Journal of Chinese Soil and Water Conservation, 52 (1)*: 27-33* (2021)
DOI: 10.29417/JCSWC.202103_52(1).0003

Integration of Soil Surface Stoniness in Soil Erodibility Estimation: A Case Study of Khorasan-e-Razavi Province, Northeast of Iran

Ali Bagherzadeh*[1] Ali Keshavarzi[2]

ABSTRACT The soil erodibility factor is supposed as a key parameter in predicting soil erosion. To evaluate the applicability of incorporating soil surface stoniness in estimating K-factor this research was conducted in Khorasan-e-Razavi province in the northeast of Iran. The values of the K-factor varied between 0.018 and 0.053 by an average of 0.038 t ha h ha^{-1} $Mj^{-1}mm^{-1}$ by Wischmeier's nomograph equation and those by incorporating surface stoniness ranged from 0.006 to 0.053 with an average of 0.033 t ha h $ha^{-1}Mj^{-1}mm^{-1}$. It was demonstrated that the most important parameters affecting soil erodibility were very fine sand and silt particles, as well as surface stoniness. The zonation of K-factor by both approaches revealed that the plains with mostly fine textural classes with a high percentage of very fine sand and silt particles along with lower percentage surface stoniness exposed to high soil erodibility compared to high lands in mountainous regions. It was revealed that the surface stoniness affects soil erodibility, where the values of estimated K-factor by incorporating surface stoniness showed 0 to 77.23 % with an average of 18.06 % reduction in soil erodibility compared with predicting soil erodibility by Wischmeier's nomograph equation. Incorporation of the surface stoniness into the K-factor resulted in a mean 27.92 % reduction of soil erodibility in the upland mountainous regions (>1500 m asl), and 13.75 % reduction in the flat plain areas (≤ 1500 m asl). It was revealed that the study area is greatly vulnerable to erosion due to high levels of soil erodibility, hence precise soil conservational and management practices in rehabilitating programs are of great importance in the study area.
Key Words: Erosion, Soil erodibility, Kst-factor, K-factor, Surface stoniness, Khorasan-e-Razavi

Introduction

Soil erodibility is a key factor in determining soil losses which represent the reaction to the process of soil detachment and transport by raindrops (Renard et al., 1997; Manyiwa and Dikinya, 2013). The susceptibility of soil to erosion, which demonstrated as K-factor, is related to soil physical and chemical characteristics such as soil organic matter, soil texture, soil structure, and permeability. Normally the soil erodibility is predicted by direct measurements on field plots (Kinnell, 2010) but due to some problems such as expenditure of field measurements and not easily transferable in space, indirectly researchers investigate the relation between soil properties affecting soil erodibility and soil erosion. Various methods by direct measurements to indirect predictions using mathematical models have been introduced for estimating K-factor. Wischmeier et al. (1971) developed a nomograph and equation for calculating soil erodibility, which has a lower accuracy than direct methods, has an extensive application in practice (Tran et al., 2002). In Wischmeier's nomograph equation the K-factor is calculated based on soil physical parameters including soil texture, soil structure, and permeability as well as soil organic matter in the topsoil (Wang et al., 2001). In recent decades some equations predominantly based on soil texture have developed by Williams (1995), and Torri et al. (1997). Rubio and Recatalá (2006) suggested the soil surface stoniness as an important factor in estimating soil erodibility. On the European scale, Panagos et al. (2014) estimated the erodibility of soil based on soil attributes including soil texture and organic matter using the nomograph of Wischmeier et al. (1971) and considering the percentage of stoniness cover. Schmidt et al. (2018) assessed soil erodibility by incorporating surface stoniness based on measured soil data, including mountain soils in Switzerland. Poesen and Ingelmo-Sanchez (1992) investigated the relation between stoniness cover and the relative inter-rill sediment yield. They exhibited a negative relationship where surface stoniness is either partly embedded in the topsoil or are on the surface of the soil. In this study, the surface, stoniness cover which protects the soil against erosion was considered in predicting soil erodibility. This revision is of great importance, especially where surface stoniness is an important controlling factor in soil erosion. The present study aims to predict soil erodibility through Wischmeier's nomograph equation and the proposed K_{st}-factor to examine the applicability of incorporating surface stoniness in determining soil erodibility and its spatial distribution to find vulnerable areas to soil erosion and enhance soil management practices in Khorasan-e-Razavi province in the northeast of Iran.

