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RESEARCH PAPER

Estimating water erosion using RUSLE, GIS and remote sensing in Wadi-Qandeel river basin, Lattakia, Syria

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Abstract

Soil erosion is the major prominent ecological risk threatening agricultural sustainability in the coastal region of western Syria. The ongoing war conditions in Syria has led to a lack of field data and measurements related to the spatial evolution of soil loss. Estimating the spatial distribution of potential soil loss is a fundamental procedure in applying the soil conservations measures within the river catchments. The current paper goals to conduct a comprehensive assessment of soil loss risk utilizing revised universal soil loss equation (RUSLE) and remote sensing (RS) data in geographic information system (GIS) environment across the entire Wadi-Qandeel river basin. Results indicate that the annual rate of soil loss in the study area was 93.02 t ha^{-1} ya^{-1} with a spatial average reaching 58.22 t ha^{-1} ya^{-1}. Additionally, the soil loss risk map was generated with classification into five susceptible zones: very low (56.44%), low (24.69%), moderate (20.80%), high (2.98%), and very high (2.22%). The present assessment showed a reliable approach to soil erosion rates and categorization of erosion-sensitive zones within the study area. These outcomes can be relied upon to create mitigation procedures for maintaining zones with high and very high soil loss susceptibility under the ongoing war conditions in Syria.

Keywords Soil loss · RUSLE · GIS · RS · Conservation · Syria

Introduction

Soil is an essential and pivotal non-renewable resource that presents a broad group of environmental services and goods, especially for human sustainability (Ferrara et al. 2015; Pal 2016; Brevik et al. 2017; Testi et al. 2010; Riccardi et al. 2020; Abd El-Ghani et al. 2012; Hateffard et al. 2021). However, a growing body of literature has indicated that soil loss is responsible for about 85% of the degradation of the global agro-ecosystems, and therefore a reduction in nourishment productivity by 17% (Wijesundara et al. 2018; Nyesheja et al. 2019; Bahir et al. 2021; Mountassir et al. 2021a, b). Soil erosion by water (SEW) is one of the most severe environmental problems affecting life sustainability and welfare worldwide (Zika and Erb 2009). SEW is dynamically generated as a result of spatial integration between physical and human factors, produced a total reduction in the quality of soil health and water resources, therefore a decrease in ecosystem quality and productivity (García-Ruiz 2010; Göl 2017; Cutini et al. 2015; Balasubramani et al. 2015; Mokhtar et al. 2021; Tang et al. 2015; El Mountassir et al. 2021a, b).

In this regard, Syrian soils are characterized by high susceptibility of water soil erosion risk due to lithology, high rainfall intensities, rough relief, topsoil fertility, degraded vegetation, edaphic, and accelerated human activity, especially in the coastal region of Syria (Mohammed et al. 2020a; Abdo 2021). Further, about 18% of the agricultural land in Syria is prone to soil loss hazard that exceeds 100 t ha^{-1} $year^{-1}$ in many western mountainous areas (ACSAD 2007; Husein and Kalkha 2019; Abdo 2019). Particularly, SEW in Wadi-Qandeel river basin is the basic environmental hazard that threatens farming, feeding, and secure sustainability. The intensive pattern of rainfall, high runoff peaks, flood, rugged terrain, steep slopes, shallow soil profiles, and sparse vegetation are the major physical criteria that motivate the water erosion in Wadi-Qandeel river basin. At the same time, SEW can be accelerated by the growth of

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anthropogenic activities such as deforestation, overgrazing, urbanization, landuse/landcover change (LULC), intensive cultivation on steep slopes, excessive soil plowing, land abandonment, poor maintenance procedures, military infrastructure, and armed conflicts (Emadodin and Bork 2012; Jafari and Bakhshandehmehr 2016; Nabiollahi et al. 2017; Abdo 2018; Mohammed et al. 2021).

The matter of SEW simulating was the pivot of many spatial evaluations in the coastal area of Syria. Barakat et al. (2014) and Husein and Kalkha (2019) utilized the Coordination of Information on the Environment (CORINE) approach to map the risk of SWE across many coastal watersheds. Mohammed et al. (2016) predicted SEW by utilizing the Water Erosion Prediction Project (WEPP) model for Lattakia governorate. The Revised Universal Soil Loss Equation (RUSLE) method was applied in the GIS environment to evaluate the SEW in many basins in Syrian coastal region (Abdo and Salloum 2017a, b; Almohamad 2020).

