Agriculture & Food Security

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Risk assessment of soil erosion by using CORINE model in the western part of Syrian Arab Republic

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Abstract

Background: Soil erosion is a major threat to the natural ecosystem and agricultural sector in the western part of Lattakia Governorate, Syrian Arab Republic. The main goals of this research are to investigate erosion risk by using the Coordination of Information on the Environment (CORINE) Model and to prioritize areas for conservation practices. To achieve these goals, soil samples were collected from the field, the climatic data (i.e., rainfall) and Digital Elevation Model (DEM) were obtained and utilized to perform CORINE model in Geographic Information System (GIS) environment.

Results: The results showed that only 13.2% of the study area was classified as high erodible. In addition, 45.24%, 49.15% and 5.29% of the study area were under low, moderate and high actual erosion risk, respectively. This research identified slope and land use/land cover as key factors responsible for soil erosion in the study area.

Conclusions: The CORINE model acknowledged as a good tool for predicting soil erosion and highlighting the areas affected by soil erosion in the study area with high precision.

Keywords: Land degradation, CORINE, Food security, Sustainable development goals (SDGs)

Background

Besides biodiversity loss and water shortage, soil erosion considers a vital issue exacerbating the problem of food security globally [80, 81, 87]. In this sense, it has emerged that land degradation and particularly soil erosion is a big threat to food security and sustainability of agroecosystem in many parts of the world [41, 80, 81]. The current estimates indicate that soil loss is undoubtedly detrimental to worldwide food production, exacerbating a non-trivial reduce in cultivation and food production of 33.7 million tonnes [84, 86]. These numbers raise concerns about the sustainability of food security, especially in developing countries due to huge rapid population growth, climate change, accelerated landcover/landuse change, poor land maintenance measures, epidemics, food safety and wars [2, 82, 95, 103]. However, this enhances the effective link between the importance of reducing soil erosion and sustaining global food security [9, 50, 65, 83].

In this context, the relevant scientific literature indicates that integrated agricultural management, mitigating food-related greenhouse gas emissions, and reducing erosion and rural poverty are among the most important measures to ensure food security in developing countries [7, 37, 91, 98]. Moreover, the scarcity of spatial data involved in agricultural systems management poses constraints to the sustainability of global food security [48, 90, 92]. The formulation and development of spatial policies related to agricultural management constitute the cornerstone for decision-makers in the framework of sustainable land use and intensive agricultural production

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[74]. Moreover, improving dietary diversity to meet the needs of the global food market requires preserving the components of agricultural production, especially soil erosion mitigation and nutrient protection [21, 41, 80, 81]. Several socioeconomic factors influence the extent to which smallholder farmers have adopted measures to adapt to the consequences of climate change, especially in areas with a high risk of erosion [11].

Globally, rapid land degradation is one of the most serious issues because of its adverse effect on economy and eco-environment like the losses of land resources and soil productivity [104] which our society has been experiencing. One-third of the world's arable land has been lost due to soil erosion since 1970s; [89, 104]. Although the soil erosion is considered as a natural phenomenon in any part of the world, however, it is taking place through a set of processes like detachment, splashing and transportation which are accompanied by each other [29, 30, 73]. Plan Bleu [72] reported that 0.1–1 t/ha/year is the average amount of soil erosion which takes place because of natural soil erosion, while 10–1000 times faster soil erosion has been observed because of the interference of human beings. Fascinatingly, Bhange et al. [18] reported that more than 75 billion tons of soil is lost each year because of soil erosion [105], while Quinton et al. [75] estimated the total global sediment flux of about 35 ± 10 Pg year^{-1}. Once the amount of soil erosion was estimated globally, it was found that most countries have been enduring from soil erosion, for example, approximately 90% of the United States croplands have experienced soil loss between 5–12 t/ha/year, while 6 t/ha/year was the soil loss from the farmlands; [99]. The Mediterranean region experiences 50% of soil erosion annually [42]. Several studies also reported that many countries of Mediterranean region had been effected by soil erosion, for instance, Portugal [33, 44, 71], Spain [32, 78], Italy [40, 53, 79], France [24, 35, 54]; Morocco [23, 34, 51]; Tunisia [38, 43, 88], and Syrian Arab Republic [1, 61, 63, 64]. Whereas more than three-quarters of Turkey's soil is found to be highly soil erosion susceptible, the UNCCD [96] reported that 72% of the Turkey's soil has been affected by soil erosion. It is very difficult to evaluate the impact of soil erosion precisely as it varies from loss of soil quality (on-site consequences), to the pollution of natural water bodies and groundwater (off-site consequences) [19, 22, 36, 47, 52, 67, 100].

Likewise, to other (Middle East and North Africa) MENA countries, soil erosion in Syrian Arab Republic is a major problem, especially in the coastal area, where the soil is shallow and the vegetation and soil cover is seriously damaged due to many factors such as intensive agriculture, unsustainable agricultural practices, deforestation, flashflood and current conflict [2, 3, 56, 59, 60]. Kbibo et al. [49] reported that farm lands in the coastal area of Syrian Arab Republic (i.e., Tartous and Latakia governorates) have been suffering from drastic impact of soil water erosion, due to agricultural activities. Nevertheless, experimental studies were carried out during 2012–2013 and estimated that the amount of soil erosion ranged between 0.14 ± 0.07 and 0.74 ± 0.33 kg/m^2 in agricultural land; whereas, the soil erosion ranged between 0.03 ± 0.01 and 0.24 ± 0.10 kg/m^2 in the burned forest area [57]. To the best of our knowledge, Barakat et al. [15] and Barakat [16] had used CORINE model for assessment of soil erosion in Syrian Arab Republic. Unfortunately, such studies were limited to a specific basin in the Syrian Arab Republic coastal area. However, the utilization of CORINE model for assessing soil erosion is still limited in Syrian Arab Republic and needs to be employed over the country for proposing management plans. In conclusion, the main research goals are to investigate erosion risks in the western part of Latakia Governorate and to prioritize areas for conservation practices through using CORINE model.

Methods

Study area

The study area is located in the western part of Latakia governorate in Syrian Arab Republic, covering an area of 296 km^2, between the geographical location of °35 43′ 6.43″–°36 00′ 00″ E and °35 37′ 32.08″–°35 29′ 51.98″ N as illustrated in Fig. 1. The study area is subject to the Mediterranean climate and is placed in the 1st agro-ecological zone (i.e., rainfall over 600 mm), as other costal part of Syrian Arab Republic [55]. Generally, the precipitation occurs from September to May, with the highest amount in January (75–120 mm). The average temperature ranges between 17.2° and 22.3 °C. The study area is characterized by diversified landforms types such as coastal plain, medium heights hills, and alluvial plain (lower part of the basin). The highest elevation of the study area is 267 m. above sea level.

