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Prioritizing of the Sub-Watersheds using the Soil Loss Cost Approach (A Case Study; Selj-Anbar Watershed, Iran)

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ABSTRACT

Aims The present study has used results of the application of Revised Universal Soil Loss Equation (RUSLE) in integrated with the economic cost of soil loss to prioritize sub-watersheds of Selj-Anbar Watershed in Mazandaran Province, northern of Iran.
Materials and Methods Overlay of five input layers of RUSLE model, viz., rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management (C) and support and conservations practices (P) factors has been done in Geographical Information system (GIS) platform for the study watershed. Then, the soil loss and sedimentation cost have assessed using soil nutrient depletion analysis. In this method, monetary value to the depleted nutrients based on the cost of purchasing an equivalent amount of used chemical fertilizer in the watershed was assigned.
Findings The average soil loss and sediment rates of 4.92 and 1.98 t ha-1, respectively was obtained for the study watershed. In addition, the direct and indirect costs caused by soil loss during the five-year period in the Selj-Anbar Watershed were obtained 4.32×105 and 6.40×105 US$ which was totally equal to 10.98×105 US$. The highest (5.59×104 US$) and lowest (1.16×104 US$) annual cost of soil loss was estimated in the sub-watersheds S1-1-1 and S1-1-2, respectively.
Conclusion Spatial distribution of soil loss and erosion cost could provide a basis for comprehensive and sustainable watershed management. The sub-watersheds with high soil erosion and cost rates deserve superior priority for implementation of conservation activities.

Keywords Economic Assessment; Erosion Price; Nutrient Balance; Ranking; Soil Degradation

CITATION LINKS

[1] Length-slope factors for the Revised Universal Soil Loss: ...[2] Spatial modeling of soil erosion risk and ... [3] Interactive impacts of climatic, hydrologic and anthropogenic ... [4] Environmental and economic costs of soil erosion ... [5] Soil loss estimation of S7-2 Catchment of ... [6] GIS based soil erosion estimation using RUSLE ... [7] Guimarães MdeF. Valuation and assessment ... [8] Analysis and assessing effectability of runoff ... [9] Variability of soil erosion intensity due ... [10] Prioritization of sub-watersheds for sustainable ... [11] Assessment of soil erosion hazard and prioritization ... [12] Sub-watershed prioritization based ... [13] Prioritization of sub-watersheds for soil ... [14] Micro-watersheds prioritization for effective soil ... [15] Degree and length of land slope as it affects ... [16] Predicting rainfall-erosion losses from cropland ... [17] Predicting rainfall erosion Losses: A guide ... [18] Predicting soil erosion by water: a guide to conservation ... [19] Investigating application of GIS and RS to estimate ... [20] Spatial estimation of soil erosion in Iran using RUSLE ... [21] Adapting the RUSLE to model soil erosion ... [22] Using monthly precipitation data to estimate ... [23] Analysis of soil loss data from plots ... [24] Environmental cost of soil erosion in Sri ... [25] Estimation of economic impact of Iranian ... [26] Economic cost of soil nutrients loss ... [27] Evaluation of the economic effects of soil erosion ... [28] Soil erodibility mapping using the RUSLE ... [29] Evaluation of the risk of water erosion of the... [30] Natural Resources Office of Mazandaran Province... [31] Spatial modelling of soil erosion potential ... [32] Conversion of the universal soil loss equation ... [33] Event soil loss, runoff and the universal soil... [34] A study on the width and placement of vegetated... [35] Prioritization of micro-watersheds of Upper Bhama... [36] Sedimentation engineering/prepared by the ASCE ... [37] Principles of applied... [38] Soil erosion: A food and environmental ... [39] The price of soil erosion: An economic ... [40] Identification of priority areas for controlling ...

Introduction

Soil erosion and sedimentation threaten valuable resources of soil and water [1-5]. The high value of tangible and intangible damages of soil loss [6, 7] have caused the decision makers and authorities of watersheds to pay more attention to soil erosion mitigation and sediment management strategies [8, 9]. Beyond this, identifying soil erosion hotspot areas for conservation prioritization is essential to implement a stringent mitigation policy in the watershed scale [6, 9]. However, the prioritization is very helpful for understanding the behavior of each sub-watersheds process, and providing more reliable information to efficient flood mitigation and soil erosion control over a watershed [10-14].