〔1〕Department of Agriculture, Mashhad Branch, Islamic Azad University, P.O. Box: 91735-413, Mashhad, Iran.
〔2〕Laboratory of Remote Sensing and GIS, Department of Soil Science, University of Tehran, Karaj 31587-77871, Iran.
*Corresponding Author. E-Mail: abagherzadeh@mshdiau.ac.ir

Materials and Methods

1. Study area

The present study was conducted in Khorasan-e-Razavi province with a surface area of 115966.83 km^2 in the northeast of Iran. The study area is located between latitude 33° 87´ to 37° 70´ N and longitude 56° 32´ to 61° 28´ E (Fig.1). The elevation values of the study area vary between 233 and 3305-meter asl. (Fig.2). The study area has an arid to a semi-arid climate with long-term annual precipitation ranged from 315 to 145 mm and an annual temperature of 12.8℃ to 17.8℃ in the north and south of the province, respectively. Soil erosion is considered the most important reason for land degradation in Khorasan-e-Razavi province due to diversified climatic and soil characteristics, high susceptibility of soil to erosion, unsuitable developmental activities, land-use change, overgrazing, and the exploitation of natural pastures. Hence, the assessment of factors affecting soil erodibility in the study area and recognition of areas which more prone to erodibility have great importance in controlling erosion and rehabilitation programs in the province.

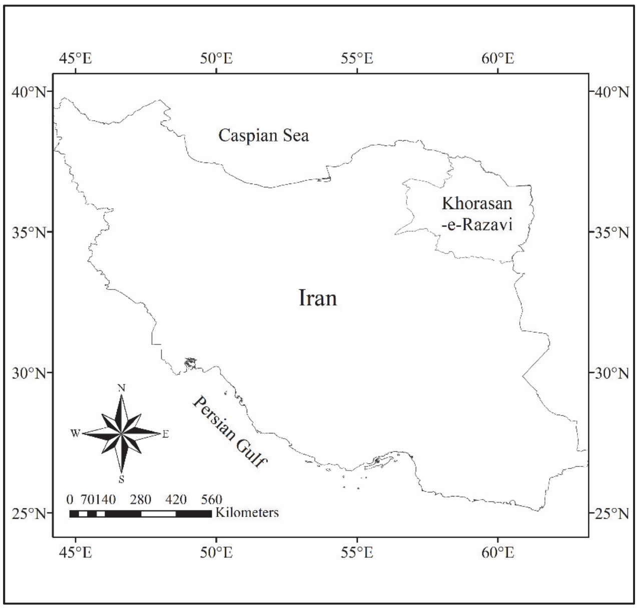

Fig.1 Geographical position of Khorasan-e-Razavi province

2. Soil structure

Consistent soil structure and high aggregate stability enhance porosity and decrease soil erodibility (Bronick and Lal, 2005). The soil structure codes got from the National Soils Handbook No. 430 (USDA, 1983), in which each soil texture assigned a Structure code. The values of structure codes in the upper soil layer in the study area ranged from very fine granular to medium or coarse granular with a dominant value of 3 (Table 1). The zonation map of the topsoil structure classes revealed that 2.23 % (2588.62 km^2) of the study area were classified into very fine granular structure, while 26.74 % (31011.79 km^2) of the region were categorized into fine granular structure. Also, medium, or coarse granular soil structure accounted for 71.03 % (82366.42 km^2) of the study area (Fig.3).

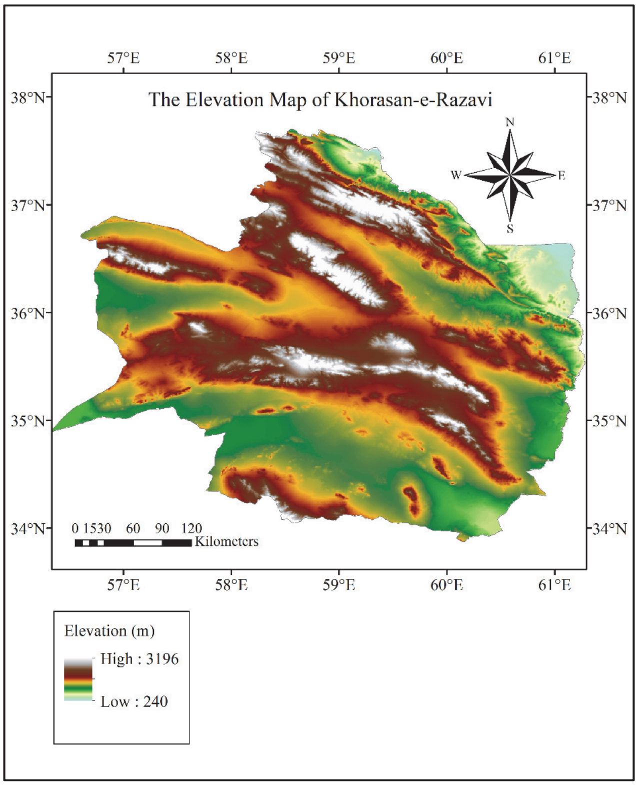

Fig.2 The elevation map of Khorasan-e-Razavi province

Table 1 The classes of soil structure and their attributes

Structure code	Description	Rating
1	very fine granular; 1-2 mm	Good
2	fine granular: 2-5 mm	Normal
3	medium or coarse granular: 5-10 mm	Poor
4	blocky, platy, massive: >10 mm	very Poor

3. Topsoil permeability

For determining soil permeability, the classes described in the US Department of Agriculture's National Soils Handbook No. 430 (USDA, 1983) were assigned according to soil texture classes (Rawls et al., 1982). The soil permeability and the relevant class in the upper soil layer in the study area were as follows: clay loam and sandy clay loam 2.0–5.1 mm h^{-1} (Class 4) 5.20 mm h^{-1}, loam 5.2–10.4 mm h^{-1} (class 3) and sandy loam 20.4–25.0 mm h^{-1} (class 2), (Table 2). The spatial zonation of soil permeability revealed that 19.54 % (22659.21 km^2) of the study area were classified into moderately fast permeability class, while 44.29 % (51364.01 km^2), and 36.17 % (41943.6 km^2) of the surface area were categorized into moderate and moderate slow permeability classes, respectively (Fig.4).

