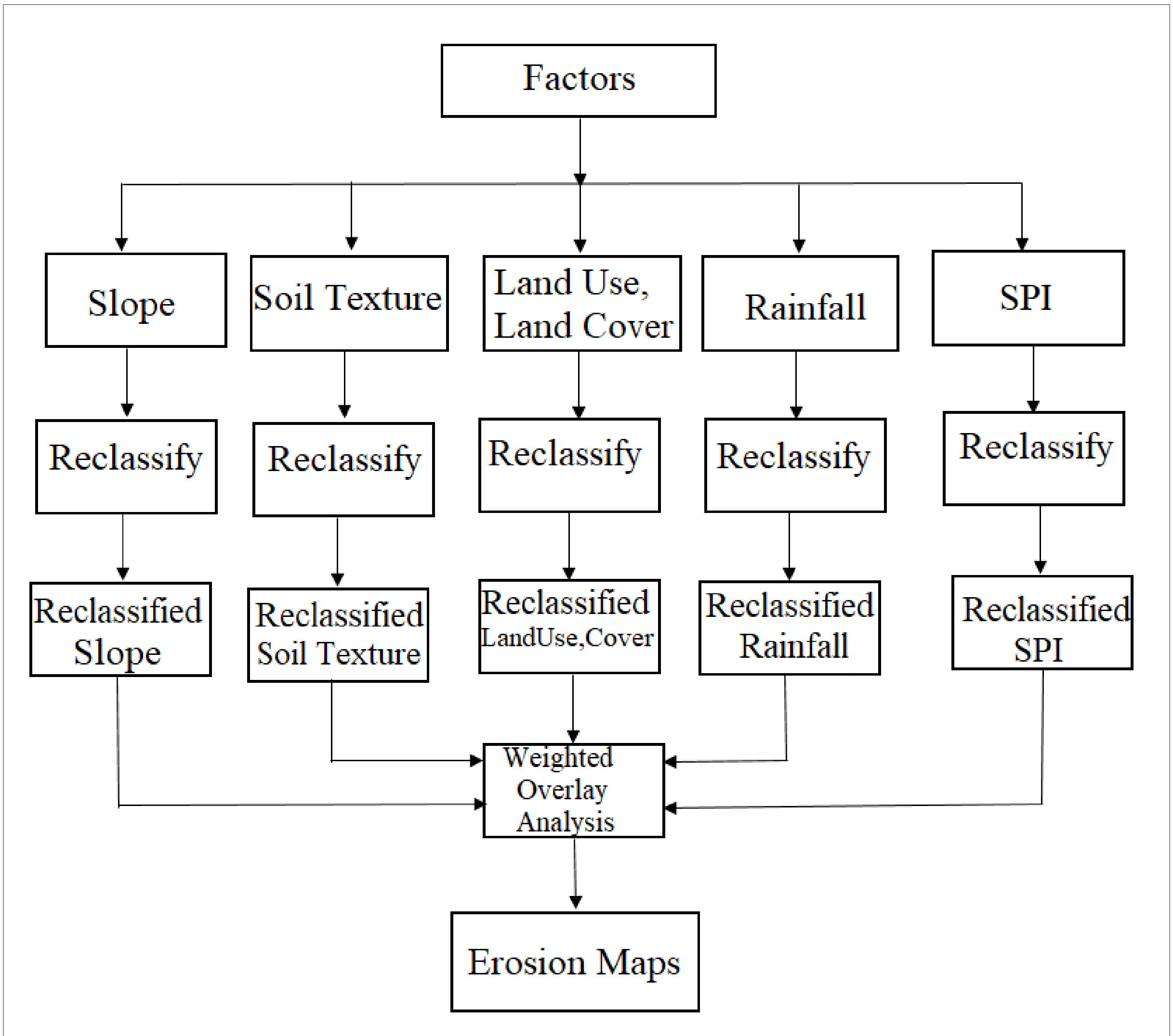

Figure 3. Overall procedures used for erosion risk mapping using MCDA in ArcGIS 10.4.1.

2.4.1 Multi-criteria decisional analysis mapping (MCDA):

Different methods to determine the risk zones of soil erosion, which calculate the amount of erosion and require a lot of data and criteria (Wischmeier and Smith, 1978), can be applied to characterize the erosion phenomenon in the study area. The MCDA is used to analyze a series of alternatives or objectives to rank them from the most preferable to the least preferable using a structured approach. The result of MCDA is often a set of weights linked to the various alternatives. The weights indicate the preference of the alternatives relative to each other. They may also be seen as an advantage or disadvantage when changing from one alternative to another. The choice of methodologies for calculating these weights varies from text to text. Several authors (Stewart and Scott 1995., Joubert et al. 1997., Jankowski et al. 2001., Ayalew and Yamagishi 2005., Kourgialas and Karatzas., 2011) have used the methods highlighted by Malczewski (1999) when calculating weights in MCDA. The AHP developed by Saaty (1977,1984), is the simplest of the multicriteria methods. It is based on the synthesis and aggregation of weights assigned to the criteria of the different levels of the hierarchy. The weights and ranks of each parameter were assigned after the pair-wise comparison using the rating scale. Table 2.

Table 2. Scale of comparisons of criteria (Saaty 1984).

Important	Verbal definition of the importance of one factor over the other	Scale
More Important	Extremely	9
	Very strongly	7
	strongly	5
	Moderately	3
	Equally important	1
Equally Important	Moderately	1/3
	Strongly	1/5
	Very Strongly	1/7
Less Important	Extremely	1/9

2.4.2 Pair-wise comparison matrix:

The application of AHP requires the development of a pairwise comparison matrix between the five factors affecting soil erosion, and this depends on the importance of each factor in the occurrence of erosion. The pairwise comparison of each pair of elements in each level is made to corresponding elements in the above level, depending on their importance. Where the comparisons can then be represented by multiple square matrices, (Chen 2006), as follows:

$$\mathbf{C} = (\mathbf{Cij})\mathbf{n} * \mathbf{n} \tag{3}$$

where C consistency ratio, each matrix of order n as the matrix. Table 3 shows a multiple square matrix.

Table 3. Multiple Square Matrix.