Numerous methods have been developed for soil erosion estimation in the watershed scale. Zingg (1940) [15] relationship was the first equation proposed to estimate the erosion rate on a particular slope. In this relation, only two factors of slope steepness and slope length were considered. Then, progressively with increasing knowledge of the scientists, other factors were added to predict a more accurate amount of soil erosion status. The Universal Soil Loss Equation (USLE) [16, 17] or Revised USLE (RUSLE) [18] models have been the most used methods to effectively predict soil loss in different conditions [19, 20]. Integrating the remote sensing, geographic information system (GIS), and USLE/RUSLE facilitate to estimate soil loss by cell to cell [21] which has led to accurately values of rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and management (C) and support and conservations practices (P) factors [17, 18].

There were many studies predicted the soil loss by USLE/RUSLE [6, 18-22]. Both on- and off-site impacts were reported due to soil loss and erosion [1, 4, 7, 23]. Today, the science of economic valuation of natural resources and its various techniques contributes a lot to the economy of natural resources and environment. This science provides precise information in the short term to the managers of natural resources, agriculture, and the environment. Economic valuation of soil loss impact has also been widely used in the subjects of this science technique [24, 25]. Recently, connecting the soil loss status in the watershed scale with respect to its economic cost got high importance in order to prioritize the sub-watersheds for adapting future appropriate and successful measures [7, 24, 26, 27].

Telles *et a*l. [7] reviewed the physical processes of soil erosion and their economic effects. They concluded that limited data and information were available on the economic losses resulting from soil erosion. Hembram and Saha prioritized the sub-watersheds of Jainti River Basin, Eastern India based on soil erosion using fuzzy AHP and compound factor. The results of prioritization showed the different erosion prone categories through whole the study basin. In addition, Toubal *et al.* [28] mapped the soil erodibility of Wadi Sahouat watershed, Algeria using RUSLE to prioritize erosion control. 3.4% of the study basin is classified as highly susceptible to erosion, 4.9% with a medium risk, and 91.6% at low risk. Rastgar *et al.* [26] also estimated the economic cost of soil nutrient loss from rangelands of northern Iran using RUSLE and replacement cost method. They reported the 27.44 t ha^{-1} y^{-1} soil loss and 6.80 $\times 10^6$ US$ for the Nour-rud Watershed. Their results also verified the direct relationship between soil nutrient loss and its costs. Besides, Adhami and Sadeghi [12] prioritize some of the sub-watersheds of Golestan Province based on sediment yield using game theory. Their results indicated the Galikesh, Qazaqli, Gonbad, Siyah Ab and Tamar as the most preferred, Tangrah and Naharkhoran as second priority and eventually Pole Ordougah sub-watershed as sub-watersheds with a better condition. Recently, Mohammadi *et al.* [20] provided a general view of soil loss in Iran using RUSLE. Their results revealed that about 4×10^{12} t of the country soil is eroded which leads to land degradation. The literature review showed that integrating the soil loss results and their economic cost has been less considered. Therefore, this study was attempted to prioritize the sub-watersheds of Selj-Anbar Watershed in Mazandaran Province, northern Iran based on integrating the soil loss status and its economic cost in a GIS and remote sensing environments.

Materials and Methods

Description of the study area: The Selj-Anbar Watershed with an area of 4228.92 ha located at 50° 46' 10" to 50° 51' 35" E longitude and 36° 23' 19" to 36° 27' 60" N latitude. In terms of the country's divisions, the Selj-Anbar Watershed located in the western part of

Mazandaran Province is located on the border of Tonekabon County and Qazvin Province. The study watershed also includes nine sub-watersheds and contains three villages of Maran, Selj-Anbar and Kalamlat (HorAbad) as presented in Figure 1. In addition, the Yoj and Ceren villages are the nearest villages outside of the study watershed [29].