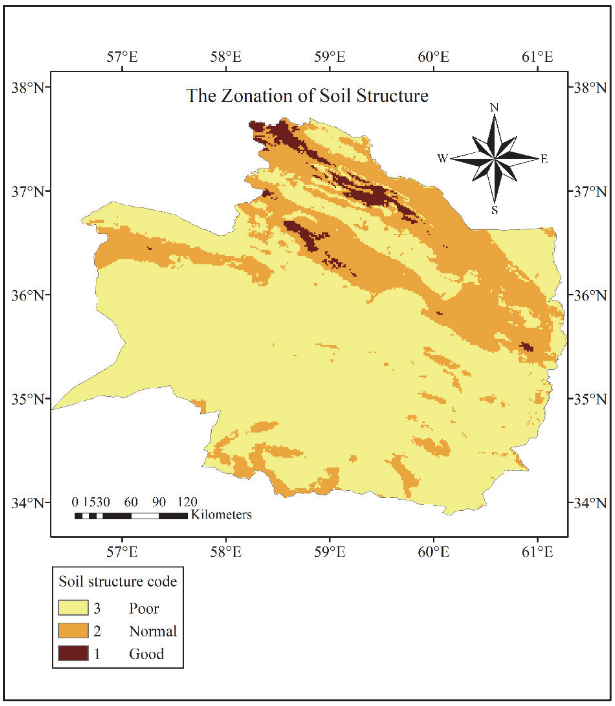

Fig.3 The zonation of soil structure code in Khorasan-e-Razavi province

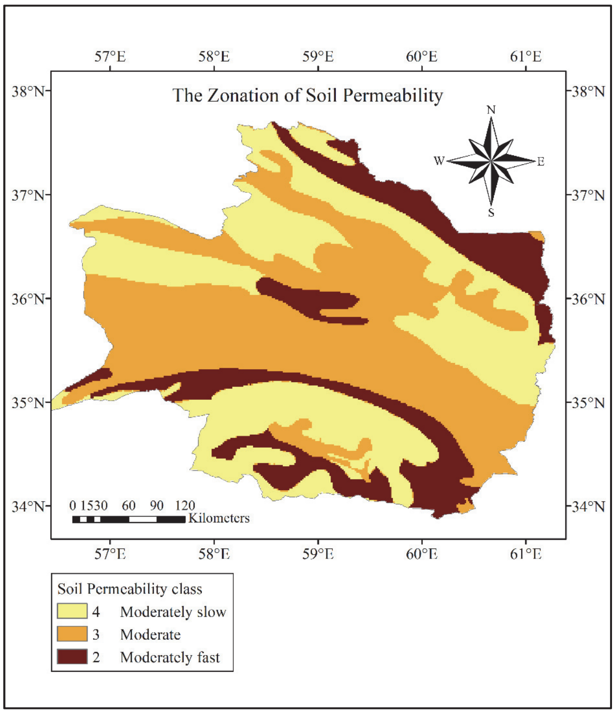

Fig.4 The zonation of soil permeability classes in Khorasan-e-Razavi province

Table 2 Soil permeability classes and their attributes

Permeability class	Description	Soil texture	Saturated hydraulic conductivity (mm h^{-1})
1	fast and very fast	sand	>61.0
2	moderately fast	loamy sand, sandy loam	20.3-61.0
3	moderate	loam, silty loam	5.1-20.3
4	moderately low	sandy clay loam, clay loam	2.0-5.1
5	slow	silty clay loam, sandy clay	1.0-2.0
6	very slow	silty clay, clay	<1.0

4. K-factor estimation

The soil physical and chemical properties at 1000 m grid cell size derived from Soil-Grids (ver. 2.0). On this basis over 134666 study points were selected in the study area. The nomograph equation of Wischmeier et al. (1971) was used and cited for soil erodibility estimation. The equation formula includes five soil parameters (texture, organic matter, the percentage of clay, very fine sand and silt particles, structure, and permeability) (Wischmeier and Smith, 1978) and (Renard et al.,1997) as:

$$K = [(2.1\times M^{1.14}\times 10^{-4}\times(12 - OM)+3.25\times(S - 2) +2.5\times(P - 3))/100]\times 0.1317 \quad \text{(Eq.1)}$$

Where:

M is the textural factor, equal with $M=(100-C) \times (VFS+Si)$

C is the percent of clay (<0.002 mm). VFS+Si is the percent of very fine sand (0.05 - 0.1mm) and silt (0.002 - 0.05 mm). OM is the percent of organic matter, S is the structure code in which (1) is very fine granular and crumb structure (≤1 mm), (2) is finely granular and crumb structure (1-2 mm), (3) is moderately granular and crumb structure (2-5 mm) and large granular structure (5-10 mm) and (4) are prismatic, columnar, and cubic structures. P is the soil permeability code in which (1) is rapid to very rapid (≥12.5 cm hr^{-1}), (2) is moderate to rapid (6.25-12.5 cm hr^{-1}), (3) is moderate (2-6.25 cm hr^{-1}), (4) is moderate to slow (0.5-2 cm hr^{-1}), (5) is slow (0.125-0.5 cm hr^{-1}), and (6) very slow (≤0.125 cm hr^{-1}). K is the soil erodibility factor (t ha h $ha^{-1}Mj^{-1}mm^{-1}$). The topsoil textural classes in the study area observed as clay loam, sandy clay loam, loam, and sandy loam and the values of soil organic matter in the topsoil of the study area varied between 0.17 and 3.97 % by an average of 1.08 %.

5. K_{st}-factor estimation

The K_{st}-factor is based on estimating the percentage of surface stoniness for the 0 - 15 cm (Rubio and Recatalá, 2006). Surface stoniness has a protective effect against sediment production and can consider as a natural surface stabilizer of the soil. In a study by Poesen and Ingelmo-Sanchez (1992), they found a negative relationship between surface stoniness and the relative inter-rill sediment yield. This phenomenon observed where surface stoniness was either partly embedded in the topsoil or scattered on the surface of the soil. Poesen et al. (1994) introduced a soil erodibility reduction factor expressed as an exponential decay function based on experimental field data as follows:

$$S_t = e^{-0.04(R_c-10)} \quad \text{(Eq. 2)}$$

Where,

S_t is the stoniness correction factor,

R_c is the percentage of stones cover, where 10 %<R_c<100 %.

The K-factor incorporating surface stoniness percentage was calculated as:

$$K_{st} = K\times S_t \quad \text{(Eq. 3)}$$

The statistical values of soil properties used in estimating soil erodibility as well as K-factor, K_{st}-factor, and the percent of K-factor reduction due to surface stoniness has shown in Table 3.

Statistical and Spatial analysis

Statistical analysis performed using SPSS software (V.16.0). Also, a kriging interpolation function was used by applying ArcGIS (ver.10.7) to visualize the zonation of soil erodibility and soil erodibility incorporating soil surface stoniness. The classification of soil erodibility factor was done based on Bergsma (1973).

Results and discussion

1. soil erodibility factor

The soil erodibility factor represents the effect of soil physical characteristics on soil loss. Soil properties are one of the main parameters that affect the runoff and erosion processes (Kavian et al. 2014). Concretely, the soil erodibility factor is the long-term average response of the soil to the erosive powers of rainstorms; that is, the soil erodibility factor is a parameter that represents an integrated annual mean value of the total soil reaction to soil erosion processes. These processes consist of detachment and transport of the soil by the impact of raindrops and surface flow, localized deposits due to the topography and roughness induced by tillage, as well as the rainwater infiltration into the soil profile (Young et al. 1987). The values of the K-factor based on Wischmeier's nomograph equation ranged from 0.018 to 0.053 (t ha h $ha^{-1}Mj^{-1}mm^{-1}$) with a mean value of 0.038 and a standard deviation of 0.004 (t ha h $ha^{-1}Mj^{-1}$ mm^{-1}), (Table 3). A comparison between the estimated K-factor and the soil textural classes show that the highest mean values of the K-factor are in the sandy clay loam (0.041) with a standard deviation of 0.001, followed by loam (0.040) with a standard deviation of 0.004 and clay loam (0.037) with a standard deviation of 0.003, while the lowest mean values recorded for the sandy loam (0.035) with a standard deviation of 0.003 (Table 4). It can be related to the fact that the coarse textural classes due to their greater surface areas and higher cohesion strength are less susceptible to soil detachment. Thus, medium-sized texture classes are more prone to soil erodibility. Most of the soils belong to the poor (P) soil structure class, corresponding to the medium or coarse granular soil structure (class: 3). The rest of the soil structure classes categorized into a normal class of fine granular soil structure (class: 2). Most of the soils had a moderate permeability class (3) with a saturated hydraulic conductivity of 5.1-20.3 mm h^{-1}. Soil organic matter has a great effect on the K-factor as soils with the lowest values of the organic matter indicated the highest soil erodibility. The K-factor classified into moderate, high, and very high classes which comprised 11.73 km^2 (0.01 %), 105703.89 km^2 (91.15 %) and 10251.21 km^2 (8.84 %) of the study area, respectively (Fig.5). The zonation of soil erodibility in the study area revealed that regions exposed to elevated erodibility correspond well to soils contained higher values of very fine sand and silt particles, lower soil organic matter content, shifting fine granular to massive and blocky soil structures and lower soil permeability. The content of soil organic matter is considered as an important factor in decreasing soil erodibility due to its influence on improving soil structure and aggregate stability. In the study area, dry climate conditions and low precipitation values resulted in a poor land cover which reflected in overall low values of soil organic matter. Loch and Slater (1998) and Barthes and Roose (2002) indicated that the percentage of soil particles less than 0.1 mm has a high correlation with the maximum runoff and soil loss among a vast number of surveyed soils. Since soil erodibility results of complex relationships between soil properties, the effect of a change in each input parameter were assessed on soil erodibility, keeping all the other attributes constant. As shown in Table 5, the reduction of K-factor values contribute to the elevating soil organic matter, where the increase of soil organic matter in the range of 0.17 % to 3.97 % resulted in 0.051 t ha h ha^{-1} Mj^{-1} mm^{-1} reduction in soil erodibility factor. Also, increasing the values of very fine sand and silt, top soil permeability class, and structure code in their range resulted in 0.010, 0.007, and 0.014 t ha h ha^{-1} Mj^{-1} mm^{-1} increase in soil erodibility factor, respectively.