Assessing the annual spatial distribution of SEW rates is an urgent need for maintaining soil and water resources at the basins scales. However, utilizing the experimental methods is the most global manners of SEW modeling, particularly in regions with limited information and data. In other words, the integration of remote sensing (RS) data, geographic information system (GIS) environment and RUSLE model is a useful, reliable and accurate method in producing the spatial distribution of SEW map. For the prior matter discussed, the current research will explore the quantities and spatial distribution of SEW in Wadi-Qandeel river basin by using the RS data in calculating RUSLE factors in GIS software, therefore suggesting constructive spatial preservation strategies with suitable applications.

Materials and methods

Study area

Wadi-Qandeel watershed is one of the coastal river watersheds in Lattakia governorate in the west of Syria (Fig. 1). The study basin covers about 152.23 km^2, and the highest elevation of 809 m above mean sea level (m a.m.s.l.) (elevation range of 0–809 m a.m.s.l.). This basin bordered Al-Kabeer alshamali river basin to the east, the Mediterranean

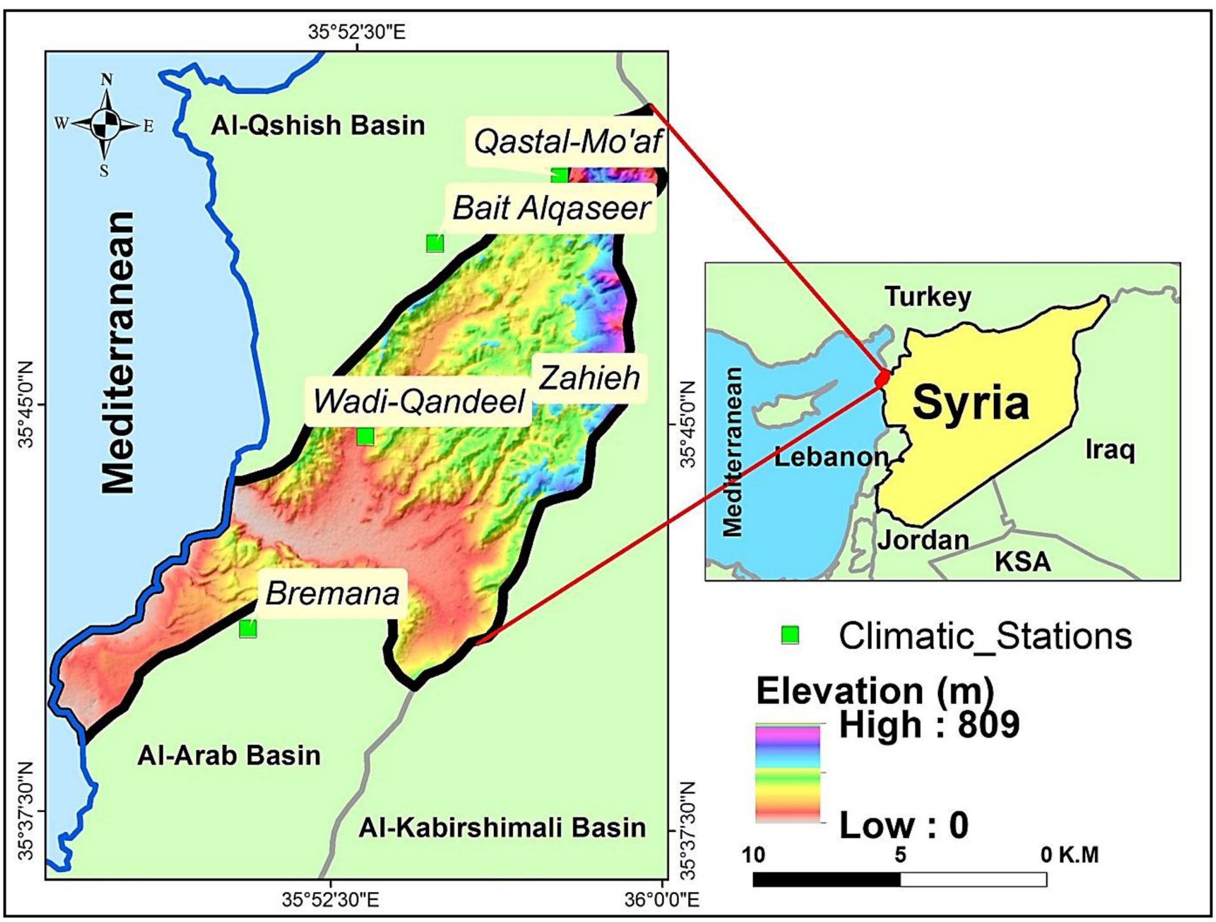

Fig. 1 Site of Wadi-Qandeel river basin

to the west, Al-arab river basin to the south, Al-Qshish river basin to the north. The study area includes various geological formations, starting from the Cretaceous to the Quaternary. Cretaceous formations composed of Albian, Lower Cenomanian, and Upper Cenomanian with lithological structures of limestone, dolomite, marls, ophiolites, limy marl, and sandy limestone. The basin mainly subjects to the Mediterranean climate pattern: mild and rainy winter and long, dry, and hot summer (Khallouf et al. 2021). The average annual precipitation in the catchment varies from 847 to 1301 mm (Fig. 2), and most rainfall is concentrated in the winter months (68%). Further, the annual mean in summer temperature is 26° and in winter 15°. The warmest month is August (28.6°) and the coldest is January (13.8°). High relative humidity prevails throughout the year due to the effects of the Mediterranean water mass. The annual average of humidity is 72%. Study area is characterized by the density of the streams network, mainly reflecting the spatial integration between geological, tectonic and climatic characteristics. Wadi-Qandeel drainage network originates at Ballouran village in the Al-shrashir area at an altitude of 802 m above sea level, and flows westward down to its concentration point with the Mediterranean (Abdo 2020). Agriculture and tourism are the basic economic activities of the population. Olives, citrus and agricultural crops are among the most important crops in the basin.