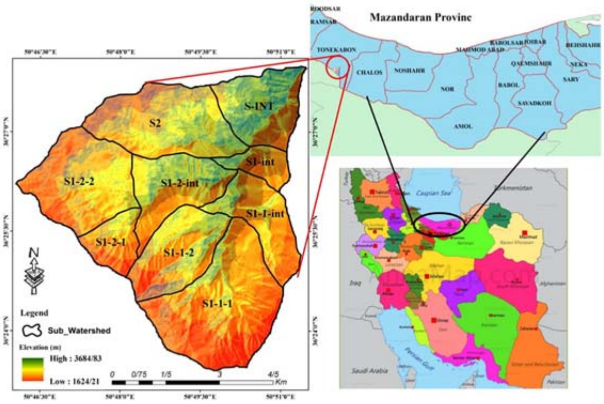

Figure 1) General view of Selj-Anbar Watershed, Mazandaran Province, Iran

Data sources: In this research, topographic map of 1:25000 was used for the preparation of Digital Elevation Model (DEM), slope steepness and slope length maps. Furthermore, the data of weather stations which exist in the Selj-Anbar Watershed was used to calculate the rainfall erosivity factor (R). Hereafter, Landsat 8 satellite scenes (OLE) of September 2017 was downloaded (www.earthexplorer.usgs.gov) for generating the land cover map. In this regards, the ArcGIS 10.4 and Erdas Imaging 2014 softwares were used as the basis environment. The soil data originally provided from Natural Resources Office of Mazandaran Province, Noshahr [30].

RUSLE application: In order to estimate the economic loss of the soil loss as the main objective of the present study, the amount of soil loss must first be calculated in the watershed. Different methods of USLE, MUSLE, RUSLE, WEPP, etc., have been used for soil loss and erosion estimating in different scales. The RUSLE as a widely used approach especially in data-scarce and ungauged regions was applied to quantify the soil loss in the Selj-Anbar Watershed. RUSLE output (soil loss) specified based on the following six factors [20]:

$$E = R \times K \times L \times S \times C \times P \quad (1)$$

In this Eq., E was the computed spatial average soil loss, (t ha^{-1} y^{-1}); R, K, L, S, C, and P were rainfall erosivity (MJ mm ha^{-1} h^{-1} y^{-1}), soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}), slope length, slope steepness, cover and management, and conservation practices factors, respectively.

For the determination of R factor, the Fournier index (F) value derived from Eq. 2 was used [18, 31]:

$$F = \frac{\sum_{i=1}^{12} P_i^2}{\sum_{i=1}^{12} p} \quad (2)$$

In this equation p_i was the average rainfall in a month i and p was the average annual rainfall (mm). Then, according to F values, the final R factor estimated as described in Eqs. 3 and 4 [22, 31]:

$$R = \frac{0.0739F^{1.847}}{17.2} \qquad F < 55\,mm \quad (3)$$

$$R = \frac{95.77 - 6.081F + 0.4770F^2}{17.2} \qquad F \geq 55\,mm \quad (4)$$

The K factor as an empirical measure of soil erodibility and a function of intrinsic soil properties was estimated using below Eq:

$$100K = 2.1 * 10^{-4} * M^{1.14} * (12 - OM) + 3.25 * (S - 2) + 2.5 * (P - 3) \quad (5)$$

Where M was the particle size parameter (% silt + % very fine sand)x(100 - % clay), OM was the organic matter content (%), S was the soil structure code (very fine granular = 1, fine granular = 2, coarse granular = 3, lattice or massive = 4) and P was the soil permeability class (fast = 1, fast to moderately fast = 2, moderately fast= 3, moderately fast to slow = 4, slow = 5, very slow = 6) [32]. The primary soil samples were collected from soil profiles which are created in each homogenous land units. Homogenous land units were provided according to the overlay of three maps of slope, geology and land use [30].

