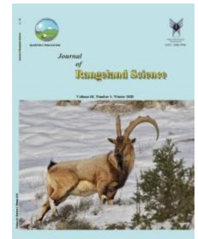
Contents available at ISC and SID

Journal homepage: www.rangeland.ir



Research and Full Length Article:

Soil Erosion Reduction by Implementing a Carbon Sequestration Project in East of Iran

Atefeh Gholami[A], Amir Sadoddin[B*], Majid Ownegh[C], Mohsen Hossein Alizadeh[D], Alireza Yari[E]
[A] PhD Candidate, Gorgan University of Agricultural Sciences and Natural Resources, Department of Arid Zone Management, Gorgan, Iran
[B] Associate Professor, Gorgan University of Agricultural Sciences and Natural Resources, Department of Watershed and Arid Zone Management, Gorgan, Iran, *(corresponding author). Email: amir.sadoddin@gmail.com
[c] Professor, Gorgan University of Agricultural Sciences and Natural Resources, Department of Watershed and Arid Zone Management, Gorgan, Iran
[D] Assistant Professor, Gorgan University of Agricultural Sciences and Natural Resources, Department of Watershed and Arid Zone Management, Gorgan, Iran
[E] Executive Manager of Carbon Sequestration Project, General Office South Khorasan, Birjand, Iran

Received on: 24/09/2018
Accepted on: 23/01/2019

Abstract. In this research, the impact of a carbon sequestration project, in the Hossein Abad Plain in Southern Khorasan Province of Iran, on the status of water and wind erosion was evaluated. The study area has a harsh climatic condition with low annual precipitation and is prone to well-known 120-day winds in summer. Since 2005, various soil conservation treatments (plantations, over-sowing, plantation aided by semi-circular rainwater harvesting structures) have been implemented in the area. The importance of this research is that so far there was no comprehensive assessment to indicate the impact of soil conversation measures on soil erosion. Therefore, current research aims to evaluate the effect of the carbon sequestration project on soil erosion during 2004 - 2016. Therefore, water and wind erosion was assessed by the Universal Soil Erosion (USLE) model and Iranian Research Institute of Forest and Rangelands Ekhtessasi – Ahmadi (IRIFR-E.A.) model, respectively. The general trend of water erosion using the USLE model indicates a reduction in soil erosion by greater than 19.9 t. ha^{-1}. yr^{-1} over the whole study area which is larger than 2300 km^2. Accordingly, all treatments had a significant impact on erosion in the study area whereby the greatest reduction in annual rate of erosion occurred in over-sown areas (by 5.92 t. ha^{-1}. yr^{-1}). The lowest erosion rate in 2016 was observed in the afforested areas (3.0 t. ha^{-1}. yr^{-1}). Wind erosion during 2004-2016 was improved from moderate and high erosion intensity classes to the low class in treated areas. According to the results of the USLE and IRIFR-E.A. models, the implemented carbon sequestration project has effectively reduced soil erosion in the study area. Therefore, the continuation of these treatments as well as extension programs to empower local communities is highly recommended.

Key words: Erosion, Carbon sequestration, Afforestation, Over-sowing, Water Harvesting

Introduction

Erosion and sedimentation are two problematic phenomena in Iran. Intensive short-term rainfall, sensitive geological formations and scattered vegetation are the most important factors for severe soil erosion in this country. At the same time, land use change and poor land management are major human factors contributing to land degradation (Akbari *et al.,* 2016). In order to prevent soil erosion and sedimentation in Iran, several efforts have been made, particularly focusing on vegetation rehabilitation. However, both the implementation and evaluation of natural resources rehabilitation projects require erosion and sedimentation mapping. Soil erosion and sedimentation are complex phenomena and many factors can affect their severity. Given the complexity of soil erosion processes, various methods have been developed for its evaluation. For example, direct methods such as artificial rain-simulators (Sheikh *et al.,* 2016) and tracer elements (Walling and He, 1999) as well as fast computer-based methods using aerial and satellite images and geographic software packages (Dabral *et al.,* 2008; Astorga *et al.,* 2018) could be mentioned.