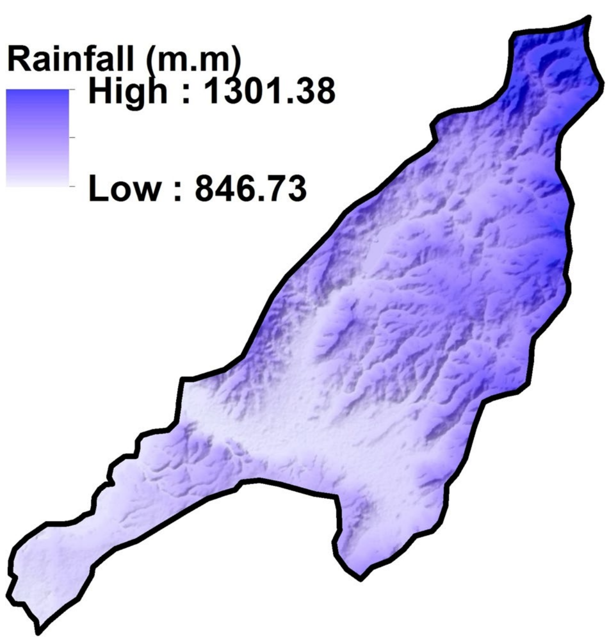

Fig. 2 Spatial distribution of rainfall values

RUSLE model parameters

The universal equation of soil loss RUSLE (Wischmeier and Smith 1978; Renard et al. 1997) has been commonly used to evaluate the spatial dimension of soil erosion rates in order to generate the conservation goals, with a reasonable scale of validity (Balasubramani et al. 2015; Djoukbala et al. 2019). RUSLE is a well-established soil erosion empirical model and most of its parameters have undergone profound modifications since its introduction. RUSLE composes of five geo-parameters that represent the following inputs: rainfall erosivity (*R*), soil susceptibility to erosion based on its physical–chemical properties (*K*), terrain (*LS*), vegetation(*C*), and maintenance (*P*), respectively. Meanwhile, RUSLE model has been applied in areas with different cases worldwide generally and in the Mediterranean basin environment particularly: Kefi et al. (2012), in Tunisia; Demirci and Karaburun (2012), in Turkey; Chadli (2016), in Morocco; Fagnano et al. (2012), in Italy; in Algeria; Benkadja et al. (2015), in Algeria, etc. The average annual soil erosion per unit area is given by the following equation (Eq. 1) of RUSLE (Wischmeier and Smith 1978):

$$A = R \times K \times LS \times C \times P, \quad (1)$$

where A is the average annual soil erosion (t ha^{-1} year^{-1}), R is the rainfall erosivity, K is the soil erodibility, LS is the hill slope length and steepness, C is the vegetation factor, and P is the support practice. In order to standardize pixel resolution DEM and Landsat imageries resolution, all inputs and outputs for the calculation of erosion risks is in 30-pixel resolution for each sub-factors of RUSLE model. In this regard, RUSLE model was used to estimate SEW as a result of achieving accurate and reliable spatial outcomes for the river basins in the eastern Mediterranean region, the flexibility of its application in areas with limited data, and the possibility of relying on its outputs in formulating strategies for water and soil resources mitigation and conservation measures.