The combined effect of L factor was also determined using the following approach:

$$L = \left(\frac{X}{22.13}\right)^m \quad (6)$$

where X and m were slope length and slope contingent coefficient, respectively. X was estimated according to the following Eq. [1]:

$$X = (Flow\ accumulation * Cell\ value) \quad (7)$$

For S factor, the below Eqs. were used based on the slope steepness condition [33]:

$$S = 10.8Ssin\Theta + 0.03 \qquad Slope<9\% \quad (8)$$

$$S = 16.8sin\Theta - 0.5 \qquad Slope\geq 9\% \quad (9)$$

In addition, the S factor estimated according to the below Eq. for slopes with length less 4.6 m.

$$S = 3\sin(sin\theta)^{0.8} + 0.56 \quad (10)$$

To generate a C factor, the following formulae were used [34].

$$C = \frac{(1 - \mathrm{NDVI})}{2} \quad (11)$$

where NDVI was the normalized difference vegetation index values derived from Landsat TM, 2017. The ground controlling was done throughout whole homogenous land units over of the study watershed.

The P factor was also determined according to table proposed by other researchers [35]. For land use/covers of bare soil, fallow and river bed the P factor of one was allocated. Whilst, the P factor of 0.8 was scored for thin forest, forest with moderate density open forest area. Finally, the land use/ cover of wheat was determined with the p factor of 0.1.

The quantitative output of annual soil loss was eventually computed by multiplying the R, K, L, S, C, and P factors using the Raster Calculator tool in ArcGIS 10.4.

Finally, the sediment delivery ratio (SDR) method was used to obtain the ratio of sediment yield to the total soil loss [36, 37].

$$SDR = 0.42\ A^{-0.125} \quad (12)$$

where, A was the watershed area.

Soil loss cost analysis: During the soil loss process, essential soil nutrients are removed from the soil [26, 38]. Therefore, measuring the depleted nutrients and the cost of their providing could be considered as a good index to predict the soil loss effects. Generally, the fertile soils have essential elements of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca) and sulfur (S), and other chemical matters. The amount of these elements in Iranian rangelands estimated as given in Table 1.

Table 1) Some of essential plant nutrients (%) reported for the Iranian rangelands [30]

N	P	K	Mg	Ca	S
0.3-0.03	1-0.01	0.1-0.01	1-0.1	1.5-0.2	0.1-0.01

For the present study, based on the replacement cost method [26, 38], the cost of applied fertilizers to offset the nutrient losses due to soil loss were quantified and considered as the direct effect of soil loss in the Selj-Anbar Watershed. Towards these attempts, the cost of N, P, K and Mg were taken into account. In this method, the fertilizer prices were predicted via considering world price of substances for restoring soil fertility without subsidy [26]. The replacement-cost approach calculates the costs that would have to be incurred to eroded soil replacement. To calculate the indirect cost of soil loss, the cost of dredging and disposing of the accumulated sediment was estimated as the following Eq.

Sediment dredging cost = sediment (t ha^{-1}) × cost of sediment dredging per m^3 (US$ t^{-1}) × watershed area (ha) (13)

The cost of sediment dredging is a component of the social cost of soil loss and sedimentation as well as it is considerable, although it vary according to technical, logistical and financial conditions [39]. Finally, the benefit to cost ratio (B/C) of the watershed management activities were estimated. According to the calculations were done the cost of one m^3 un-eroded soil was equal to 8.00 US$ (US Dollar equals to 42000 Rials in 2018; Central Bank of Iran statistics). Hence, with multiplying this price to the total un-eroded soil, the economical benefit of soil loss control measures could be estimated.

Findings

The results of RUSLE factors for Selj-Anbar Watershed were depicted in Figure 1. The R factor in the Selj-Anbar Watershed was obtained between 13.27 and 36.37 MJ mm ha^{-1} h^{-1} y^{-1}. The average, minimum and maximum K factor was also equal to 0.14, 0.05 and 0.30 MJ ha h ha^{-1} MJ^{-1} mm^{-1}, respectively. In the current work, the DEM and Eqs. 6 to 10 were used for the calculation of the LS factor. According to Figure 2, the minimum and maximum of LS factor in the Selj-Anbar Watershed were respectively 0.56 and 18.38. To prepare the map of C factor, using the TM satellite imagery of 2017, the NDVI was prepared and then, based on the stated relationship (Eq. 11), the average C factor was 0.23. Based on Figure 2, the maximum and minimum amount of C factor were 0.1 and 0.42, respectively. The highest amount of C factor was in areas without rocky outcrops and its lowest value was in areas with good forest cover and good rangelands. The P factor in the Selj-Anbar Watershed was ranged between one and 0.5. Based on Figure 2, p=0.5 was related to the agricultural area.