The main economic activity in the area of study is agricultural activities, where the common agricultural crops are wheat, citrus and olive (Fig. 2). Moreover, several types of vegetation such as *Ceratonia siliqua*, *Pistacia lentiscus*, and *Inula viscosa* dominate the study area.

Soil samples and analysis

The soil properties are most important factors for CORINE model. Therefore, in this study, a field survey was conducted to collect soil samples (Fig. 3). Soil and land cover characteristics were described for each location. Stoniness and soil depth were measured. Soil physical and chemical properties like texture, organic matter (OM in percentage), pH, electrical conductivity (EC),

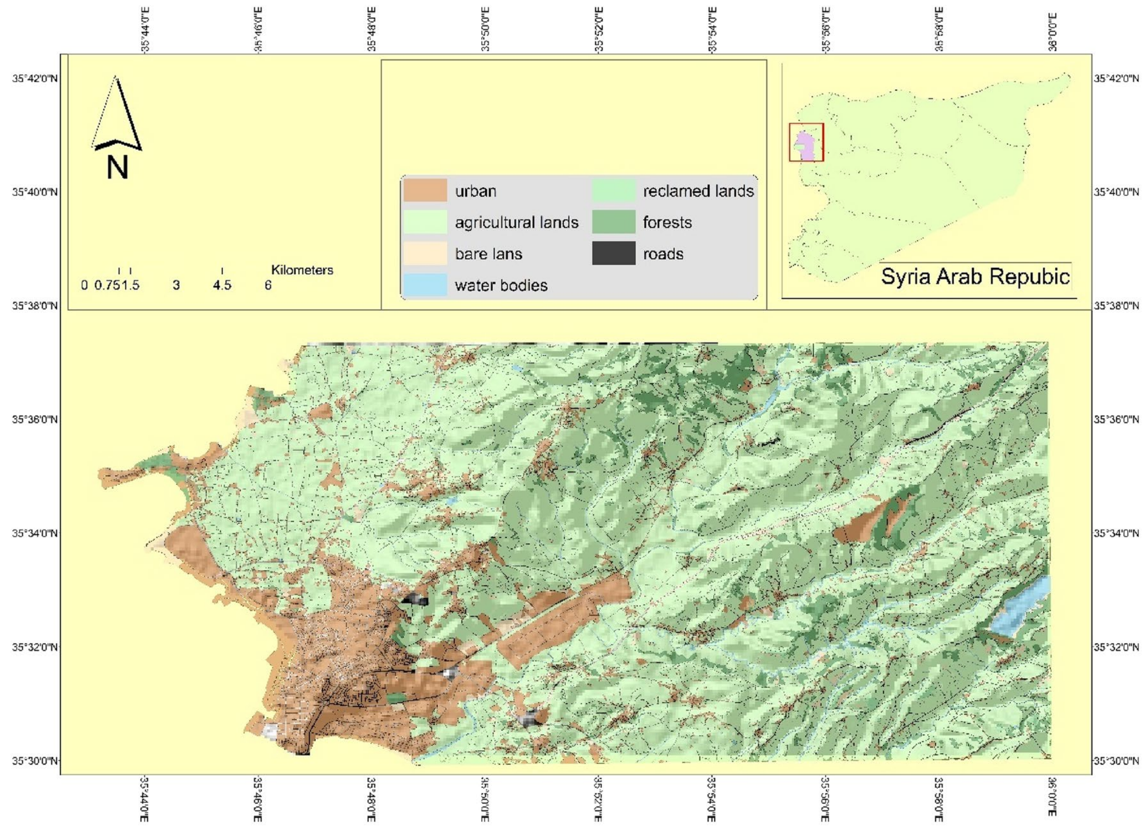

Fig. 1 The study area

Fig. 2 Agricultural crops

cation exchange capacity (CEC) and calcium carbonate ($CaCO_3$ in percentage) were estimated from collected soil samples in soil science laboratory.

Theoretical background of CORINE model

In 1985, the CORINE programme was lanced by the European Union (EU) for land observation and monitoring, which primarily used for land cover/land use mapping and monitoring in the EU [25]. In a later stage, the CORINE database was used for multidisciplinary purposes, which served as a main input for mapping soil erosion risk [69, 70], soil organic carbon [6, 8], transitional landscapes [97], and land use change [25].

The well-known CORINE model is one of the semi-qualitative cartographic methods that can easily be integrated with GIS environment to utilize and process remote sensing (RS) data [104]. The CORINE model can be employed for determining (soil erosion) SR