Rainfall erosivity factor (R)

The rainfall erosivity (R) factor considers the influence of rainfall kinetic energy and generated runoff on the erosion (Wischmeier and Smith 1978; Demirci and Karaburun 2012; Salloum and Abdo 2015; Djoukbala et al. 2018; Abdo and Hassan 2018). R factor, moreover, is importantly affected by the patterns, spatial–temporal distribution, intensities, momentums, and kinetic energy, raindrops size (Farhan et al. 2013; Carollo et al. 2018; Serio et al. 2019). According to available monthly rainfall data

(1989–2019) of five climatic stations established in and around the study basin the map of R value was prepared by using Eq. (2) developed by Wischmeier and Smith (1978):

$$R = \sum_{1}^{12} 1.735 \times 10^{\left(1.5\log_{10}\left(\frac{Pi}{P}\right)-0.08188\right)}, \quad (2)$$

where R is a rainfall erositivity factor (MJ mm ha^{-1} h^{-1} per year); P_i is monthly rainfall (mm); P is an annual rainfall (mm). Figure 3 illustrates the spatial distribution of precipitation erosivity. On value, R factor values ranged from 621.78 to 1234.55 MJ mm ha^{-1} h^{-1} year^{-1}.

Soil erodibility factor (K)

K factor describes the strong linking of topsoil particles against the rainstorms events, which is commonly acquired by evaluating the physical–chemical topsoil properties of a specific plot (Wischmeier et al. 1971; Das et al. 2018; Saïdi et al. 2014). K factor is an assessment of the susceptibility of topsoil to detachment and transport by rainfall and runoff. It reflects the soil erosion rate caused by rainfall erosivity factor (R) in each point of the study area (Koirala et al. 2019). In the present assessment, soil features were evaluated based on the analysis of soil samples conducted by the National Center for Agricultural Research in Al-Hanadi region. K factor map was delineated by utilizing the following equation presented by Wischmeier and Smith (1978), Renard et al. (1997) and Panagopoulos and Ferreira (2010):

$$K = \frac{2.1 \times 10^{-4}(12 - OM) \times M^{1.14} + 3.25(s - 2) + 2.5(p - 3)}{100} \quad (3)$$

where OM is the organic matter (%), s is soil structure class, p is permeability class, and M is aggregated variable derived from the granular soil texture: $M = (\%\text{Msilt}) \times (\%\text{silt} + \%\text{sand})$, and the modified silt (Msilt) is a percentage of grain size between 0.002 and 0.1 mm. Figure 4 indicates the spatial distribution of the K values, which ranged from 0.021 to 0.032 ton ha MJ^{-1} mm^{-1}.

Slope length and steepness factor (LS)

Slope Length and Steepness Factors (LS) approach the impact of the relief on the acceleration of soil erosion (Lu et al. 2004). LS factor was generated from two sub-factors: a slope degree parameter (S) and a slope–length parameter (L); which are extracted from the Digital Elevation Model (DEM) (Hickey 2000; Boggs et al. 2001). In this context, the LS factor is the most essential causative parameter of overland flow that considers the major reason to soil loss. The relation of soil erosion to slope degrees of hill and mountains area is influenced by the flora density and soil properties (Koirala et al. 2019). The terrain of the study basin is featured by steep slopes which reach more than 45 degrees, as Fig. 5 shows. By using the digital elevation model (DEM) with 30 m resolution (ASTER GDEM Validation Team 2009) LS factor map was created according to Eq. (4)