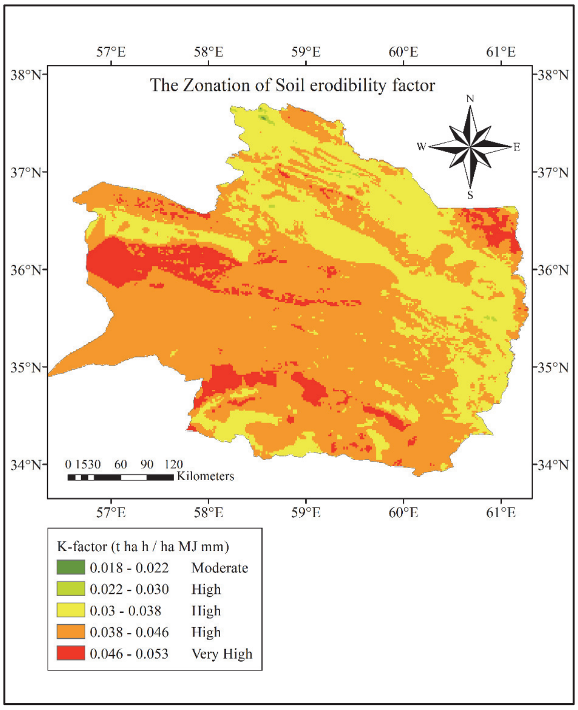

Fig.5 The zonation of soil erodibility factor in Khorasan-e-Razavi province

2. Soil erodibility factor by incorporating surface stoniness

The values of the K_{st}-factor varied between 0.006 and 0.053 t ha h $ha^{-1}Mj^{-1}$ mm^{-1}. The mean K_{st}-factor determined at 0.033 t ha h $ha^{-1}Mj^{-1}mm^{-1}$ with a standard deviation of 0.008 t ha h $ha^{-1}Mj^{-1}mm^{-1}$, (Table 3). The K_{st}-factor categorized into moderate, high, and very high classes which comprised 7848 km^2 (6.77 %), 105412.86 km^2 (90.90 %), and 2705.96 km^2 (2.33 %) of the study area, respectively (Fig.6). The percentage of surface stoniness cover altered from 2.25 %, mainly in the low plains to 40.60 % in the high land mountainous regions of the study area (Fig.7).

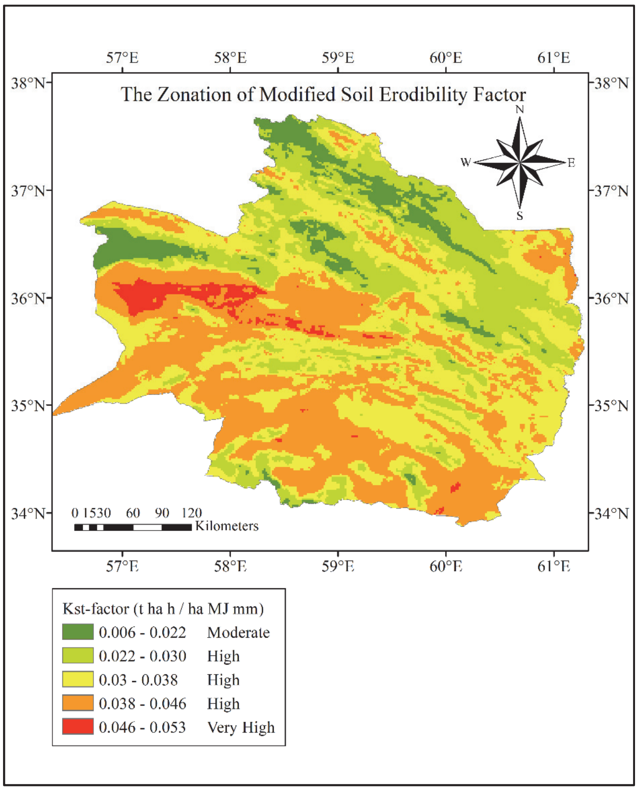

Fig.6 The zonation of Soil erodibility incorporating surface stoniness in Khorasan-e-Razavi Province