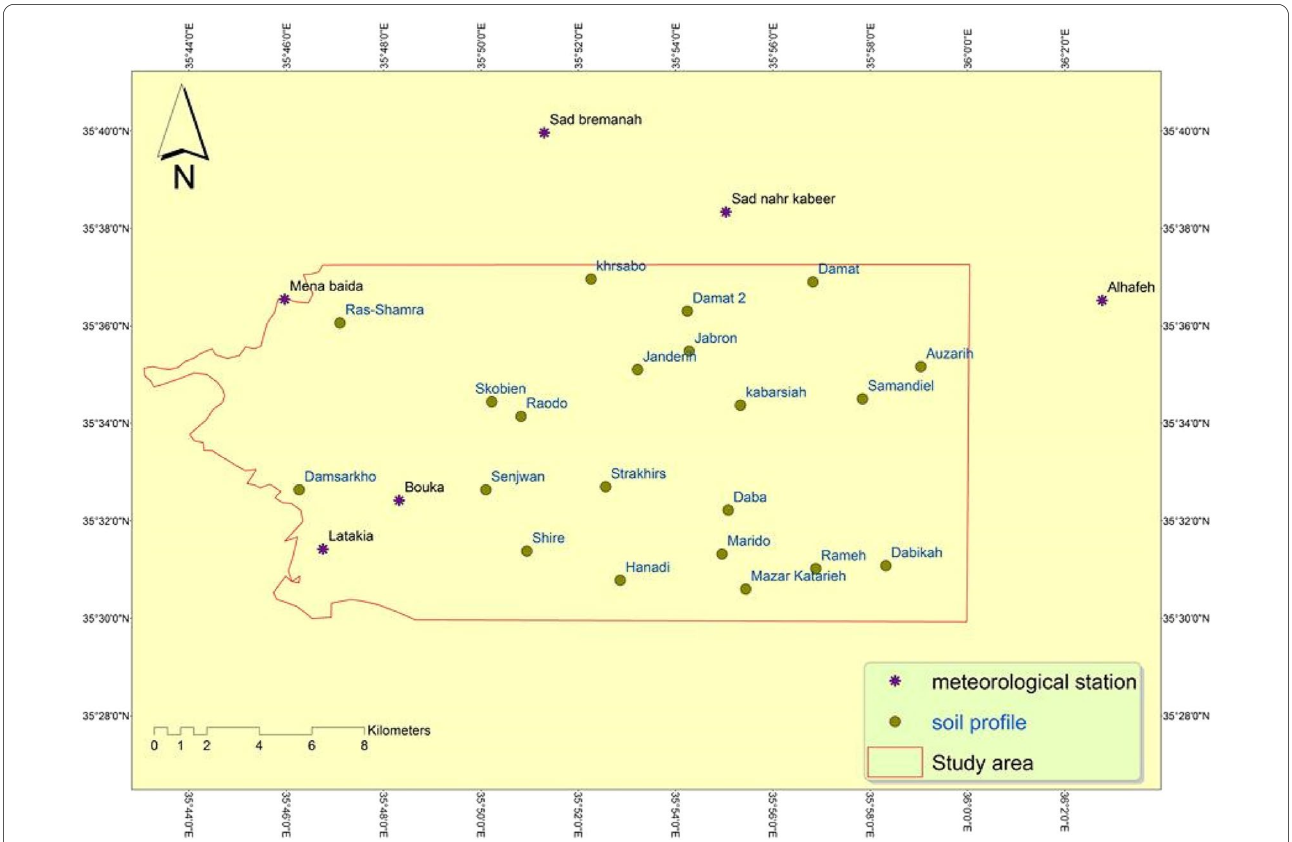

Fig. 3 Distribution of soil samples in the study area

based on universal soil loss equation (USLE) [77]. The other advantage of the CORINE model is the ability to map the potential soil erosion risk (PSER) and the actual soil erosion risk (ASRR) in lucrative way [13]. Within CORINE framework, the PSER has been computed based on rainfall erosivity, soil erodibility, and topography, while the ASRR has been estimated based on PSER and vegetation cover. Nevertheless, PSER and ASRR are necessary tools for hydrologists and catchment managers, because they play a vital role in any catchment development plan.

Generally, CORINE model is widely used due to its simplicity; flexibility and efficiency compared with physical-based models (i.e., WEPP; EPIC), which need high input data as well as broad field information assortment [10, 76, 104]. Many researchers all over the world, especially in Europe and the Mediterranean region used CORINE model in order to identify the widely exposed area to soil erosion, such as Turkey [13, 17, 76, 101]), Iran [94], China [104], Lebanon [85], Egypt [31]; Morocco [46] and many other parts of the world.

The CORINE model framework for erosion risk assessment

The soil erodibility (SE), rainfall erosivity (RE), land use land cover (LULC) and slope (S) were prepared for modeling the CORINE model. Soil depth, stoniness and texture maps were prepared using Inverse Distance Weight (IDW) method based on the data collected from the field and from the laboratory analysis to produce SE map. The RE calculated based on meteorological data. The Landsat image was used to produce LULC map, while the DEM was used for producing slope map. Based on CORINE approach, the PSER was estimated by overlying the SE, RE, and S layers; while merging between PSER and LULC produce the ASRR (Fig. 4).

Soil erodibility index (SE)

The SE reflects the stability of soil aggregation against the erosion processes. The SE is strongly correlated with the soil aggregate stability and the shear strength [20, 28, 102]. Eq. 1 was used to calculate the soil erodibility factor (SE):

$$\mathrm{SE} = \text{Texture class} * \text{depth class} * \text{stoniness class}, \tag{1}$$

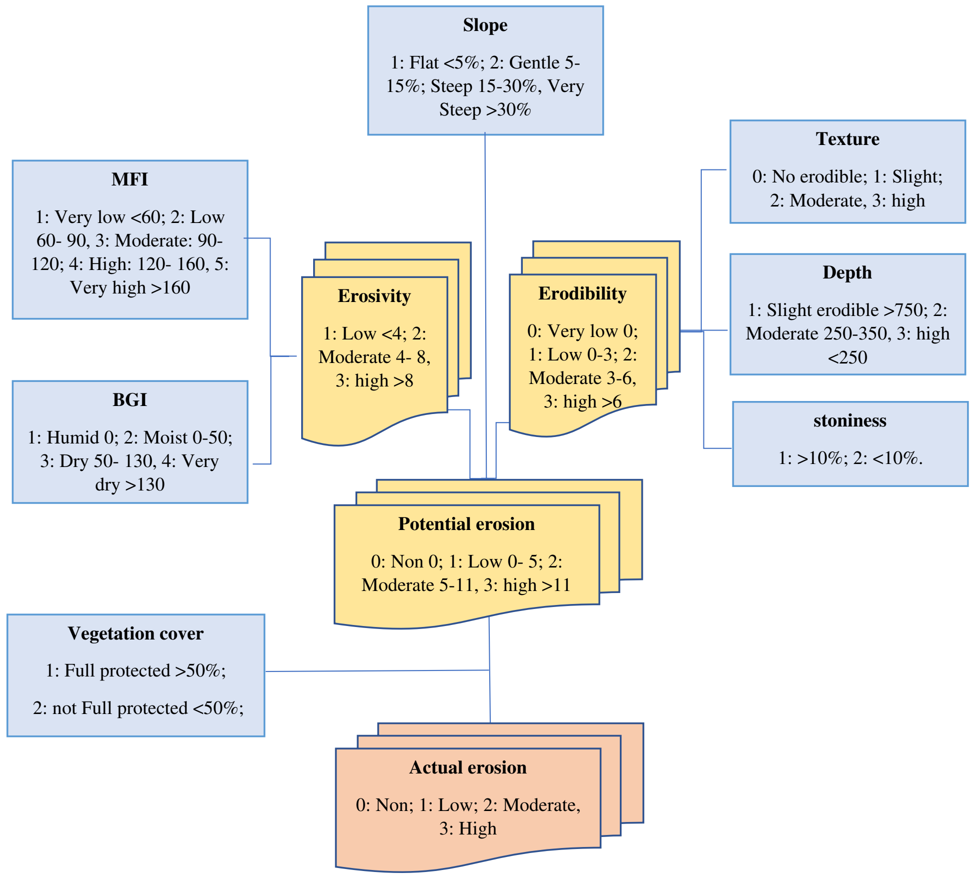

Fig. 4 Flowchart of CORINE model

where texture class; depth class and stoniness class can be defined by Fig. 4.