Factors	Slope	Land Use/ Land Cover	Soil Texture	Rainfall	SPI
Slope	C11	C12	C13	C14	C15
Land Use/ Land Cover	C21	C22	C23	C24	C25
Soil Texture	C31	C32	C33	C34	C35
Rainfall	C41	C42	C43	C44	C45
SPI	C51	C52	C53	C54	C55

Matrices that have reciprocal properties can be expressed., (Saaty 1980), by the following equation,

$$\mathbf{C} = (\mathbf{1/Cij})\mathbf{n} * \mathbf{n} \tag{4}$$

After the pairwise comparisons have been completed, a weight value is assigned to the element with a higher importance in the pair. As for the lesser important element in the pair, a reciprocal of the value will be assigned to it. Normalization followed by averaging the weights is then done to obtain the relative weight for each of the elements in the hierarchical model, (Kasperczyk and Knickel 2006). Based on equation (4), we arrive at the matrix. Table 4.

Table 4. The representation of matrices that have reciprocal properties.

Factors	Slope	Land Use/ Land Cover	Soil Texture	Rainfall	SPI
Slope	1/C11	1/C12	1/C13	1/C14	1/C15
Land Use/ Land Cover	1/C21	1/C22	1/C23	1/C24	1/C25
Soil Texture	1/C31	1/C32	1/C33	1/C34	1/C35
Rainfall	1/C41	1/C42	1/C43	1/C44	1/C45
SPI	1/C51	1/C52	1/C53	1/C54	1/C55

Then, the pairwise comparison matrix will be normalized by dividing each element in the matrix by the sum of its columns, (Bunruamkaew 2012) to get the following matrix. Table 5.

Table 5. Decision matrix.

Factors	Slope	Land Use/Land Cover	Soil Texture	Rainfall	SPI
Slope	C10/10	C10/5	C10/3.33	C10/2.5	C10/2
Land Use/Land Cover	C5/10	C5/5	C10/5	C10/3.33	C10/2.5
Soil Texture	C3.33/10	C5/10	C3.33/3.33	C10/5	C10/3.33
Rainfall	C2.5/10	C3.33/10	C5/10	C2.5/2.5	C10/5
SPI	C2/10	C2.5/10	C3.33/10	C5/10	C2/2

researcher's vision and referring to previous studies within the same field, pair-wise comparisons, and ranking of factors were done. Table 6. Analyzing

soil erosion areas, the slope was considered the most Weights of all factors in the hierarchical model based on the influential factor (highly sensitive to erosion), whereas SPI was considered less sensitive to contributing soil erosion. The values in each cell represent the scale of relative importance for the given paired factors. The diagonal has a value of "1" throughout because the diagonal represents factors being compared to itself with a scale of "1" (equal importance). On the lower diagonal, the scale values are infractions because the factors are being paired in the reverse order and the scale of relative importance is given as the reciprocal of the upper diagonal pair-wise comparisons. Hence, to identify the erosion Hotspot areas in the north Jordan Valley basin, factors are ranked as follows: slope first; land use second; soil texture third; rainfall fourth; and SPI fifth. For more details, refer to Andualem 2020).

Table 6. Comparison matrix of the five factors adopted.

Factors	Slope	Land Use/Land Cover	Soil Texture	Rainfall	SPI
Slope	1	2	3	4	5
Land Use/Land Cover	0.50	1	2	3	4
Soil Texture	0.33	0.50	1	2	3
Rainfall	0.25	0.33	0.50	1	2
SPI	0.20	0.25	0.33	0.50	1
Sum	2.28	4.08	6.83	11	15

These verbal judgments are based on a good expert knowledge of the field and the importance of each factor in the phenomenon of erosion. To calculate the weights of each factor, we will need to convert each value in the table of the comparison matrix in Table 6, to a percentage of the sum per column. Then the weight of each factor is the average of each row of the standardized matrix multiplied by 100%, Table 7.

Table 7. Standardized Matrix of Erosion Factors.

	Slope	Land Use/Land Cover	Soil Txt	Rainfall	SPI	Total	Average	Weight %
Slope	0.44	0.49	0.44	0.38	0.33	2.08	0.42	41.64
Land Use/Land Cover	0.22	0.25	0.29	0.29	0.27	1.31	0.26	26.18
Soil Txt	0.15	0.12	0.15	0.19	0.20	0.81	0.16	16.10
Rainfall	0.11	0.08	0.07	0.10	0.13	0.49	0.10	9.84
SPI	0.09	0.06	0.05	0.05	0.07	0.31	0.06	6.23
Total	1	1	1	1	1	5	1	100

2.4.3 Consistency analysis:

In the AHP, the pair-wise comparisons in a judgment matrix are considered to be adequately consistent if the corresponding consistency ratio (CR) is less than 10% (Saaty 1980). First, the consistency index (CI) needs to be estimated. This is done by adding the columns in the judgment matrix and multiplying the resulting vector by the vector of priorities (i.e., the approximated eigenvector) obtained earlier. This yields an approximation of the maximum Eigenvalue, denoted by λmax. Table 8 refers to the consistency matrix used to calculate the consistency ratio.

Table 8. Consistency measurement matrix.

Factors	Slope	Land Use/Land Cover	Soil Txt	Rainfall	SPI	Total	Average	Weight %	Consistency Measure
Slope	0.44	0.49	0.44	0.38	0.33	2.08	0.42	41.40	5.11
Land Use/ Land Cover	0.22	0.25	0.29	0.29	0.27	1.32	0.26	26.30	5.10
Soil Txt	0.15	0.12	0.15	0.19	0.20	0.81	0.16	16.10	5.06
Rainfall	0.11	0.08	0.07	0.10	0.13	0.49	0.10	9.80	5.02
SPI	0.09	0.06	0.05	0.05	0.07	0.32	0.06	6.40	5.03
Total	1	1	1	1	1	5.02	1	100	Average 5.06=
	CI=0.02				RI = 1.12				CR=1.45

Then, the CI value is calculated by using the formula:

$$\mathbf{CI} = (\boldsymbol{\lambda}\mathbf{max} - \mathbf{n})/(\mathbf{n} - \mathbf{1}) \quad (5)$$

where is calculated using the formula:

$$\boldsymbol{\lambda}\mathbf{max} = \sum_{i=0}^{n}(\boldsymbol{Xij}) \times (\mathbf{Wij}) \quad (6)$$

Next, the consistency ratio CR is calculated by using the formula:

$$\mathbf{CR} = (\mathbf{CI}/\mathbf{RI}) \times \mathbf{100} \quad (7)$$

where RI refers to the mean of an Index of Consistency, the matrix Order and CI refer to the Index of Consistency as expressed.

A randomly generated pairwise comparison matrix is used to obtain the random consistency index, RI. The values of $\boldsymbol{RI}$ for matrices of order 1 to 15 (1 to 10 elements in one level). Table 9, (Saaty 2016., Satty 1984). The RI value in this study was 1.12.

Table 9. Random indices for matrices of comparisons (Saaty 1984).