The spatial zoning for the percentage reduction in K-factor due to surface stoniness is shown in Figure 8. It was revealed that by incorporating surface stoniness the values of K_{st}-factor showed a reduction of 0 to 77.23 % with an average of 18.06 % and a standard deviation of 14.66 compared to the K-factor (Table 3). The most decrease in soil erodibility corresponds well to upland mountainous regions above 1500 m asl which prone to more surface stoniness. The mean reduction percent of soil erodibility in areas above 1500 m asl was 27.92 % versus 13.75 % in the areas below1500 m asl (Table 5). Also, it was found that the mean K_{st}-factor in areas above 1500 m asl (0.028 t ha h ha^{-1} MJ^{-1} mm^{-1} with a standard deviation of 0.008) was lower than the corresponding value in areas below1500 m asl (0.035 t ha h ha^{-1} MJ^{-1} mm^{-1} with a standard deviation of 0.007) (Table 5). This is in agreement with the results found by Schmidt et al. (2018). They estimated that the stoniness cover reduces the predicted mean soil erodibility of Switzerland by 8.2 % to 0.0297 t ha h ha^{-1} MJ–1 mm^{-1}, where the incorporation of the stoniness into the K-factor resulted in a mean reduction of 12.2 % in the lowland regions and 1.8 % in the upland Alpine regions. The contribution of surface stoniness in estimating K-factor was also investigated by Panagos et al. (2014) in the study of Soil erodibility in the European Union. They calculated a mean Kst-factor of 0.032 t ha h $ha^{-1}Mj^{-1}mm^{-1}$ with a standard deviation of 0.009 t ha h $ha^{-1}Mj^{-1}mm^{-1}$ and demonstrated that the surface stoniness act as the most important factor affecting soil erodibility. It seems that the exclusion of this effect in K-factor calculations result in an overestimating of soil erosion, especially in semi-arid regions like Khorasan-e-Razavi province, where high surface stoniness was observed.

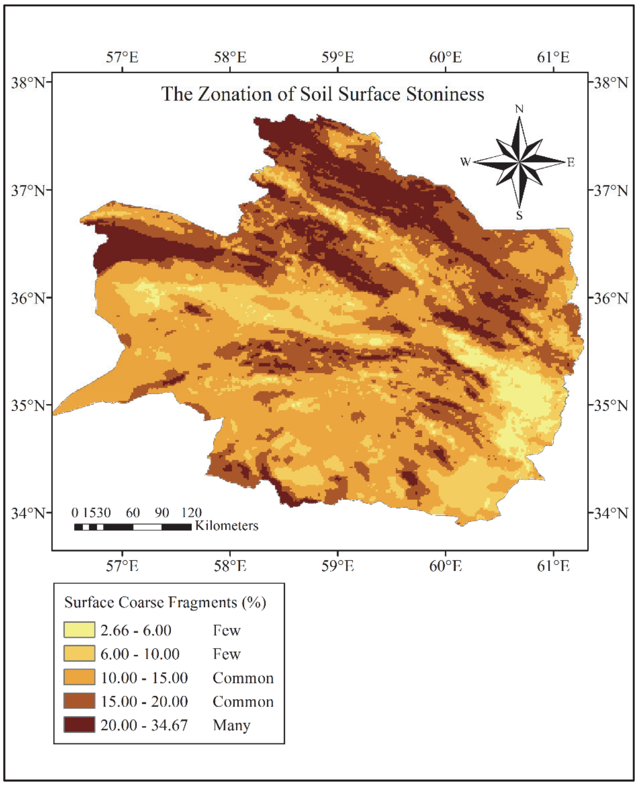

Fig.7 The zonation of soil surface stoniness in Khorasan-e-Razavi province

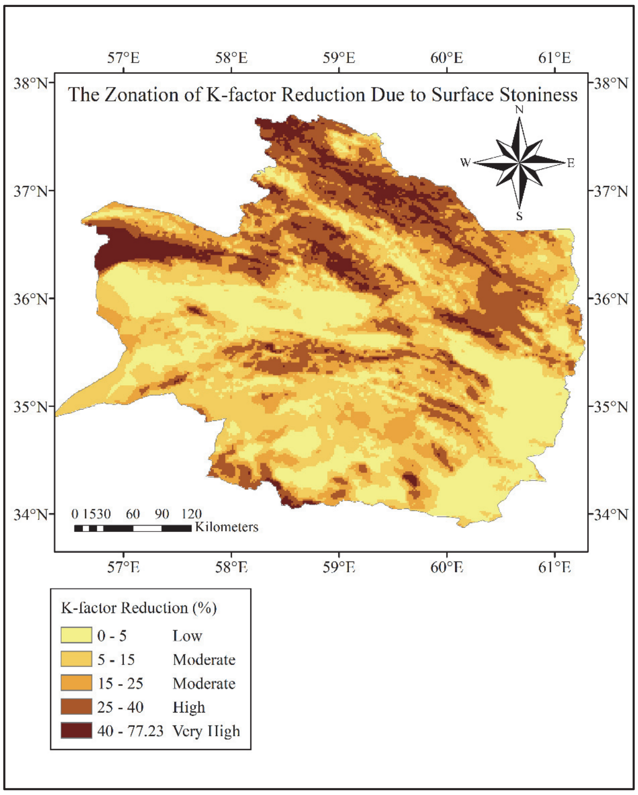

Fig. 8 The Zonation of the reduction percent of soil erodibility due to surface stoniness in Khorasan-e-Razavi Province