Rainfall erosivity index (RE)

The RE is the ability of raindrops to destroy soil aggregates and then caused erosion [66]. The climatic data were collected from 6 meteorological stations during 1986–2016 as described in Table 1. Generally, the erosivity is a computation between the Modified Fournier Index (MFI) [12] and the Bagnouls–Gaussen Aridity Index (BGI) [14]. The MFI was computed using Eq. 2:

$$\mathrm{MFI} = \sum_{i=1}^{12} \frac{(\text{Monthly precipitation})^2}{\text{Mean anual precipitation}}. \tag{2}$$

Similarly, BGI was computed using Eq. 3:

Table 1 Characterization of meteorological stations and BGI and MFI values

Station	*X*	*Y*	Average rainfall	Average temperature	Max T	Min T	BGI	MFI
Sad Nahr Kabeer	35.91722	35.64	788.9	19.15	24.7	13.6	102.631	120.6409
Alhafeh	36.04611	35.61	1049.2	17.4	20.7	14.1	34.117	138.8918
Latakia	35.77917	35.52	713.6	20.6	24.9	16.2	120.409	102.6655
Bouka	35.80528	35.54	835.3	20	25.4	14.6	93.866	122.8693
Mena Baida	35.766	35.61	797.7	22.35	29.6	15.1	108.676	114.0132
Sad Bremanah	35.855	35.67	886.2	20.05	24.7	15.3	98.355	118.8277

$$\mathrm{BGI} = \sum_{i=12}^{12} (2t_i - P_i)K_i, \quad (3)$$

where t_i is the mean temperature; P_i is the total precipitation; K_i is the part of the month and $2t_i - P_i > 0$.

After calculating MFI and BGI, the generated results were reclassified according to [26] as shown in Figs. 5 and 6.

Slope (S)

In the Mediterranean region, the topography plays an important role in soil erosion especially with poor vegetation [68]. The DEM of the study area was obtained from https://earthexplorer.usgs.gov/ with the spatial resolution of 30 m. the slope was produced and then reclassified according to CORINE [26].

Vegetation cover

The Landsat 8OLI image was downloaded from USGS earth explorer and used for extracting vegetation of the study area. The Normalized Differential Vegetation Index was estimated using Eq. 4:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}}, \quad (4)$$

where the VIS and NIR represent the spectral reflectance measurements acquired in the visible and near-infrared regions of electromagnetic wave spectrum, respectively [94]. Hence, the NDVI values range between 1 and −1. The results were rescaled to 0–100 and then reclassified (more than 50% was considered as fully protected, and less than 50% was considered as not fully protected).

In the ultimate stage, the PSER and ASRR maps were produced by overlaying all input layers over each other.

Results

Soil characteristics

According to the United States Department of Agriculture Soil (USDA) Taxonomy (2010), two major soil orders have been detected in the study area, as previously reported by Ghanem et al. [39]. The first one is *Entisols*, which has been divided into the following sub-groups: *Typic xerorthents*, *Lithic xerorthents* and *Typic xerofluvents*. While, the second one is *Inceptisols,* which has been divided into the following sub- groups: *Typic Calcixerepts*; *Lithic Calcixerepts*, and *Calcic Haploxerepts*. The general feature of each unit is illustrated in Table 2, while the physical and chemical properties can be seen in Table 3.

Based on findings of soil depth analysis, the overall soil depth of the study area can be considered as good ranging between 25 and 75 cm that indicates the development of weathering processes have been going on. Meanwhile, the clay content ranges between 34 and 50%, thus, most of the studied profiles have a good