Size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.11	1.24	1.32	1.41	1.45	1.49

If λ max is the most massive value of the matrix of its own, the matrix can be determined easily; "n" is the matrix sequence. The CR is a ratio of the random index to the matrix consistency index.

The value is from 0 to 1. A CR of 0.1 or less is considered a respectable level, and over 0.1 implies a revision is required because the individual factor ratings are not being handled uniformly (Malczewski 1999). When these approximations are applied to the previous judgment matrix, it can be verified that the following are derived: λmax = 5.11; CI = 0.02, and CR =0.014. Once the weighting is done, the different factors adopted and the coherence ratio value is acceptable CR = 0.01, the superposition of the 5 input factors adopted will be carried out under ArcGIS software 10.4.1 according to the following equation:

Risk of Erosion = (0.42 * Slope) + (0.26 * Land Use/Land Cover) + (0.16 * Soil Txt) + (0.10 * Rainfall) + (0.06 * SPI).(8)

2.4.4 Field Study:

As an important step for the study, field visits were made to different areas within the study area to verify the accuracy of the results in determining the sites most affected by the risk of soil erosion in the field, in addition to the accuracy of the selection and the importance of (GIS and RS) as effective tools in evaluating soil erosion sites and thus matching the results reached using (GIS and RS) with the field reality. Figure 4 shows the sites of the field verification visits.

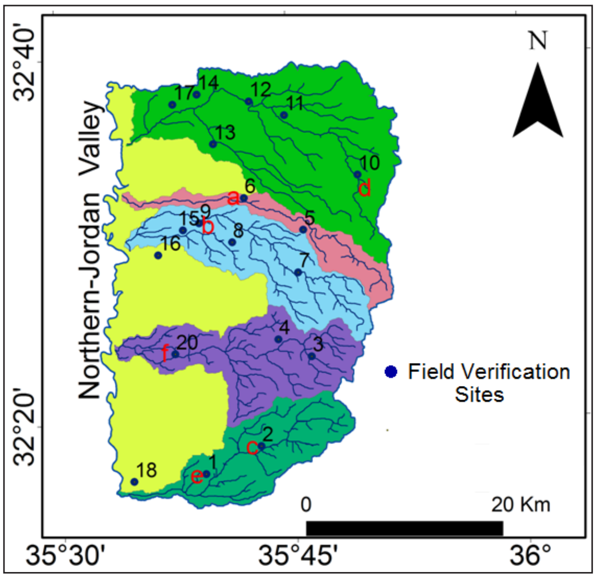

Figure 4. The sites of the field verification visits are shown in numbers. (a, b, c, d, e, f) represent the sites of soil erosion types in Figure 11.

3. Results and discussion:

After the factors of soil erosion are compared with each other by developing a comparison matrix, they are also compared regarding the importance of one concerning another and accordingly given a rating as per the Saaty scale. The present study was conducted to determine the zones of a Northern Jordan valley that contribute to a large amount of soil erosion.

3.1 Soil erosion contributing factors:

To estimate the spatial distribution of soil erosion-hazard areas in the Northern Jordan Valley, five factors are used: Slope, land use/land cover, soil texture, rainfall, and SPI.

3.1.1 Slope:

The slope gradient is a crucial factor that affects soil erosion from the land surface. The slope is one of the most important topographical features that cause soil degradation, (Andualem 2020). The slope ranges from (0 to 58.2°) in Northern Jordan Valley (Figure 5a).

3.1.2 Land use / Cover:

land use/cover changes were considered significant factors in soil erosion in the study region. Land/cover was one of the critical factors influencing surface flux, and decay in land use, (Sinshaw et al. 2021). In this regard, nine types of land use/land cover were recognized in the study area. Land use/land cover classes were investigated and computed as presented in Figure 5b.

3.1.3 Soil Texture:

Soil is an important element in conserving soil watershed moisture. The soil characteristics also control surface water in an aquifer system and are directly linked to absorption, percolation, and permeability levels. Soil texture affects the water content and drainage ability of soils. This is because texture controls the nature of soil pores, thus increasing the possibility of soil erosion, (Burke et al. 1999, Hook and Burke 2000). The soil texture of the study area showed about six major soil texture classes. Figure 5c.

3.1.4 Rainfall:

The effect of rainfall characteristics as a major determining factor is crucial to deal with observed variability in soil erosion, (Ran et al. 2012). Among storm characteristics, rainfall intensity is a very important factor. The close relationship between water erosion and rainfall intensity is due to the impact of raindrops on the soil surface in high-intensity storms which causes increased soil particle detachment and higher rainfall intensity results in higher rates of infiltration excess runoff, and a much greater transport of suspended sediment load, (Van Dijk et al. 2002., Falkland 1993., Al-Sababhah and Alomari 2020). The rainfall ranges from (243 mm to 569 mm). Figure 5d.

3.1.5 Stream Power Index (SPI):

Soil erosion by water is directly linked to slope morphology in the areas (Danielson 2013). SPI determines the erosive water flowing capacity, assuming the flow is proportional to the catchment area and the pitch. The potential energy for sediment is also an indicator (Kakembo et al. 2009). The highest focus on soil erosion has been the higher range of SPIs based on 'researchers' and 'experts' expertise. The SPI ranges from (-13.8 to 11.4). Figure 5e.

3.2 Reclassification of Soil erosion contributing factors:

The model applied in this study allows for determining the zones sensitive to soil erosion in the study area. Based on the sensitivity classes of the factors that control soil erosion, we have established the reclassification maps of the risk of soil erosion in the northern Jordan Valley.

3.2.1 Slope:

The slope map was reclassified into five major slope classes depending on the Food and Agriculture Organization (FAO) slope classification and susceptibility to erosion, Areas that are found on flat and gentle slopes were taken as very low and low susceptible to erosion, and vice versa, Figure 6a.

3.2.2 Land Use / Land Cover:

Land use and land cover changes are also considered as one of the major factors which cause soil erosion in an area, thus leading to land degradation. The northern Jordan Valley basins have five major types of land use and land cover. The land use and land cover types were reclassified according to their susceptibility to erosion where agricultural and bare land areas were considered very highly vulnerable to erosion, due to the soil structure disturbance. At the same time, water and urban areas were considered very lowly vulnerable to erosion. Figure 6b.

3.2.3 Soil Texture:

The susceptibility of soil texture to erosion was reclassified based on the characteristics of soil concerning soil erosion, where silt clay was considered very highly vulnerable to erosion, while clay loam was considered as low vulnerable to erosion, Figure 6c.

3.2.4 Rainfall:

The classified rainfall map was prepared based on areas with high rainfall values assigned to very high and high susceptibility to erosion. Figure 6d.