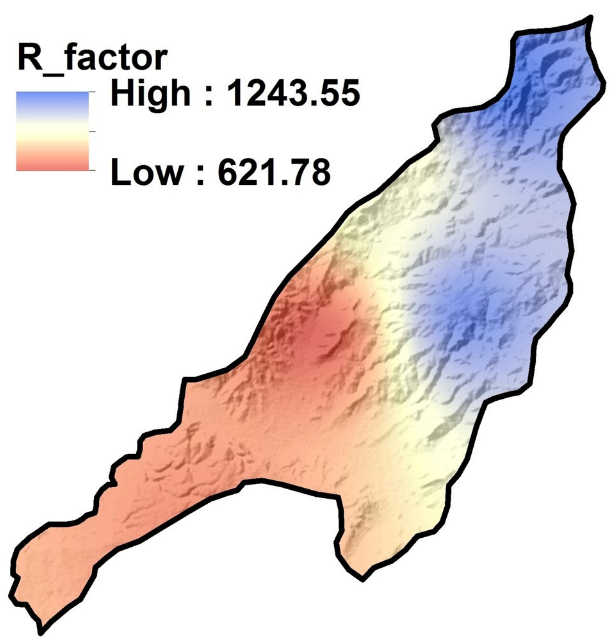

Fig. 3 Spatial distribution of R factor values

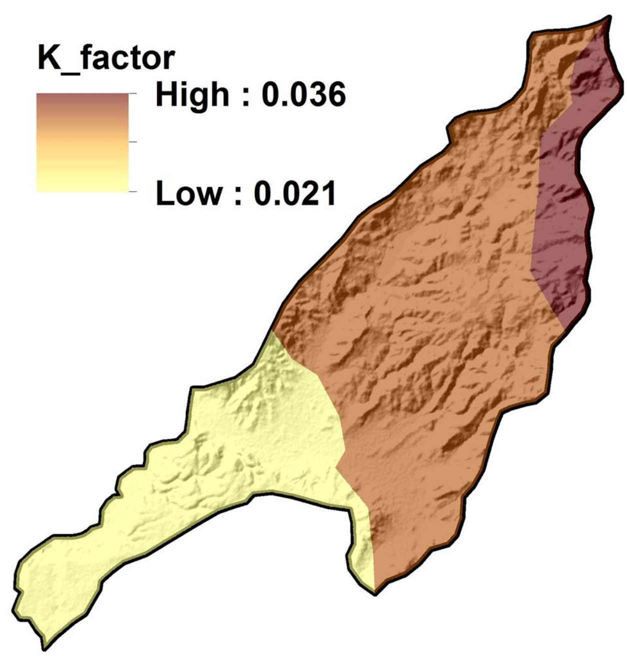

Fig. 4 Spatial distribution of K factor values

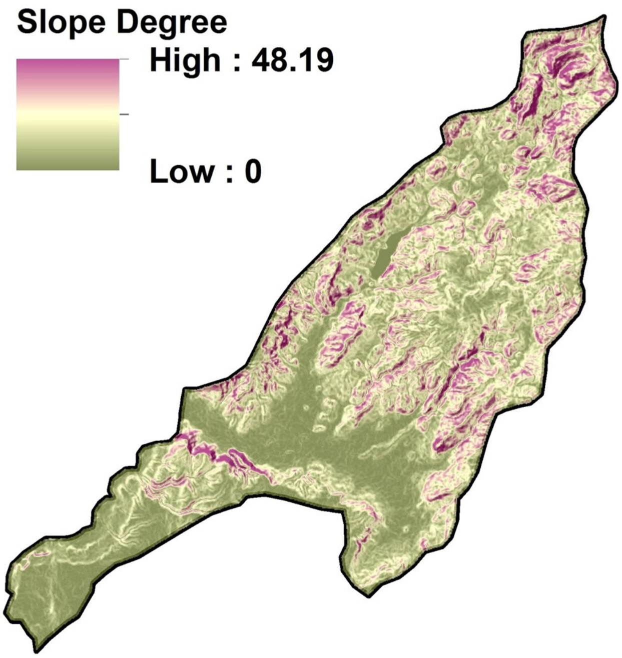

Fig. 5 Spatial distribution of slope values

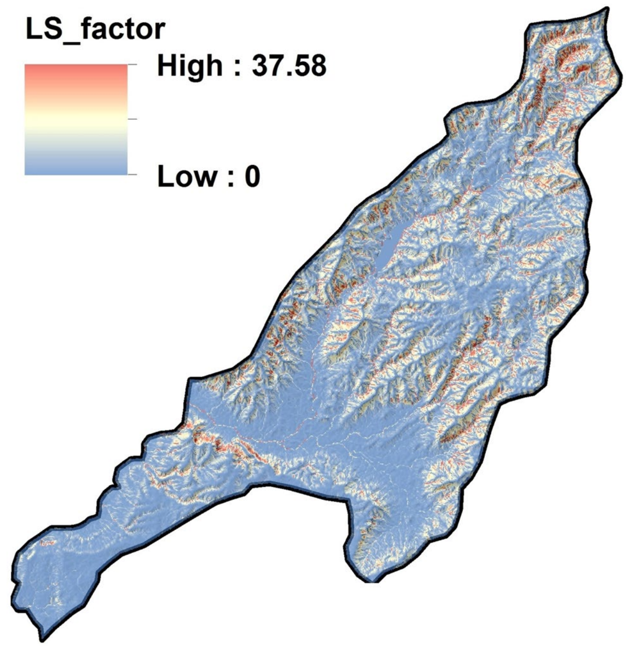

Fig. 6 Spatial distribution of *LS* factor values

$$LS = (FlowAccumulation \times \frac{CellSize}{22.13})^{0.5} \times (\frac{sinslope}{0.0896})^{1.3} \quad (4)$$

where FlowAccumulation is the grid layer of flow accumulation expressed as the number of grid cells, and CellSize is the length of a cell side. *LS* values of the study area are in the range of 0–37.58 as illustrated Fig. 6.