Based on Figure 3, the average soil loss in the Selj-Anbar Watershed was 4.92 t ha^{-1} y^{-1}, and the maximum and minimum soil loss rates were 38.29 and 0.36 t ha^{-1} y^{-1}, respectively. The minimum and maximum of SDR were 0.32 and 0.4, respectively (Figure 3). Regarding SDR and soil loss of the watershed, the average sediment in the region was 1.98 t ha^{-1} y^{-1}, with a maximum and minimum of 0.14 and 9.9 t ha^{-1} y^{-1}, respectively (Figure 3). Table 2 furthermore shows the sediment and soil loss levels of Selj-Anbar sub-watersheds.

Accordingly, the soil loss of the Selj-Anbar Watershed was 20806 t y^{-1}. In order to estimate the direct cost of soil loss, the minimum amount of nutrients in terms of the main elements of N, P, K, and Mg was considered as described in Eqs. 14 to 17:

(20806.14* 0.03)/100= 6.24	Minimum net soil N loss (t)	(14)
(20806.14*0.01)/100=2.08	Minimum net soil P loss (t)	(15)
(20806.14*0.2)/100=41.6	Net soil K loss (t)	(16)
(20806.14*0.1)/100=20.8	Net soil Mg loss (t)	(17)

In the next step, the amount of chemical elements loss was compared with the chemical fertilizers content. Urea chemical fertilizer contains 46% N, superphosphate fertilizer contains 24% pure oxygen-free P, potassium sulfate fertilizer contains 42% P and magnesium sulfate fertilizer containing 16% Mg. Accordingly, the minimum amount of chemical fertilizers loss was described as given in Table 3.

The prices approved for each 50 kg of Urea, super phosphate, Potassium sulfate and Magnesium sulfate fertilizers were 9.17, 13.10, 17.86 and 17.86 US$. Considering these prices, the cost and necessary fertilizer for the Selj-Anbar Watershed in order to compensate the loss of these fertilizers due to soil loss, was recorded as follows.

According to the amount of soil loss in the watershed of 20806 t, the cost of direct soil loss of one-year soil was 8.64×10^4 US$. Also, soil replacement cost according to Table 4 for one year was 12.80×10^4 US$. By considering the direct and indirect costs, it can be concluded that the total cost of soil loss was about 2.20×10^5 US$ in one year, which was equal to 11.00×10^5 US$ during the period of five-year period (The program period). In accordance with Table 4, the priority was given to watershed management in Selj-Anbar sub-watersheds. Accordingly, the S1-1-1 sub-watershed had the highest priority and the S1-2-2 sub-watershed had the least priority.

On the other hand, for the control of soil loss and sedimentation with an average cost of 238 US$ (Watershed Management Deputy-Sixth Development Plan), 100×10^4 US$ are needed. Thence, the B/C ratio for Selj-Anbar Watershed was calculated to equal to 1.09.

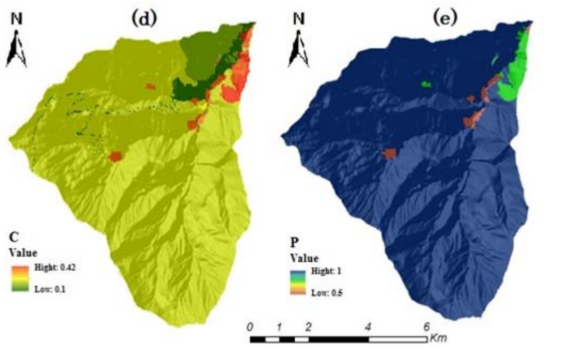

Figure 2) Results of R (a), K (b), LS (c), C (d) and P (e) factors for Selj-Anbar Watershed, Iran