3.2.5 Stream Power Index (SPI):

Areas with high SPI values are considered highly erosive, whereas areas with low SPI values are classified as low, and susceptible to erosion. Figure 6e.

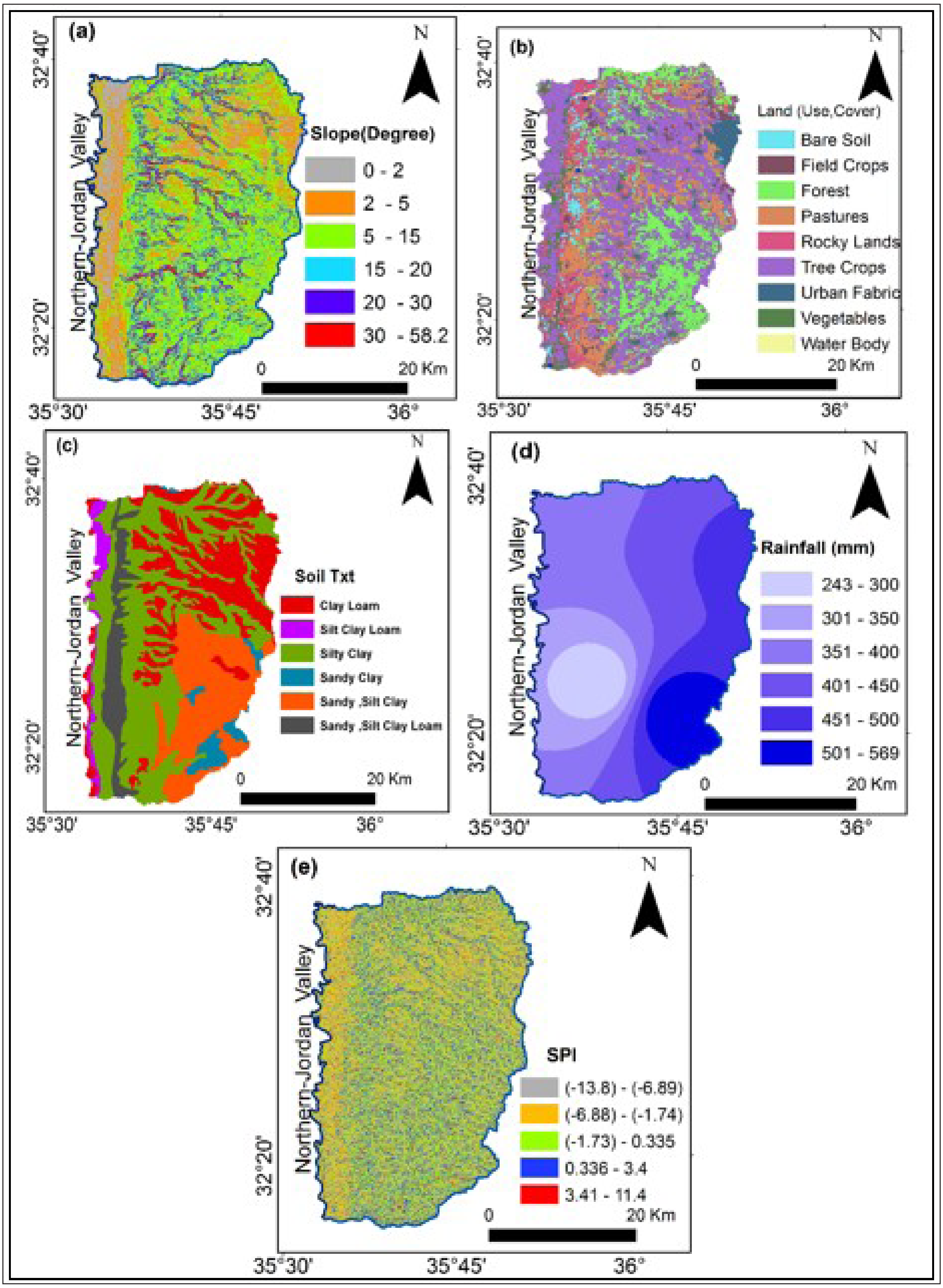

Figure 5. Soil erosion contributing factors: (a) Slope(Degree), (b) Land Use/Land Cover, (c) Soil Texture, (d) Rainfall (mm), (e) SPI.