Vegetation factor (C)

Vegetation cover is a complex criterion in soil loss control, because of dissipating the kinetic energy of raindrops, delaying the surface runoff, and enhancing the infiltration capacity (Hu et al. 2015; Salloum and Abdo 2016; Sujatha and Sridhar 2018; Acar et al. 2014). In this context, *C* factor reflects the vegetation condition that can be rapidly varied than other RUSLE parameters (Beskow et al. 2009). Landuse/landcover and Normal Difference Vegetation Index (NDVI) are two methods that soil erosion modelling scholars use in calculating *C* values. In the current assessment, the *C* factor values were calculated using the NDVI index which is given by Eq. 5

$$\text{NDVI} = (\text{NIR} - \text{RED})/(\text{NIR} + \text{RED}) \quad (5)$$

where NIR is the near-infrared band (band 4, 0.76–0.90 µm), and RED is the red band (band 3, 0.63–0.69 µm). Landsat 8 OLI image taken in March 2020 was considered in calculating NDVI values which ranged between − 0.3 and 0.83

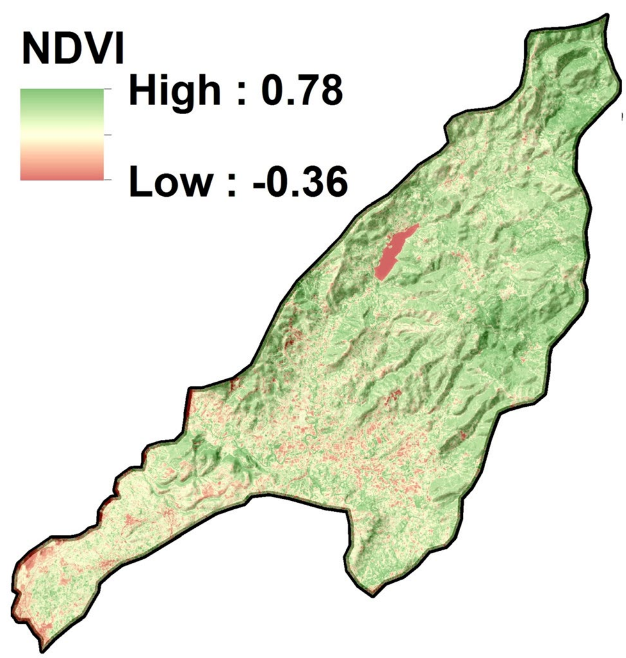

Fig. 7 Spatial distribution of NDVI values

(Fig. 7). The values of *C* factor was calculated using the Eq. 6

$$C_{\text{factor}} = exp\left[-\alpha\frac{NDVI}{(\beta - NDVI)}\right] \quad (6)$$

where α and β parameters determine the shape of the NDVI curve. Reasonable results are produced using values of $\alpha = 2$ and $\beta = 1$. *C* factor values ranged between 0.02 and 1 (Fig. 8).

Conservation support practice factor (P)

Maintenance practice factor (*P*) is the ratio of soil loss after a selective support exercise to the corresponding soil loss after up and down farming (Samanta et al 2016). However, P factor basically influences soil erosion by modifying the streaming pattern, degree or orientation of overland flow, and by decreasing the runoff potentials (Ozsoy and Aksoy 2015). For cultivated land, the conservation practices included contouring, terracing, strip cropping, and subsurface drainage (Renard et al. 1997). *P* factor values range from 0 to 1, the value 0 suggests good conservation support practices and the value 1 suggests poor conservation support practices (Wischmeier and Smith 1978; Das et al. 2018). Field monitoring indicates the loss of prevention support procedures in the study area. Consequently, *P* factor value for the entire study basin is 1 as proposed by Wischmeier and Smith (1978).