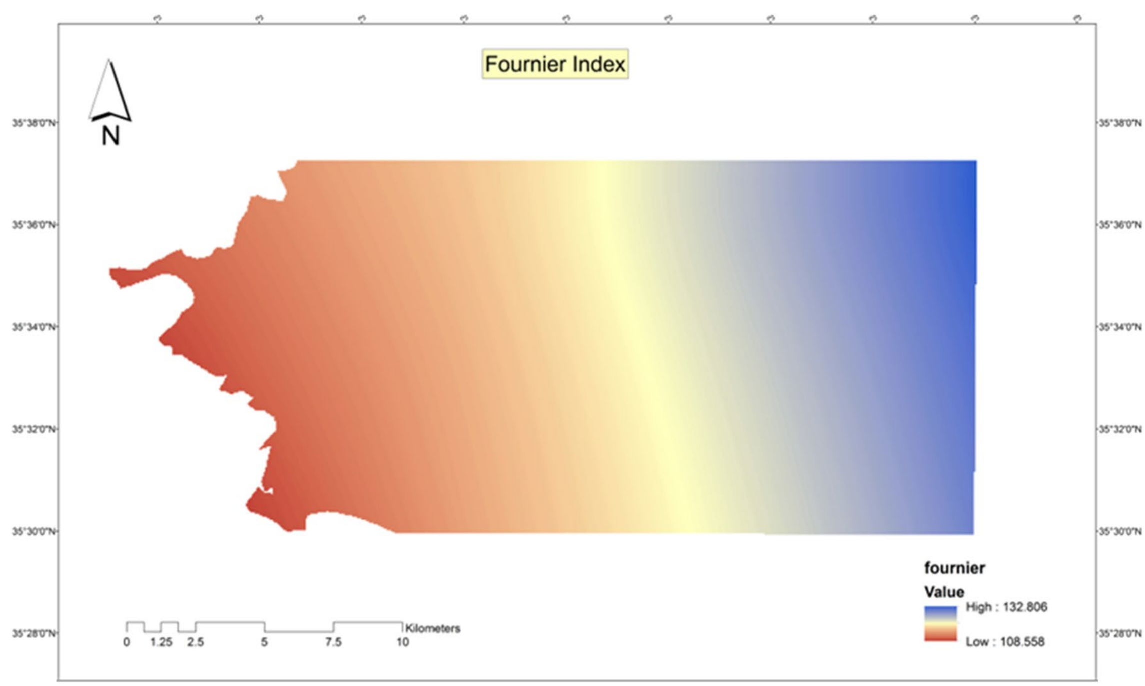

Fig. 5 MFI map

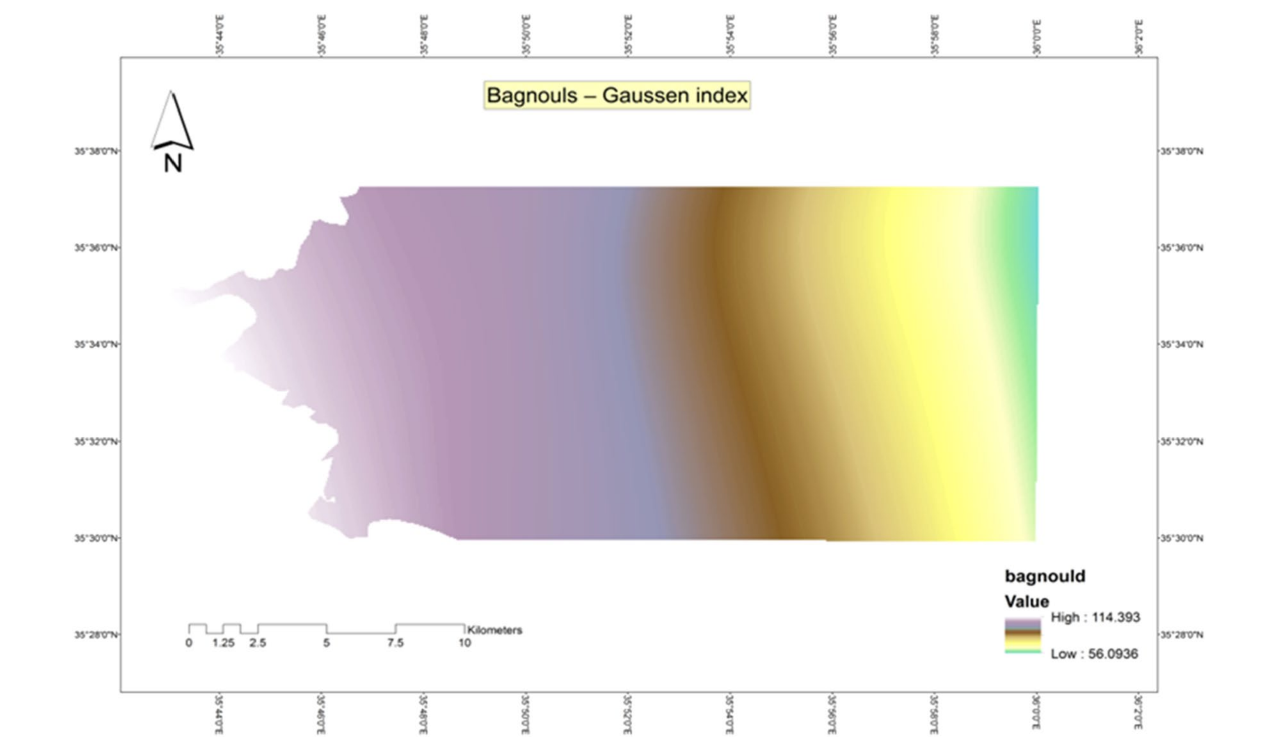

Fig. 6 BGI map

Table 2 The general features of each soil sub-group

Land unit	Soil sub-t group	Area (%)	Elevation (m)	Slope (%)	Stoniness (%)	Land use type
clp	*Typic Calcixerepts*	15.8	0–50	5	15	Citrus Olive
val	*Typic xerofluvents*	20.01	25–50	5–8	8–12	Citrus Olive
gslo	*Typic Calcixerepts*	27.27	25–150	8–15	15	Olive Cereal
mslo	*Typic xerorthents*	15.58	75–225	15–30	15–30	Olive Forest
sslo	*Lithic xerorthents*	4.6	75–200	> 30	35	Olive Forest
slp	*Calcic Haploxerepts*	7.9	75–275	8–15	5–15	Olive Citrus

percentage of clay content. The findings of the pH test indicate that the soil of the study area can be considered as mildly alkaline (the pH ranges between 7.9 and 8.5). The EC value of soil was less than 0.4 μS·cm^{-1} with low content of organic matter (0.8–1%) and high content of $CaCO_3$.

PSER

The soil erodibility reflects the soil resistance to erosion factors such as raindrops forces and runoff [20]. Thus, the soil erodibility measurement is very important for studies on soil erosion and land use planning. The findings indicate that almost 56% of the study area contained a good amount of clay content (i.e., C, CS, SiC) which suggest high resistance to soil water erosion due to the stability of soil aggregates. While only 15% of the study area was under high erosion risk hazard due to high loamy content (i.e., L, Sil, Si, SL). To sum that, 56% of the study area is in class 1, according to texture classification, while 62% is in class 1, according to depth classification; and 58% of the

Table 3 The physical and chemical properties of each soil sub-group

Land unit	Ec dS/m	pH	CEC cmol/kg	CaCO3%	OM %	Clay %	Silt %	Texture
clp	0.36	8.2	38.5	35.70	1.130	43.93	29.75	Clay
val	0.703	7.82	25.15	43.30	0.907	36.90	23.90	Clay loam
gslo	0.57	8.12	36.28	50.53	1.075	34.15	29.69	Clay loam
mslo	0.47	8.4	32.89	47.15	0.880	50.39	30.11	Clay
sslo	0.37	7.79	34.49	62.80	0.990	43.96	42.49	Silty clay
slp	0.35	8.29	38.79	48.60	0.800	38.52	34.52	Clay loam

Table 4 Distribution of soil erodibility factors

Soil texture			Soil depth			Stoniness		
	Class	%		Class	%		Class	%
1	C, CS, SiC	55.74	1	75	61.8	1	> 10%	42.5
2	SCL, CL, S, LS, SiCL	29.6	2	75–25	32.5	2	< 10%	57.5
3	L, Sil, Si, SL	14.66	3	25	5.7			