Table 3 Statistical values of soil erodibility parameters in Khorasan-e-Razavi province, (n= 134666) *: mode value

Soil properties	Range	Mean	STD	CV (%)
Sand (%)	22-58	43.74	4.42	10.11
Very fine sand (%)	4-12	8.75	0.884	10.11
Silt (%)	25-48	35.77	2.74	7.67
Clay (%)	13-31	20.54	2.62	12.75
Surface stoniness (%)	2-47	14.89	5.58	37.47
Organic matter (%)	0.17 - 3.97	1.08	0.56	52.01
Soil structure code	1-3	2*	0.519	14.87
permeability class	2 - 4	3*	0.205	6.90
K-factor (t ha h / ha MJ mm)	0.018 - 0.053	0.038	0.004	11.27
K_{st}-factor (t ha h / ha MJ mm)	0.006 - 0.053	0.033	0.008	23.75
K-factor reduction due to surface stoniness (%)	0 - 77.23	18.06	14.66	81.15

Table 4 Statistical values of the soil erodibility factor based on soil texture classes in Khorasan-e-Razavi province

	K-factor (t ha h ha^{-1}Mj^{-1} mm^{-1})			
Soil texture	Range	Mean value	Standard deviation	CV (%)
Sandy Loam	0.019 - 0.046	0.035	0.003	8.55
Loam	0.018 - 0.053	0.040	0.004	11.07
Sandy Clay Loam	0.034 - 0.042	0.041	0.001	3.24
Clay Loam	0.021 - 0.048	0.037	0.003	8.14

Table 5 Statistical values of soil erodibility parameters in upland mountainous regions above 1500 m asl and in the plains below 1500 m asl in Khorasan-e-Razavi province, (n= 134666)

	DEM≤1500 m			DEM> 1500 m		
Soil properties	Range	Mean	STD	Range	Mean	STD
Sand (%)	22-58	43.99	4.73	27-56	43.16	3.55
Very fine sand (%)	4.4-11.6	8.80	0.95	5.4-11.2	8.63	0.71
Silt (%)	25-48	35.57	2.95	27-46	36.23	2.15
Clay (%)	13-31	20.50	2.69	13-29	20.64	2.46
Surface stoniness (%)	2-39	13.25	4.86	2-47	18.63	5.29
Organic matter (%)	0.17-3.28	0.96	0.44	0.17-3.97	1.35	0.71
Soil structure code	1-4	4*	0.50	1-4	3	0.55
Permeability class	2-4	3*	0.23	2-4	3	0.11
K-factor (t ha h / ha MJ mm)	0.022-0.053	0.040	0.004	0.018-0.050	0.039	0.005
K_{st}-factor (t ha h / ha MJ mm)	0.011-0.053	0.035	0.007	0.006-0.049	0.028	0.008
K-factor reduction due to surface stoniness (%)	0-68.65	13.75	12.57	0-77.23	27.92	14.33

*: mode value

Conclusion

In the present study soil surface stoniness as a protective factor against soil susceptibility to erosion was estimated in predicting soil erodibility. This correction factor is of great importance especially for the regions where stoniness values of the soil surface are high enough to hinder soil degradation by erosion. It was found from our investigation that the regions with lower than 10 % surface stoniness and soil erodibility higher than 0.030 t ha h ha^{-1} Mj^{-1} mm^{-1} are more susceptible to erosion and should be treated with considerable care in terms of agricultural practices and vegetation cover. The soil erodibility map presented in Fig.6 is an important contribution to the estimation of soil erosion since the K-factor is very crucial among the input factors used in estimating Soil loss, according to RUSLE and other models. Also, K-factor can usually not be readily determined or calculated by individual soil erosion models without access to extensive data. It is acknowledged that the correctness of soil erodibility estimation by incorporating soil surface stoniness cannot be validated since no measured soil erodibility data due to field complications were available.

Acknowledgment

We appreciate the Islamic Azad University, Mashhad branch for their support of the research.

References

[1] Barthes, B., and Roose, E. (2002). "Aggregate Stability as an Indicator of Soil Susceptibility to Runoff and Erosion Validation at Several Levels." *Catena*, 47(2), 133-149.

[2] Bergsma, E. (1973). Erosion factors, Part II. International Institute for Aerospace Survey and Earth Sciences, 9/71. Revision 8/77.

[3] Bronick, C.J., and Lal, R. (2005). "Soil structure and management: a review." *Geoderma*, 124 (1-2), 3-22.