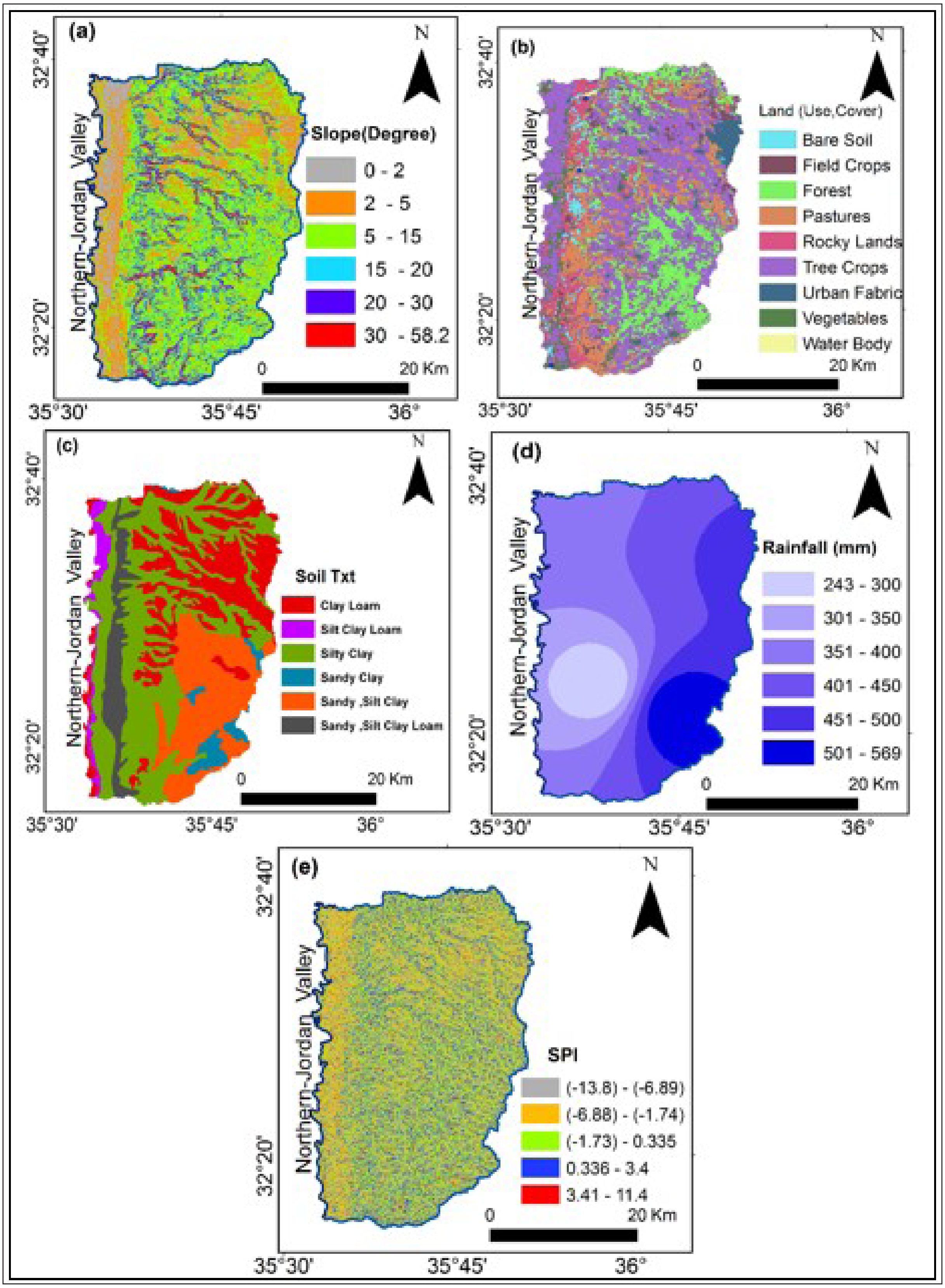

Figure 6. Classified soil erosion contributing factors: (a) Slope(Degree), (b) Land Use/Land Cover, (c) Soil Texture, (d) Rainfall (mm), (e) SPI.

3.3 Weighting of soil erosion contributing factors:

All soil erosion contributing factors were classified into five categories representing the degree of risk scale of that category on the possibility of soil erosion within the same factor. A standard scale of 1-9 according to the Saaty (1984) system was used to determine the degree of impact, with a value of 9 indicating a higher degree of risk.

Referring to the above, these verbal judgments are based on a good expert knowledge of the field and each factor's importance in the erosion phenomenon. To calculate the weights of each factor, we will need to convert each value in the table of the comparison matrix in Table 6, to a percentage of the sum per column. Table 8. Then the weight of each factor is the average of each row of the standardized matrix. Table 7 indicates the weights of the factors, the percentage of weights for each factor, the levels of erosion risk, and the classification of factors. Table 10.

Table 10. Classification and Weighting of Factors.

Factor	Domain	Risk Level	Proposed Weight	Weighting Rate	Total Weight	Percentage (%)
Slope	0-5	Very low	2	0.33	2.08	41.4
	5-10	Low	2.5	0.38		
	10-15	Moderate	3.33	0.44		
	15-20	High	5	0.49		
	20-58.2	Very high	10	0.44		
Land Use/Land Cover	Agricultural and Bare Land	Very low	2	0.27	1.32	26.3
	Forests	Low	2.5	0.29		
	Pastures	Moderate	3.33	0.29		
	Tree Crops	High	5	0.25		
	Water and Urban Areas	Very high	10	0.22		
Soil Texture	Clay Loam	Very low	2	0.20	0.81	16.1
	Sandy Clay	Low	2.5	0.19		
	Sandy Silt Clay Loam	Moderate	3.33	0.15		
	Silty Clay	High	5	0.12		
	Silt Clay Loam	Very high	10	0.15		
Rainfall	243-315	Very low	2	0.13	0.49	9.8
	315-368	Low	2.5	0.10		
	368-420	Moderate	3.33	0.07		
	420-488	High	5	0.08		
	488-569	Very high	10	0.11		
SPI	(- 13. 6)-(- 6. 9)	Very low	2	0.07	0.32	6.4
	(- 6. 9)-(- 1. 75)	Low	2.5	0.05		
	(- 1. 75)-0.34	Moderate	3.33	0.05		
	0.34-3.40	High	5	0.06		
	3.40-11.4	Very high	10	0.09		
Total					5.02	100 %

The risk classes were assigned to the five selected factors. Then the AHP pair-wise comparison matrix was constructed based on the preferences of each factor relative to the others. As input, it takes pair-wise comparisons of the factors and produces their relative weights as output. All soil erosion contributing factors were classified into five levels that represent the degree of risk scale of that category on the possibility of soil erosion to create a weighting map for the five factors. Figure 7.