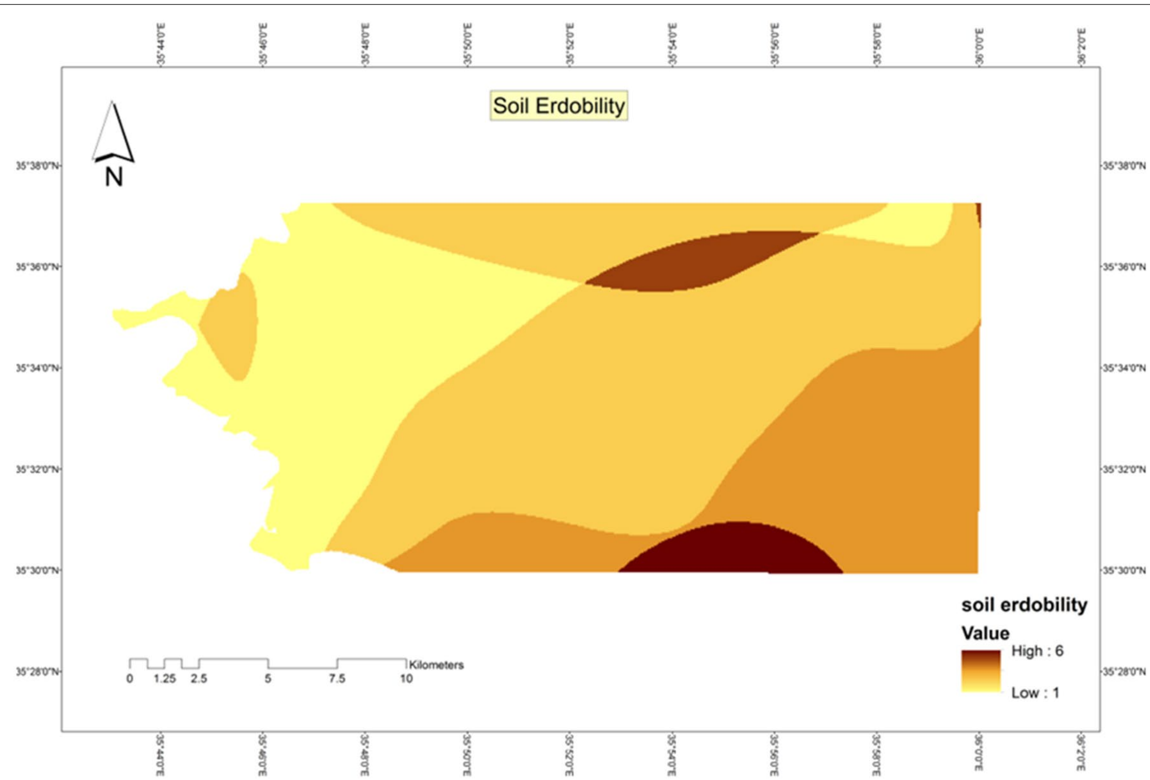

Fig. 7 Soil erodibility index

study sites have stoniness with less than 10% (Table 4). The final map of erodibility is shown in Fig. 7.

Figure 8 shows the distribution of erosivity index in the study area. The majority of the study area was under class 3 (more than 8), indicating the impact of rainfall in the study area. Particularly the erosivity index tends to be stronger (blue area) toward the eastern part, which can be explained by the effect of topography (mountain).

Undoubtedly, the slope plays a vital role in soil erosion [27]. Higher the slope represents higher the chances of soil erosion (under the same land cover) [93]. Figure 9 and Table 5 show that only 30% of the study area has slope more than 15%, which could be easily enhanced runoff and increased the probability of soil water erosion occurrences. Nevertheless, the higher slope (red color of Fig. 9) area is located in the northern and eastern part of the study area which could be considered as a potential location subjected to erosion unless there was a good land cover, as revealed from Fig. 9. The PSER was prepared by integrating mentioned data layers and the generated PSER was used as a key input for ASRR modeling.

ASRR

Generally, the study area has been characterized by the mixed agroecosystem indicates the combination of different land use such as agricultural activities and forestry. Thus, high erosion rate is expected from cultivated areas, while forest areas have good protection for soil. The NDVI map showed the intensity of vegetation cover of the study area, which ranges from -0.13 to 0.38 (Fig. 10). The findings of vegetation cover reported that 70% of the study area was classified as fully protected (i.e., forest); while 30% was not protected which could be an agricultural land or burned forest (Table 5).

In the ultimate stage, the ASRR model was generated by overlaying the LULC map and PSER map (Fig. 11). However, the result of ASRR model reported that 57% of the total study area is under the moderate and high erosion risk zones, whereas, 43% of the study area is under the low erosion risk zone.

Discussion

Output of CORINE model in the coastal area of Syrian Arab Republic

This study attempted to utilize the CORINE model in the coastal region of Syrian Arab Republic, which is considered as a promising tool for future conservation plans, as the decision-makers were able to identify the vulnerable area to soil water erosion by adopting such approach.

Strictly speaking, Fig. 11 demonstrates that the eastern and northern part of the study area were under the moderately and highly prone to soil erosion risk