[4] Imani, R., Ghasemieh, H., and Mirzavand, M. (2014). "Determining and Mapping Soil Erodibility Factor (Case Study: Yamchi Watershed in Northwest of Iran)." *Open Journal of Soil Science*, 4(05), 168-173.

[5] Kavian, A., Azmoodeh, A., and Solaimani, K. (2014). “Deforestation effects on soil properties, runoff and erosion in northern Iran.” *Arabian Journal of Geosciences*, 7, 1941-1950.

[6] Kinnell, P.I.A. (2010). “Event soil loss, runoff, and the Universal Soil Loss Equation family of models: a review.” *Journal of Hydrology*, 385(1-4), 384-397.

[7] Loch, R., and Slater, B.K. (1998). “Soil Erodibility (Km) Value for Some Australian Soil.” *Australian Journal of Soil Research*, 36(6), 1045-1056.

[8] Manyiwa, T., and Dikinya, O. (2013). “Using Universal Soil Loss Equation and Soil Erodibility Factor to Assess Soil Erosion in Tshesebe Village, Northeast Botswana.” *African Journal of Agricultural Research*, 8(30), 4170-4178.

[9] Mitra, B., Scatte, H.D., Dixonb, J.C., and McKimmeya, J.M. (1998). “Applications of fuzzy logic to the prediction of soil erosion in a large watershed.” *Geoderma*, 86(3-4), 183-209.

[10] Panagos, P., Meusburger, K., Ballabio, C., Borrelli, P., and Alewell, C. (2014). “Soil erodibility in Europe: A high-resolution dataset based on LUCAS.” *Science of the Total Environment*, 479-480, 189-200.

[11] Pazhouhesh, M., Gorji, M., Taheri, S.M., Keshavarzi, A., and Pajoohesh, M. (2011). “Determination of Soil Erodibility Factor Using Fuzzy Rule Base System.” *International Journal of Environmental Sciences*, 1, 1874-1883.

[12] Poesen, J., and Ingelmo-Sanchez, F. (1992). “Runoff and sediment yield from topsoils with different porosity as affected by rock fragment cover and position.” *Catena*, 19(5), 451-474.

[13] Poesen, J.W., Torri, D., and Bunte, K. (1994). “Effects of rock fragments on soil erosion by water at different spatial scales: a review.” *Catena*, 23(1-2), 141-166.

[14] Rawls, W.J., Brakensiek, C.L., and Saxton, K.E. (1982). “Estimation of soil water properties.” *Transactions of the American Society of Agricultural Engineering*, 25(5), 1316-1320.

[15] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C. (1997). “Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).” *United States Department of Agriculture*, Agriculture Handbook, 703.

[16] Rubio, José. L., and Recatalá, L. (2006). “The relevance and consequences of Mediterranean desertification including security aspects.” *Desertification in the Mediterranean Region. A Security Issue*, 133-165.

[17] Schmidt, S., Ballabio, C., Alewell, C., Panagos, P., and Meusburger, K. (2018). “Filling the European blank spot-Swiss soil erodibility assessment with topsoil samples.” *Journal of Plant Nutrition and Soil Science*, 181(5), 737-748.

[18] Torri, D., Poesen, J., and Boreslli, L. (1997). “Predictability and Uncertainty of the Soil Erodibility Factor using a Global Dataset.” *Catena*, 31(1-2), 1-22.

[19] Tran, L.T., Ridgley, M.A., and Duckstein, L. (2002). “Application of Fuzzy Logic Based on the Revised Universal Soil Loss Equation.” *Catena*, 47(3), 203-226.

[20] USDA (1983) *National Soil Survey Handbook*, US Department of Agriculture, Natural Resources Conservation Service. National soil survey handbook, 430.

[21] Wang, L.X. (1996). *A Course in Fuzzy Systems and Control*. Prentice-Hall, New York.

[22] Wang, G., Gertner, G., Liu, X., and Anderson, A. (2001). “Uncertainty Assessment of Soil Erodibility Factor for Revised Universal Soil Loss Equation.” *Catena*, 46(1), 1-14.

[23] Williams, J.R. (1995). *The EPIC model*, Chapter 25. In Singh, V.P., Ed., Computer Models of Watershed Hydrology, Water Resources Publications, Highlands Ranch, CO.

[24] Wischmeier, W.H., and Smith, D.D. (1978). *Predicting Rainfall Erosion Losses*, a Guide to Conservation Planning, U.S. Department of Agriculture in Cooperation with Purdue Agricultural Experiment Station, USA.

[25] Wischmeier, W.H., Johnson, C.B., and Cross, B.V. (1971). “A soil erodibility nomograph for farmland and construction sites.” *Journal of Soil and Water Conservation*, 26(5), 189-193.

[26] Young, R.A., Onstad, C.A., Bosch, D.D., and Anderson, W.P. (1987). *AGNPS: an agriculture nonpoint source pollution model*. Conservation Research Report, 35, USDA/ARS, Washington (DC), USA.

2020 年 09 月 09 日 收稿

2020 年 10 月 12 日 修正

2021 年 01 月 21 日 接受

(本文開放討論至 2021 年 06 月 30 日)