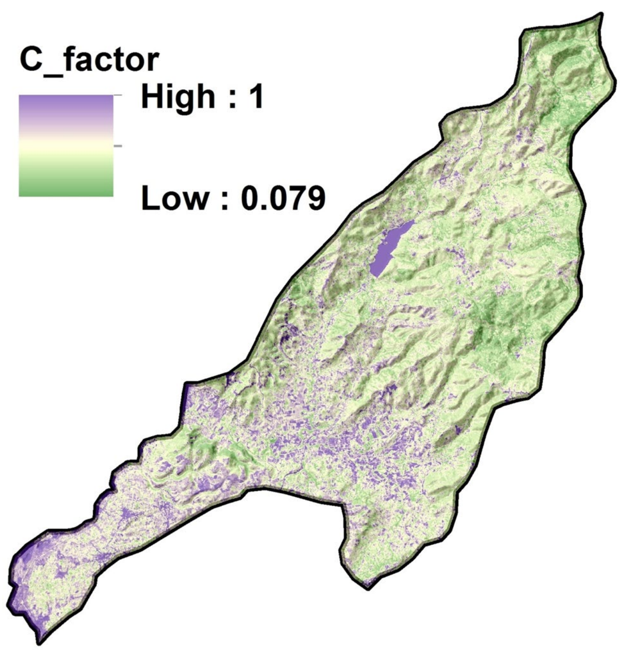

Fig. 8 Spatial distribution of *C* factor values

Result and discussion

Based on the initial information and data entered into the GIS software (ArcGIS 10.2.3), four thematic raster maps were precisely generated representing the spatial factors of RUSLE. *R*, *K*, *LS*, and *C* raster parameters were spatially multiplied in order to map the spatial distribution of potential soil loss per hectare per year at cell level as Fig. 9 illustrates. In the context of current results, the annual rate of soil loss in the study area ranged from 0 to 93.02 ton ha^{-1} $year^{-1}$, with a spatial average reached 58.22 ton ha^{-1} $year^{-1}$. Utilizing the *Natural Breaks* method, the output soil erosion map was classified into five risk classes: very low (56.44%), low (24.69%), moderate (20.80%), high (2.98%), and very high (2.22%) as Table 1 shows.

The finding soil loss rate is spatially consistent with the assessments provided by scholars in river basins

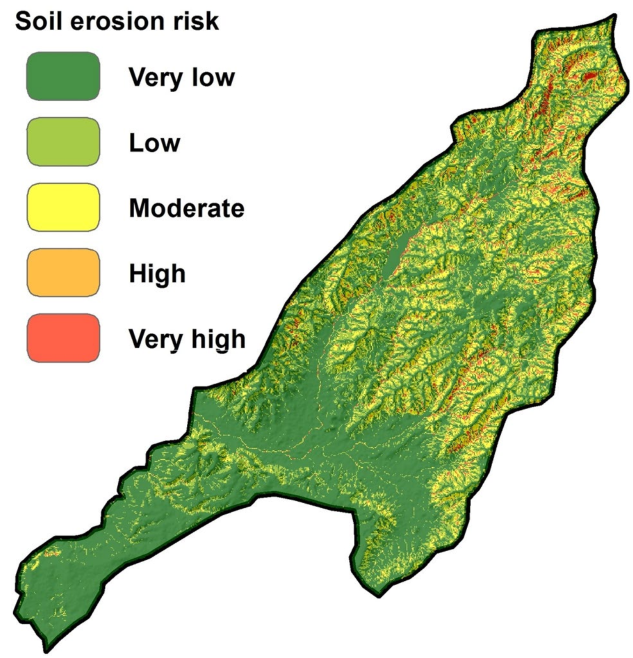

Fig. 9 Spatial distribution of soil erosion values in Wadi-Qandeel river basin

Table 1 Classification of soil erosion in study basin

Soil erosion classes	Rate of soil loss class in ton ha^{-1} $year^{-1}$	Area (km^2)	%
Very low	< 10	85.92	56.44
Low	10–20	37.58	24.69
Moderate	20–30	20.80	13.66
High	30–40	4.54	2.98
Very high	40–93.02	3.38	2.22

environment in the eastern Mediterranean as Table. 2 illustrates. In addition, the outputs of prior literature give the resulting soil erosion rate sufficient validity to be utilized in suggesting practices for spatial conservation of areas with boundaries and critical soil erosion. Meanwhile, Nearing et al. (1990), Irvem et al. (2007), Trabucchi et al. (2012), and Farhan and Nawaiseh (2015) suggested that 2 to 12 ton ha^{-1} $year^{-1}$ is the acceptable soil loss tolerances limits for the aims of agricultural and economic sustainability in the Mediterranean environment. Further, Ibrahiem (1986) and Kbibo and Nesafi (1997) reported that the tolerable limit of soil loss ranged between 1 to 2.5 t h^{-1} $year^{-1}$ for the coastal region of Syria, owing to the many geo-factors that influences the soil formation. Therefore, in light of these limits, it can be confirmed that most of the study basin lands need integrated spatial management of soil loss.