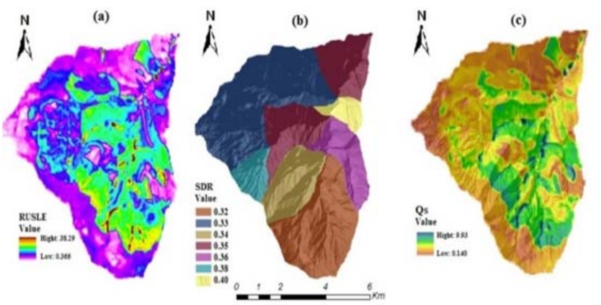

Figure 3) Results of soil loss (a), SDR (b) and sediment (c) of Selj-Anbar Watershed, Iran

Table 2) Soil loss and sedimentation levels of the Selj-Anbar sub-watersheds, Iran

Sub-watershed	**Area** (ha)	**Area** (%)	**Annual soil loss** (t y^{-1})	**Specific soil loss** (t ha^{-1} y^{-1})	**SDR**	**Annual sediment** (t y^{-1})	**Specific sediment** (t ha^{-1} y^{-1})
S1-1-1	927.24	21.94	5415.90	5.84	0.32	1897.52	2.04
S1-2-1	425.65	10.74	2037.43	4.50	0.39	814.99	1.80
S1-1-2	365.12	8.63	2143.56	5.87	0.35	877.61	2.40
S1-1-int	196.81	4.65	1123.73	5.71	0.36	514.41	2.61
S1-2-int	634.25	15	3952.50	6.23	0.35	1463.64	2.31
S1-int	423.44	10.01	1783.06	4.21	0.40	713.33	1.68
S1-2-2	143.54	3.39	540.45	3.77	0.33	258.24	1.89
S2	627.49	15.90	2833.62	4.21	0.33	1050.51	1.56
S-INT	412.29	9.75	1135.40	3.97	0.35	652.88	1.58
Total	4228.89	100	20806.14	4.92	0.35	8373.20	1.98

Table 3) Minimum amount of fertilizer loss (Kg) and cost of fertilizer required for Selj-Anbar Watershed

Fertilizer	Urea	Superphosphate	Potassium sulfate	Magnesium sulfate	Total fertilizer essential for soil restoration
Minimum fertilizer (Kg)	13569	8669	99076	130037	251351
Cost (US$)	2488	2270	35384	86584	886

Table 4) The replacement cost of eroded soil

Sub-watershed	Area (ha)	Annual soil loss		Soil replacement Cost (×10⁴ US$)
		t y-1	m3 y-1	
S1-1-1	927.24	5415.90	4166.08	3.33
S1-2-1	425.65	2037.43	1567.25	1.26
S1-1-2	365.12	2143.56	1648.89	1.30
S1-1-int	196.81	1123.73	864.41	0.69
S1-2-int	634.25	3952.50	3040.38	2.42
S1-int	423.44	1783.06	1371.58	1.09
S1-2-2	143.54	540.45	415.73	0.33
S2	627.49	2833.62	2179.71	1.73
S-INT	412.29	1635.40	1258.00	1.00
Total	4228.89	20806.14	16004.72	12.80

Discussion

The numerical ranges of RUSLE factors for Selj-Anbar Watershed were found in line with other researches with similar regional conditions [20]. Spatial distributions of soil loss, SDR, sediment and soil replacement cost were different through the entire watershed. As it could be concluded from Tables 2 and 4, the prioritization of sub-watersheds in terms of soil loss was S1-2-int, S1-1-2, S1-1-1, S1-1-int, S1-2-1, S1-int, S2, S-INT and S1-2-2; in terms of SDR were S1-int, S1-2-1, S1-1-int, S1-2-int, S1-1-2, S-INT, S2, S1-2-2, and S1-1-1; as well as in terms of soil replacement cost were S1-1-1, S1-2-int, S2, S1-1-2, S1-2-1, S1-int, S-INT, S1-1-int and S1-2-2. The different prioritizations reflected the different behaviors of sub-watersheds in viewpoints of physiographical, hydrological and managerial aspects. These results provided powerful tools for effective watershed management planning. The general result of the soil loss was inconsistent with other researches which done with help of RUSLE in different parts of Iran [19, 20, 26]. Considering that the geology, morphology, and climatic conditions can not be changed to reduce soil loss and sedimentation, therefore, a principled and remedial solution in particular, with emphasized to integrated management of watersheds should be made. According to Telles *et al.* [7] the impressions of soil loss begin with a alteration in the soil physical, chemical and biological characteristics which could be made a gradual drop in the potential production. Toubal *et al.* [28] reported the average annual soil loss rate between 0 and 255 t ha^{-1} y^{-1} for the Wadi Sahouat watershed, Algeria. They prioritized the study sub-watersheds to three categories of high, moderate, and low prone to soil loss. They believed that these results could be important to sustain a management plan against sediment filling of the Ouizert Dam at the watershed outlet. Moreover, Lakkad *et al*. noted that the planning and implementation of conservation practices for a watershed in Gujarat, India based of priority of micro-watersheds in accordance to soil erosion would prevent further degradation of the most vulnerable area and will help in long term sustainability of natural resource of the watershed.