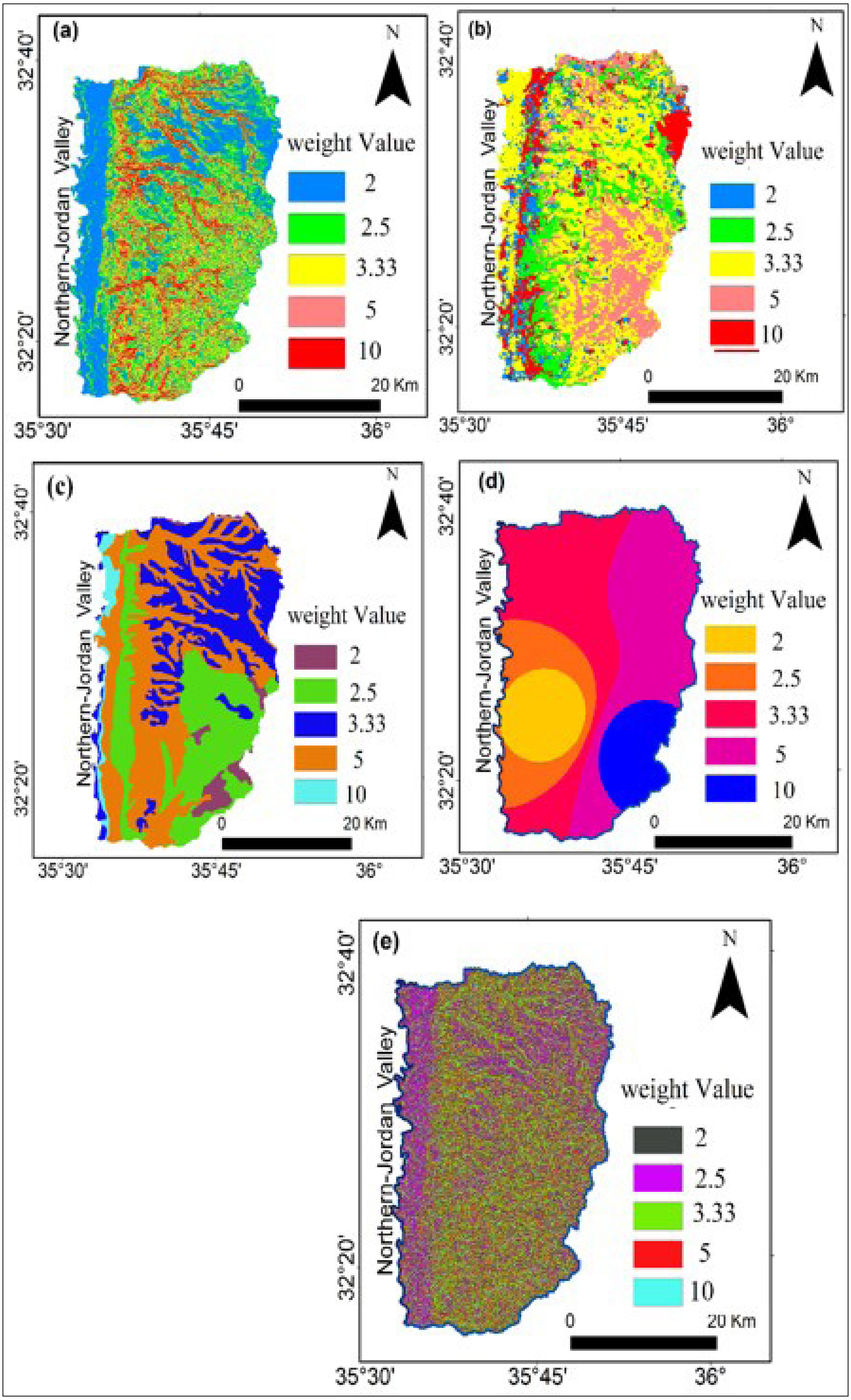

Figure 7. Weighted soil erosion contributing factors: (a) Slope(Degree), (b) Land Use/Land Cover, (c) Soil Texture, (d) Rainfall (mm), (e) SPI.

3.4 Risk levels for soil erosion contributing factors:

Soil erosion risk areas are classified into five risk levels according to the severity of erosion. The spatial distribution of each class of soil erosion risk in percent was developed by the AHP method. Figure 8.

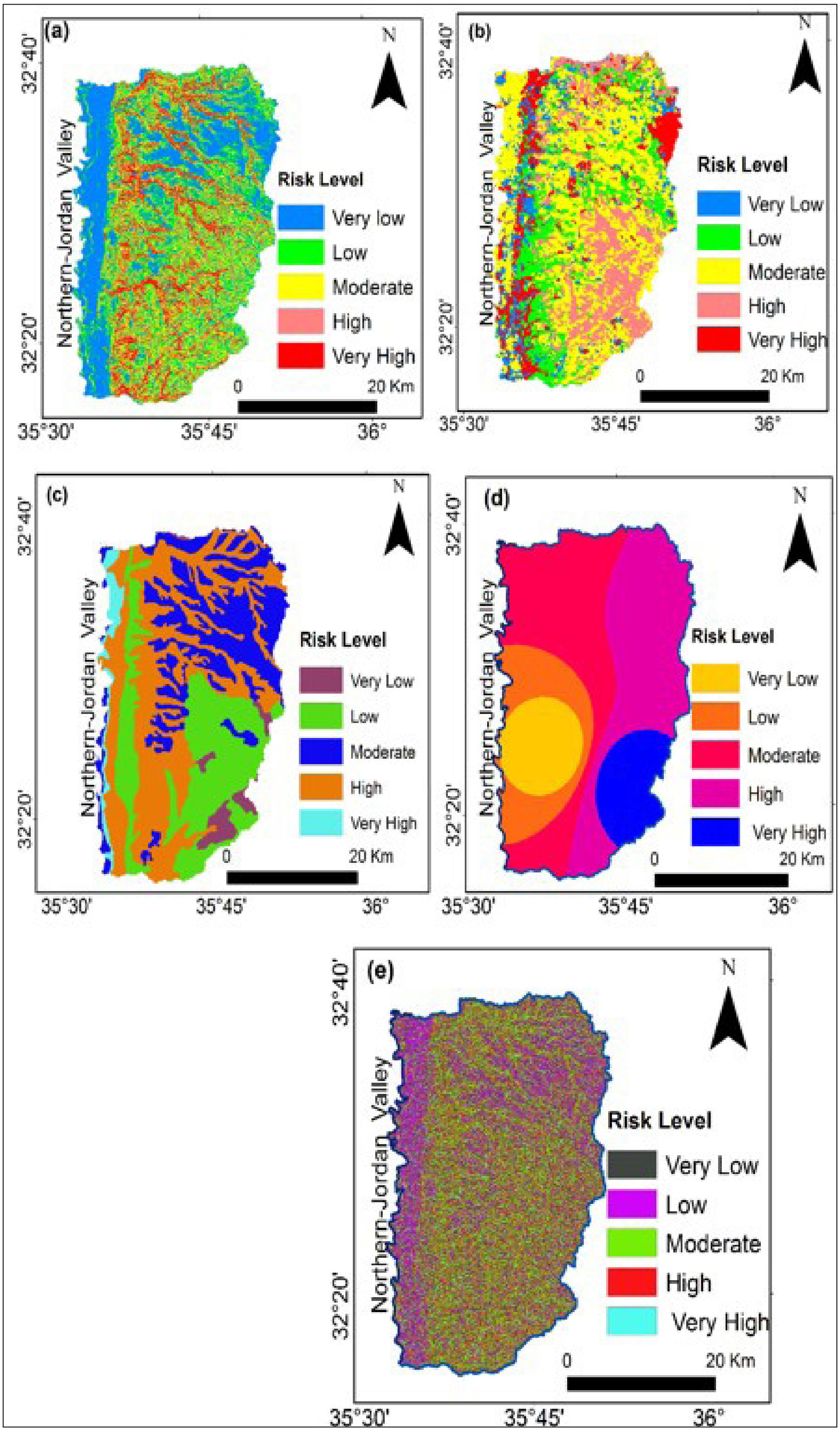

Figure 8. Risk levels for soil erosion contributing factors: (a) Slope(Degree), (b) Land Use/Land Cover, (c) Soil Texture, (d) Rainfall (mm), (e) SPI.