The spatial distributions of high and very high soil loss hazards are mostly concentrated in the northeast and central regions slopes of the study area. Further, these zones are susceptible to the high risk of soil loss as a result of the spatial integration between the kinetic energy of rainfall intensities, runoff and steep slopes. The field checking disclosed that classes with high and very high values of soil erosion are sloping lands. Importantly, vegetation did not reduce the soil loss quantities in those areas as generated erosion map indicated. This result can be demonstrated by the great spatial competition between slope and vegetation factors in favour of the slope factor. Meanwhile, the slope degrees in these areas reaches more than 45 degrees as Fig. 5 shown. These findings are consistent with many studies that have pointed out the influence of slopes on topsoil mobilization (Thomas et al. 2018; Kayet et al. 2018). Therefore, it can be reported that the slope is a pivotal factor in the acceleration of soil loss in the study area.

The current outputs, that targeted the spatial susceptibility of soil loss in the study area, are spatial predictions, and thereby are still questionable. Meanwhile, the absence of adequate data, information and field measurements across the basin due to different affecting reasons, particularly the consequences of the ongoing war, a RUSLE model presented constructive statistical-spatial estimates of potential soil loss risk. These delineated estimates can be useful for decision-makers in generating strategies for maintaining soils and mitigating areas with high and very high sensitivity to erosion. In this context, among the most important measures that can be proposed in the framework of the erosion mitigation process: (1) adjusting the slopes in areas of high and very high sensitivity by building terraces, (2) enhancing wild vegetation coverage, especially in areas with frequent fires and indiscriminate cutting, (3) investigating the root system efficiency (RSE) of agricultural crops for the proportionality and severity of cultivated slope, (4) developing agricultural techniques, especially ploughing process. The RUSLE application could also be expanded at the regional and national levels as part of the spatial management plans for river basins.

Conclusions

Soil loss represents the most geo-ecological problem threats to food security in the coastal region of Syria. In light of the paucity of spatial data related to soil loss, current research presented a reasonable assessment of the spatial distribution of soil erosion severity in one of the coastal river basins most prone to soil erosion. The goal of this study was fulfilled by feeding the GIS environment with multi-source information and data, especially RS data, in the calculation of RUSLE factors. In regard to the present findings, the generated soil erosion map shows a maximum rate of erosion 93.02 t h^{-1} $year^{-1}$. Moreover, the soil erosion amount exceeded the tolerable threshold of soil erosion for the coastal region of Syria (1 to 2.5 t h^{-1} $year^{-1}$). These predictions are closely related to the estimates computed in Syria and the Mediterranean countries using the RUSLE model. Also, it was concluded the high influence of the slope factor in enhancing soil erosion. The spatial integration process between GIS and RS data presented a promising tool for assessing annual

Table 2 Some erosion assessments in different parts of Mediterranean areas using RUSLE model

Location	Study area	Total soil erosion in ton ha^{-1} $year^{-1}$	References
Syria	Southern part of Syria	350	Mohammed et al. (2020b)
Syria	Northern Al-Kabeer river basin	55	Almohamad (2020)
Jordan	Wadi Kerak basin	64	Farhan and Nawaiseh (2015)
Morocco	Tensift basin	44.03	Meliho et al. (2020)
Algeria	Wadi Mina basin	100	Benchettouh et al. (2017)
Tunisia	Lebna basin	150	Gaubi et al. (2017)
Italy	Portofino promontory area	225	Rellini et al. (2019)
Portugal	Foupana basin	99	Panagopoulos and Ferreira (2010)
Turkey	Alaca basin	150	Imamoglu and Dengiz (2017)

rates of soil erosion in the study basin, especially in light of the ongoing war conditions in Syria. Therefore, the results of this study are necessary to manage the risk of soil erosion by taking mitigation and conservation measures. The application of this study's approach at the national level also provides an objective solution for managing areas of the high and very high soil erosion risk, especially in this period which Syria is living the consequences of the ongoing war since 2011.

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Data availability The spatial data used to support the findings of this study are available from the corresponding author upon request.

Declarations

Conflict of interest The author declares that they have no conflict of interest.

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