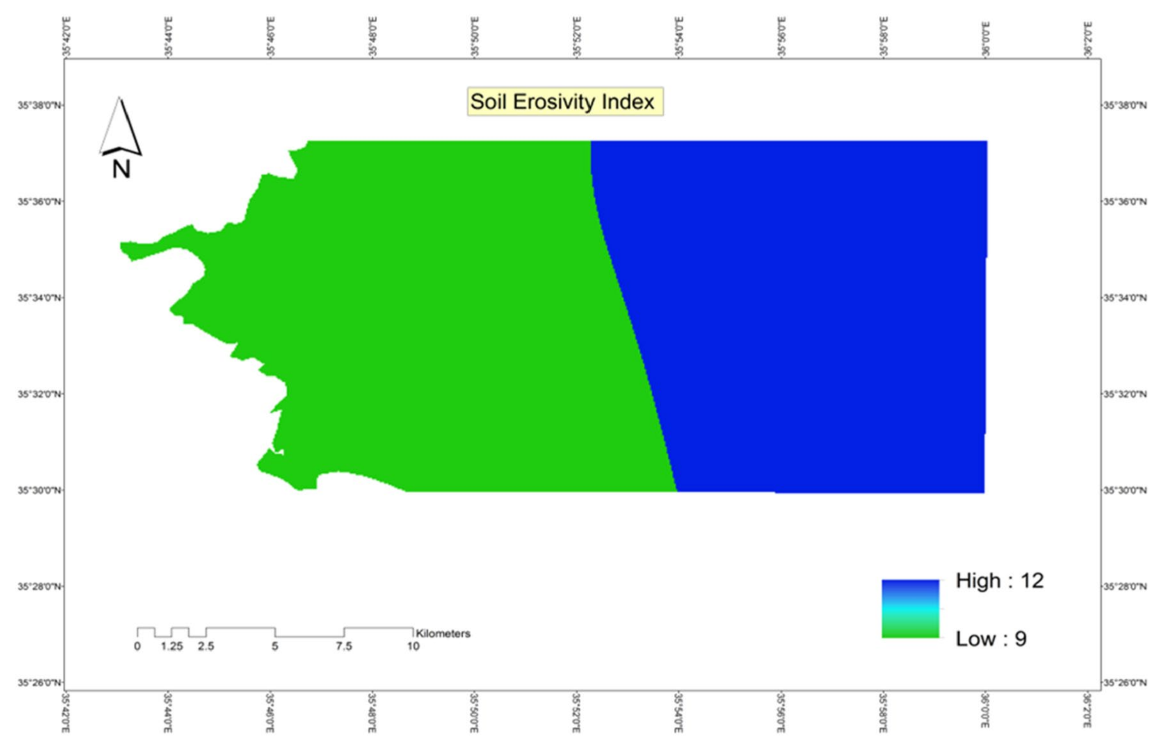

Fig. 8 Erosivity index map

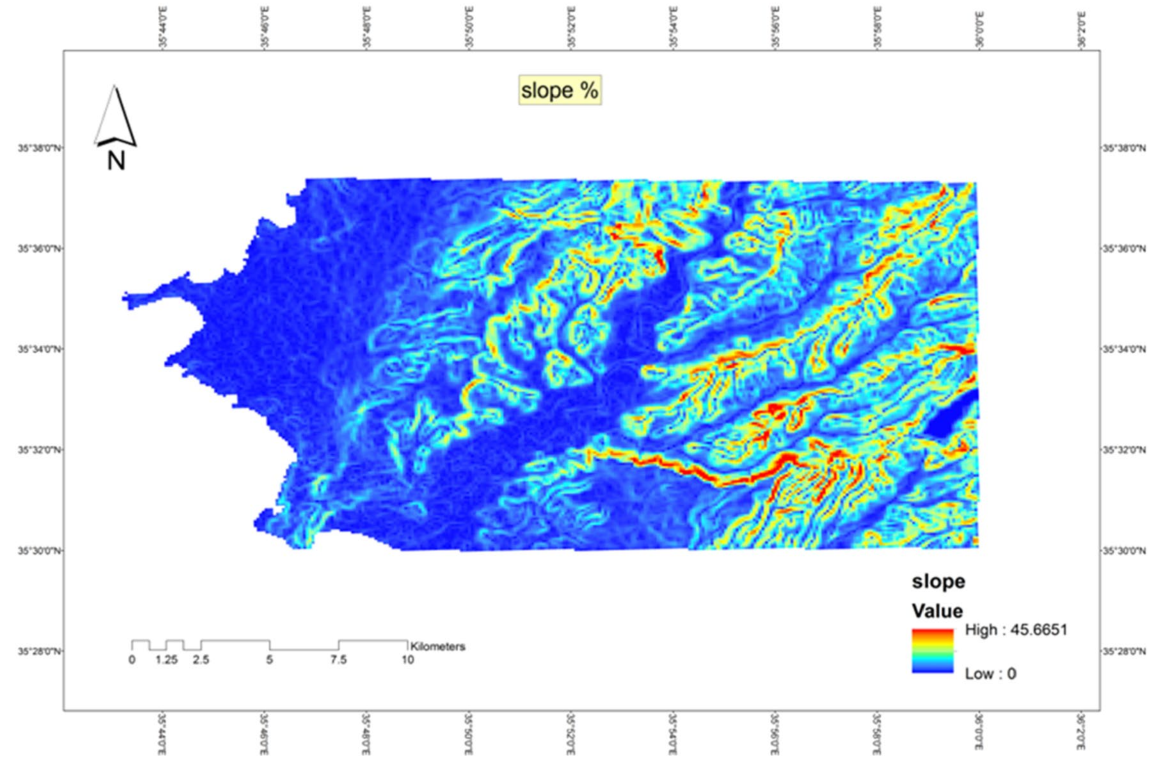

Fig. 9 Slope map

Table 5 Spatial distribution of slope, land cover, and actual erosion risk

Slope			Land cover			Actual erosion risk		
	Class	%		Class	%	Class	Area km^2	%
1	< 5	15.8	1	F	69.4	low	130.8	45.24
2	5–15	55.1	2	nF	30.6	moderate	142.1	49.15
3	15- 30	24.42				high	15.3	5.29
4	> 30	4.6						

(red and purple area) zones; while the erosion was less pronounced in the northwest part (green area) of the study area. Hence, soil erodibility (Fig. 7) and ASER (Fig. 11) reveal that the area having high erodibility value (brown area in Fig. 7) was the main distinguished area with high susceptibility to erosion hazard (purple area in Fig. 11). Except the high erosion-prone area, the erosion hazard was the final outcome of interaction between rainfall erosivity, sharp slope, and land cover. However, the areas, where the traditional agricultural activities have been highly dominated, were highly susceptible to soil erosion as can be found in vegetation map of the study area (Fig. 10) and field observation.

On the other hand, only 13.6% of the study area was classified as high erodible, while the rest of the study area was under moderate or low erodible. Such kind of result can be produced because of the presence of high content of clay and bounded with OM (%), resulting in the stable soil aggregates against raindrops and runoff. However, the land cover and slope are the most dominating factors which are responsible for making the study area as the highly soil erosion zone. Furthermore, the present study showed that the findings are identical with the work of Abdo and Salloum [4, 5, 16] and Barkat [16] who studied the erosion in the coastal region of Syrian Arab Republic and stressed the important role of topography