Areas found on flat and less than 10 degrees, were taken as having very low and low, susceptibility to erosion. About 30 % of the area lay in very low erosion risk; on the other hand, about 11.4 % lay in very high erosion. Figure 8 a. Areas that are found in agricultural and bare land were found as very highly susceptible to erosion. Their area constituted 9.7%. As for the areas covered by water and urban areas, which represent areas with a very low risk of erosion, they constituted a percentage of 11.44%. However, it can be considered that pastures with moderate impact on the risk of erosion constituted the highest percentage of the area at around 43.1 %. Figure 8 b. Northern-Jordan valley basin is dominated by Silty Clay with an area coverage of 441.2 km^2 or about 40.9% of the total area, which constitute areas of high risk of erosion, while the areas covered by clay loam have an area of 32.7 km^2 with a percentage of 3% of the total area and represent areas of very low risk of soil erosion. Figure 8 c. Areas with high rainfall/rainfall erosivity values were assigned to very high and high risk of erosion. About 117.6 km2 and 340.7 km2 area were found in a very high and high erosive area, respectively, while, about 124.5 km2 area was found in a very low erosive area, Figure 8 d. Finally, areas with high SPI values were considered highly erosive, whereas areas with low SPI values were classified with low susceptibility to erosion. As seen from the spatial distribution map of SPI, 15.5 % and 2.9 % of the area have been found in high and very high susceptibility to soil erosion. Figure 8 e. Table 11 shows the distribution of risk levels for soil erosion contributing factors.

Table 11. Distribution of risk levels for soil erosion contributing factors.

Factors	Domain	Risk Level	Area (Km)	Percentage (%)
Slope	0-5	Very low	355.6	33
	5-10	Low	287.2	26.7
	10-15	Moderate	196.7	18.3
	15-20	High	115.6	10.7
	20-58.2	Very high	122.5	11.37
Land Use/Land Cover	Agricultural and Bare Land	Very high	105	9.7
	Forests	High	175.6	16.3
	Pastures	Moderate	464.5	43.1
	Tree Crops	Low	209.2	19.4
	Water and Urban Areas	Very low	123.3	11.44
Soil Texture	Clay Loam	Very low	32.7	3
	Sandy Clay	Low	285.8	26.5
	Sandy Silt Clay Loam	Moderate	284.3	26.4
	Silty Clay	High	441.2	40.9
	Silt Clay Loam	Very high	33.6	3.1
Rainfall	243-315	Very low	124.5	11.6
	315-368	Low	150.3	13.9
	368-420	Moderate	344.5	32
	420-488	High	340.7	31.6
	488-569	Very high	117.6	10.9
SPI	(- 13. 6)-(- 6. 9)	Very low	301.3	28
	(- 6. 9)-(- 1. 75)	Low	219.9	20.4
	(- 1. 75)-0.34	Moderate	358.1	33.2
	0.34-3.40	High	167.5	15.5
	3.40-11.4	Very high	30.9	2.9

A final soil erosion map was created for the Northern-Jordan Valley basin to show the spatial distribution of erosion hazard sites. In addition to developing the soil erosion maps which are laid in erosion, potential areas have been identified to notify the respective officials at all levels of decision-makers and planners for providing sustainable soil and water conservation practices. Figure 9.

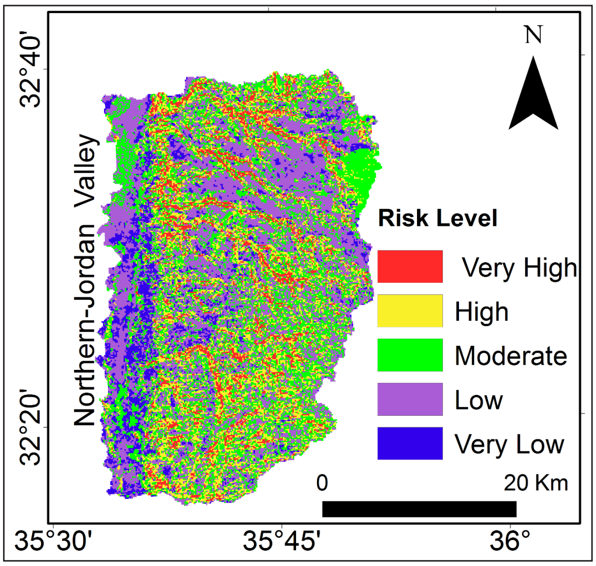

Figure 9. Soil erosion hazard map for the study area.

Where, the areas with high and very high erosion risk in the northern Jordan Valley basin are about 8.5% and 16.3%, respectively. As for the areas with low and very low soil erosion risk, they form about 36.6% and 8.9%, respectively, of the total area of the study area, Table 12

Table 12. Distribution of risk levels for soil erosion in the Northern-Jordan Valley.

Risk level	Area (km^2)	percentage (%)
Very High	91.6	8.5
High	175.6	16.3
Moderate	319.8	29.7
Low	394.8	36.6
very Low	95.8	8.9
Total	1077.6	100

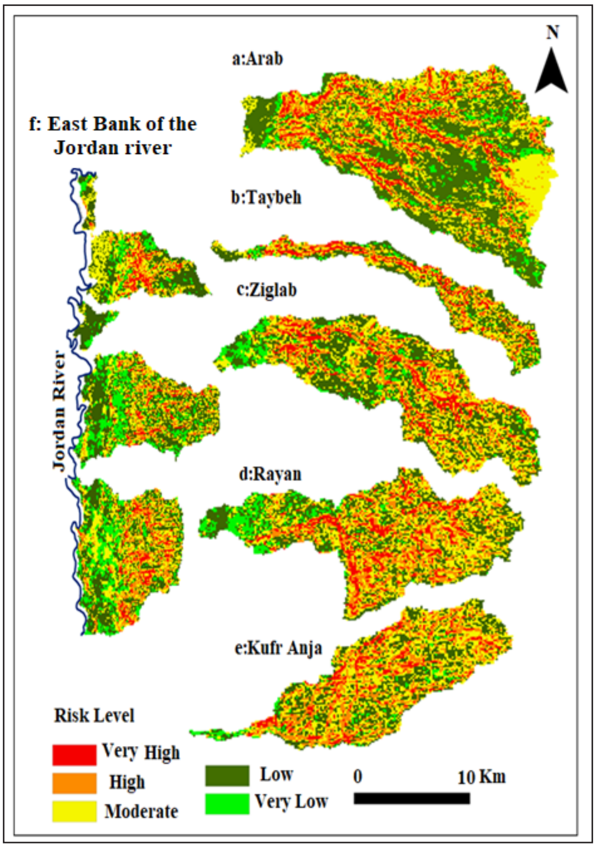

Figure 10. Soil erosion risk map for sub-basins.

3.5 Risk levels for sub-basins:

Likewise, the analysis for soil erosion was conducted for the sub-basins, including Al-Arab, Ziqlab, Al-Rayan, al-taybeh, Kufer Anja, and the areas located on the eastern bank of the Jordan River. Figure 10.