The soil loss cost which was estimated in Selj-Anbar Watershed was 11.02 × 10^5 US$ over a five-year period. Implementation of watershed management projects and the control of soil loss and conservation, undoubtedly affecting the economic and social conditions of the watershed [3, 9, 40]. On the other hand, it is necessary to carry out watershed operations in order to control soil loss and sediment. According to the Watershed Management Department (Sixth Development Plan) reports, it was estimated about 10.06×10^5 US$ would be paid to adopt the soil loss control measures for Selj-Anbar Watershed. Towards this, the B/C ratio for Selj-Anbar Watershed was obtained 1.09. This result indicated the cost-effective of soil erosion control with adopting watershed management strategies. The economic value of soil loss would be used by the decision maker to prioritize areas of soil conservation as stated by Kefi and Yoshino.

Furthermore, it is important to notify that the conservation practices implication in the inappropriate time and place could make numerous managerial problems [2, 6, 20]. For this reason, the importance of sub-watersheds prioritization for watershed management can play a significant role in reducing watersheds damages. In this research, the amount of cost caused by soil loss and sediment in the region was used to prioritize sub-watersheds and suggested to land managers as an extra option to better decision making. Sub-watersheds S1-1-1, S1-2-int, and S2 were proposed as a first priority, sub-watersheds S1-1-2, S1-2-1, S1-int and S-INT could be considered as second priority and ultimately the sub-watersheds S1-1-int, and S1-2-2 were suggested as a third priority for taking best management practices (BMPs) into account. Rastegar *et al*. concluded maximum and the minimum annual soil nutrient loss per ha of 27.4 US$ and 114.2 US respectively for the geologic unit 1 and unit 2 out of three study unit in the Nour-rud watershed, north of Iran. Several researches ascertain that economic assessment of soil loss is essential to achieve a healthy and sustainable watershed and meaningful management [4, 10, 24-27, 39]. More insight and elaborated studies considering complementary methods are needed for a comprehensive assessment of the economic soil loss cost.

Because of the lack of long-term erosion measurements at sub-watersheds and watershed scales the RUSLE model was employed to quantify the soil loss of the study watershed. So, more process and physically-based researches on erosion are needed even in its different types. Since cost estimation of soil erosion under natural resources conditions has gained a little attention until now, therefore, few attempts have been made to estimate the nutrient loss in results of soil erosion. Furthermore, it is suggested to update the present results with new prices of fertilizers due to their persistent changes in the market.

Conclusion

The main objective of this study was to understand the most pressing environmental problem i.e., soil erosion and its cost effect in a northern watershed of Iran, Selj-Anbar Watershed. The most important finding and conclusions were:

1) Mean annual soil loss varied from 540.45 to 5415.90 t y^{-1} based on RUSLE in the Selj-Anbar Watershed.

2) The corresponding soil replacement cost values ranged from 3.33 to 0.33 × 10^4 US$ with a total value of 12.80 × 10^4 US$ for the entire watershed.

3) The prioritization analysis results revealed that S1-1-1, S1-2-int, S2, S1-1-2, S1-2-1, S1-int, S-INT, S1-1-int, and S1-2-2 sub-watersheds were characterized with highest to lowest soil replacement costs.

4) The priority-based sub-watershed development is highly recommended for proper management of watersheds.

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