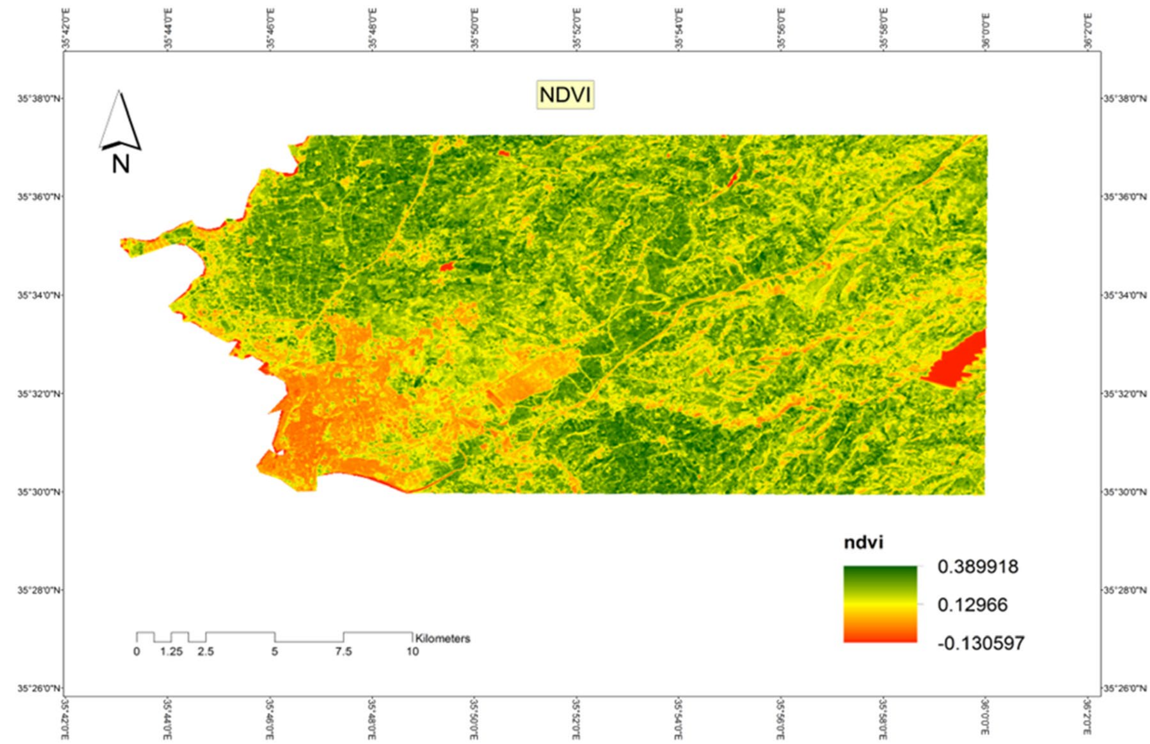

Fig. 10 Vegetation cover map

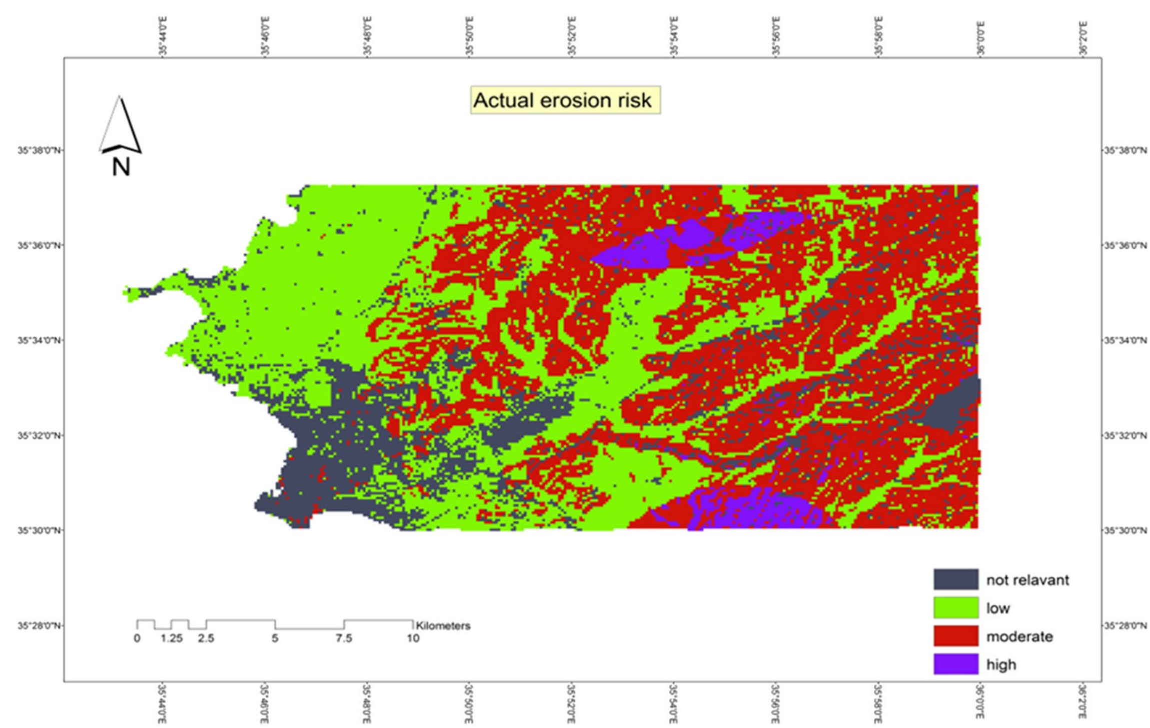

Fig. 11 Actual soil erosion risk map

in soil erosion. Similarly, Hussien [45] and Mohammed et al. [57, 58, 62] highlighted on how land use land cover affects soil erosion in Syrian Arab Republic, especially in coastal part.

The fundamental difference between PSER and ASRR models is that the ASRR model evaluate the impact of LULC on soil erosion. Thus, the erosion risk is always higher in PSER maps [104]. Within this context, this study was conducted before the massive wildfires that happened in summer 2019 in the coastal region of Syrian Arab Republic. Therefore, the results of the present study (i.e., ASRR) were subjected to be changed due to the drastic change of LULC. Interestingly, the PSER map could serve as the database for proposing rehabilitation plan in the study area.

Limitations and strengths of CORINE approach in the coastal area of Syrian Arab Republic

The limitation of the present study is the nonexistence of any kinds of quantitative studies that measure soil erosion. Thus, the reliability of CORINE model in the coastal area is still questionable. Even though, most of the input files were trustworthy, as they were obtained from international data set (i.e., DEM, Landsat-8 image). Some of the parameters were directly collected from the field (soil depth, stoniness) and others were generated in soil laboratory (soil texture). However, the validation of the prepared model is mandatory, otherwise, they will not be reliable any more. Yet, only WEPP model was calibrated and validated [63, 64], while the rest of the models which were applied in Syrian Arab Republic such as RUSLE [4, 5, 61], and CORINE model [16] were never validated. Nevertheless, one of the advantages of CORINE approach is the availability of data for the majority of the indices. However, CORINE model could be a promising tool for managing future land degradation by highlighting the most vulnerable area to soil erosion (at least in the Syrian Arab Republic).

The accelerated soil erosion in a developing country like Syria will threaten food security in the long term, especially in the coastal region. Although the coastal area of Syria is considered as a first agroecosystem area, the intensive soil erosion requires integrated management, which guarantees the improvement of rural livelihoods in particular. Meanwhile, the increasing demand for food in the coastal region, with more than 20% of the Syrian population, constitutes an additional factor on food security in light of the danger of severe erosion, climate change and the current living and economic consequences caused by the ongoing war. Following agricultural rotations, promoting environmental agriculture, landscape management, establishing terraces, establishing and implementing the agricultural policies and adopting modern cultivation methods, creating a long-term, high-quality climate and soil databases are among the most important measures for managing the soil erosion risks in the coastal region of Syria. In this regard, Mohammed et al. [62] reported that planting the slopes of the coastal area with leguminous crops reduce runoff flows and erosion rates. However, the integration between geospatial techniques and experimental models provides a constructive platform with effective spatial results in identifying areas with higher levels of erosion, hence starting to implement maintenance and protection measures, thus enhancing food security in the area.

Concluding remarks

The present work was mainly focused on predicting soil water erosion zone using CORINE approach by integrating field survey and remote sensing data in the western part of Syrian Arab Republic. The key findings of this study can be summarized, as follows:

- Almost 45% of the study area was under tolerant erosion rate.
- More than 55% of the study area was under moderate and high actual erosion risk, where the urgent conservation plans should be implemented to minimize the predicted high soil erosion zone.
- The conservation plan should be taken by the local authority in collaboration with local farmers to eliminate or minimize the soil erosion, which will have an ultimate good impact on both environment and local communities.

The CORINE approach is a good tool for predicting and highlighting the most widely erosion-affected areas, as well as saving time and money. On the other hand, the accuracy of any model is an essential issue for readability and reliability of results.

Acknowledgements
Authors would like to thank General Commission for Scientific Agricultural Research (GCSAR) (Syria), and Debrecen University (Hungary) for their unlimited support.

Authors' contributions
Writing original draft: SM. Mapping: AK. Review writing: HA, EH, ST. All authors read and approved the final manuscript.

Funding
Open Access funding provided by University of Debrecen.

Availability of data and materials
Available upon request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
Not applicable.

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Received: 10 November 2020 Accepted: 16 February 2021
Published online: 28 July 2021

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