In the analysis of soil erosion, it has been found that the Arab basin has a high and very high erosion area of about 69.8 km^2, with a percentage of about 6.5% of the total area. Hence, that catchment can be considered the most topographically-complex basin in the study area, resulting in more steep morpho-metric characteristics. Also, it has been found that this catchment has the highest slope ratio even though it is the largest watershed, which is considered a hazardous indication since it means that soil erosion could reach great volume over a small area. The low and very low area of soil erosion, was in the lands of the eastern bank of the Jordan River, covering about 191.3 km^2. This is related to the spread of favored plain areas to cash crop production and intensive agriculture which can lead to low-erosion soil. Table 13.

Table 13. Distribution of risk levels for sub-basins.

Basin	Risk Level	Area (Km^2)	Percentage (%)
Arab	Very high	27.4	9.40
	High	42.4	14.5
	Moderate	86.95	29.8
	Low	117.6	40.3
	Very low	17.2	6
	Total	291.55	100
Taybeh	Very high	8.1	13.5
	High	11.4	19.0
	Moderate	17.2	28.7
	Low	20.7	34.5
	Very low	2.6	4
	Total	60	100
Ziglab	Very high	13.6	9.54
	High	26.2	18.4
	Moderate	42.6	29.9
	Low	50.3	35.3
	Very low	9.92	7.0
	Total	142.62	100
Rayan	Very high	16.2	11.1
	High	31.3	21.4
	Moderate	44.9	31
	Low	43	29.5
	Very low	10.6	7.3
	Total	146	100
Kufr Anja	Very high	10.2	9.2
	High	28.8	25.9
	Moderate	37.1	33.4
	Low	30.8	27.7
	Very low	4.2	3.8
	Total	111.1	100
East Bank of the Jordan River (Gor,Zor, Katar, and escarpment)	Very high	15.5	4.7
	High	37.8	11.6
	Moderate	81.7	25.0
	Low	134.4	41.2
	Very low	56.93	17.4
	Total	326.33	100

3.6 Field study:

Fieldwork is used while investigating soil erosion areas. Also, field visits are an important tool for investigating spatial scale, the scenarios of interaction between the various environmental factors, and the surfaces they act upon to cause soil erosion. The types of soil erosion were distributed within the study area and were limited in the field visits to six types as their locator in Figure 3: The first type is Raindrop or splashes erosion due to the impact of falling raindrops on the soil surface leading to the destruction of the crumb structure, also known as the raindrop or splash erosion. Figure 11a. The second type of sheet erosion is the uniform removal of soil in thin layers from the land surface caused by water. Land areas with loose, shallow topsoil overlying compact soil are most prone to sheet erosion. Figure 11b. The third type of rill soil erosion is a form of water erosion in which the erosion takes place through numerous narrow and more or not-so-straight channels called streamlets, or head cuts. Rill is the most common form of erosion, which you can also observe during heavy rain. Figure 11c. The fourth type of gully erosion occurs due to the runoff of surface water causing the removal of soil with drainage lines. When started once, gullies will move by headward erosion or even by slumping of side walls unless and un-till proper steps will be taken to stabilize the disturbance. Figure 11d. The fifth type of stream bank erosion is nothing but washing away from the banks of a stream or a river. It is different from the erosion of the bed of a watercourse, which is referred to as scouring. This type of erosion is also termed Stream Bank Erosion. Figure 11e. The sixth type of soil flow frosion is the movement of water-saturated soils towards the lowest slopes, and it is active in wet regions where it transports large quantities of soil during sufficient amounts of rainfall. Figure 11f.

Figure 11. The types of soil erosion: (a) raindrop or splash erosion, (b) sheet soil erosion, (c) rill soil erosion, (d) gully soil erosion, (e) stream bank soil erosion, (f) soil flow erosion.

Overall, the area most susceptible to soil erosion has a low potential for agriculture and forestry unless soil erosion and soil maintenance were installed to make maximum use of the dominant environmental system in the study area. The potential for grazing and browsing is constantly decreasing due to active soil erosion processes, specifically with deforestation and fires, apart from stream channels and slopes, where high and very high soil erosion occurs. Soil erosion is more evident in the semi-humid and humid regions with rainfall of more than 350 mm, the degree of a steep slope, and mostly silty loam and silty clay loam, as well as in the regions of agriculture, forests, and poor pastures where the thickness of the soil is more than 25 cm to allow rainwater saturation and increase the possibility of soil erosion, Table 14.

Table 14. Data of soil erosion sites selected in Figure 11.

Variables \ Sites	a	b	c	d	e	f
Coordinates	35°42′E 32°32′N	35°39′E 32°31′N	35°42′E 32°18′N	35°49′E 32°33′N	35°39′E 32°17′N	35°37′E 32°23′N
Basin	Taybeh	Ziglab	KufrAnja	Arab	KufrAnja	Rayan
Climate Region(Iar-DM)	Semi-Humid	Semi-Humid	Semi-Humid	Semi-Humid	Semi-Arid	Semi-Humid
Rainfall(mm)	427	426	490	463	350	453
SPI Value	3.5	4.03	6.4	1.6	5.2	4.1
Temperature (C°)	18.8	19.2	17.8	18.4	21.4	20.1
Elevation (m)	330	43	700	520	410	453
Slope(Deg)	10.6	6.2	34.4	22.9	39.8	35.2
Soil Texture	Silty Clay Loam	Silty Clay	Silty Clay Loam	Silty Clay	Silty Clay	Silty Clay
Soil Depth (cm)	72	80	30	120	25	140
Land Use/Land Cover	Pasture	Tree Crops	Forest	Pasture	Forest	Pasture
Erosion Type	Raindrop	Sheet	Rill	Gully	Stream Bank	Soil Flow
Erosion Class	Very High	Very High	Very High	High	Very High	Very High

4. Conclusion

The application of the Analytical Hierarchy Process (AHP), integrated into Geographic Information Systems (GIS) is one of the most important methods for creating soil erosion risk maps. On the one hand, assessing and analyzing soil erosion risk areas in different regions of the world, especially where soil erosion is a dominant phenomenon that has economic, social, and environmental effects. On the other hand, the method used provides a strong database for decision-makers to simulate scenarios of erosion in the region and to plan erosion control interventions. To achieve this goal, the study relied on five factors, slope, land use/land cover, soil texture, rainfall, and SPI for the northern Jordan Valley basin. It was found that the areas with a very high and high risk of soil erosion are about 24.8%, and those with low and very low risk of erosion form about 45.5 % of the total area of the study area.

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