Many erosion assessment methods have been designed for agricultural lands. For example, one could refer to the Universal Soil Loss Equation (USLE) which was first developed by Wischmeier and Smith (1965). Among other models used to study soil erosion, the modified USLE model (Zhang *et al.,* 2009; Pandey *et al.,* 2009; Ben *et al.,* 2018), Water Erosion Prediction Project Model (WEPP) (Flanagan and Nearing, 1995), Pacific Southwest Inter-Agency Committee (PSIAC) and Erosion Potential Model (EPM) (Tangestani, 2006; Lovrić and Tošić, 2018) can be mentioned. Among the proposed models for wind erosion assessment, one can also refer to Wind Erosion Equation (WEQ) and its modified version Revised Wind Erosion Equation (RWEQ) (Fryrear *et al.,* 1999; Fryrear and Bilbo, 2018) and the Iranian Research Institute of Forest and Rangelands Ekhtesasi – Ahmadi model (IRIFER-E.A.) (Sadoddin *et al.,* 2011; Ildermi and Moradi, 2016; Ildermi *et al.,* 2018). The USLE and IRIFR-E.A. models applied in this study to investigate water and wind erosion have been widely used in Iran. Esrey and Habicht (1988) using Quickbird satellite imageries and PESERA and USLE models examined soil erosion in an Alpine region of Switzerland. Their results showed that the USLE model provided an accurate evaluation of soil erosion. Munro *et al.* (2008) used the USLE model to determine the impact of rangeland management and restoration on soil erosion in Ethiopia and found that the USLE model provided an accurate measure for soil erosion. A comprehensive assessment of a long-term application of USLE model in steep forestlands of Japan was presented by Kitahara *et al.* (2000). Researchers believe that the corresponding model offers satisfactory results and can easily determine the amount of erosion using available data. Bayramin *et al.* (2009) evaluated the effect of land-use conversion on soil erosion using the USLE model in the Udhig area of Turkey. Rezaei *et al.* (2016) used the IRIFR-E.A. model and Landsat satellite images to study soil erosion in an area in south-western Iran and found an overall increase in wind erosion intensity in the study area.

In this research, the USLE and IRIFR-E.A. models have been used to evaluate water and wind erosion rate. Studies have shown that these models are suitable for estimating erosion in Iran (Tangestani, 2006; Sadoddin *et al.* 2011; Gholami, 2014; Ildermi and Moradi, 2016; Ildermi *et al.* 2018). The study area is important because in 2003, with the support of the Global Environment Facility (GEF) and the United Nations Development Program (UNDP), a project was initiated to rehabilitate degraded rangelands, sequester carbon and reduce erosion. Since the initial survey of soil erosion at the beginning of the project, no comprehensive and accurate evaluation of the project effectiveness to reduce soil erosion has been published. The results of this research can help managers to evaluate the success and impact of project on water and wind erosion. In this research, data analysis was done in the GIS environment, which has been very successful in the graphical representation of the results (De Roo, 1996). Evaluating erosion using the GIS tool can help managers to quickly and accurately assess erosion and facilitate monitoring of similar projects in the future. This study aimed to evaluate the impact of carbon sequestration project implementation on soil erosion in Hossein Abad Plain in South Khorasan Province of Iran.

Materials and Methods

Study area

The study area is located at 40 km away from east of Sarbisheh township in Southern Khorasan Province, in eastern Iran (Fig. 1). Based on the 25-year meteorological record of Sarbisheh Weather Station, the mean annual rainfall is about 167 mm, 60% of which falling in winter. The mean annual temperature in this region is 12.5 °C with July as the warmest month reaching the absolute maximum temperature of 42°C. January is the coldest month with an absolute minimum temperature of -19°C. In total, in 76 days of year, the temperature drops below zero degrees Celsius. The annual rate of evaporation is very high reaching at 3190 mm. Hossein Abad Plain has very scattered vegetation cover similar to a degraded semi-arid steppe. The Hossein Abad plain has an elevation of 1830 m ASL and is surrounded by volcanic mountains. Due to high grazing pressure during the past decades, vegetation cover has become severely degraded in the study area. In addition, demographic surveys show that the area comprises of 31 villages and 3290 inhabitants. A project entitled “Carbon Sequestration in Desertified Rangelands of Hossein Abad” was initiated in 2003 with the aim of carbon sequestration, soil erosion, and rehabilitation of vegetation cover with afforestation, over-sowing, and afforestation associated with crescent-like micro catchments for rainwater harvesting over 13572 ha of the degraded lands of the study area. The project was terminated in 2012. Water erosion in Hossein Abad Plain is considered negligible as this area annually receives a negligible amount of precipitation. Before the implementation of this project, wind erosion was severe due to sparse vegetation cover on the one hand and the activity of the 120-day winds in summers on the other hand (Hosseinalizadeh and Seyedalipour, 2009).

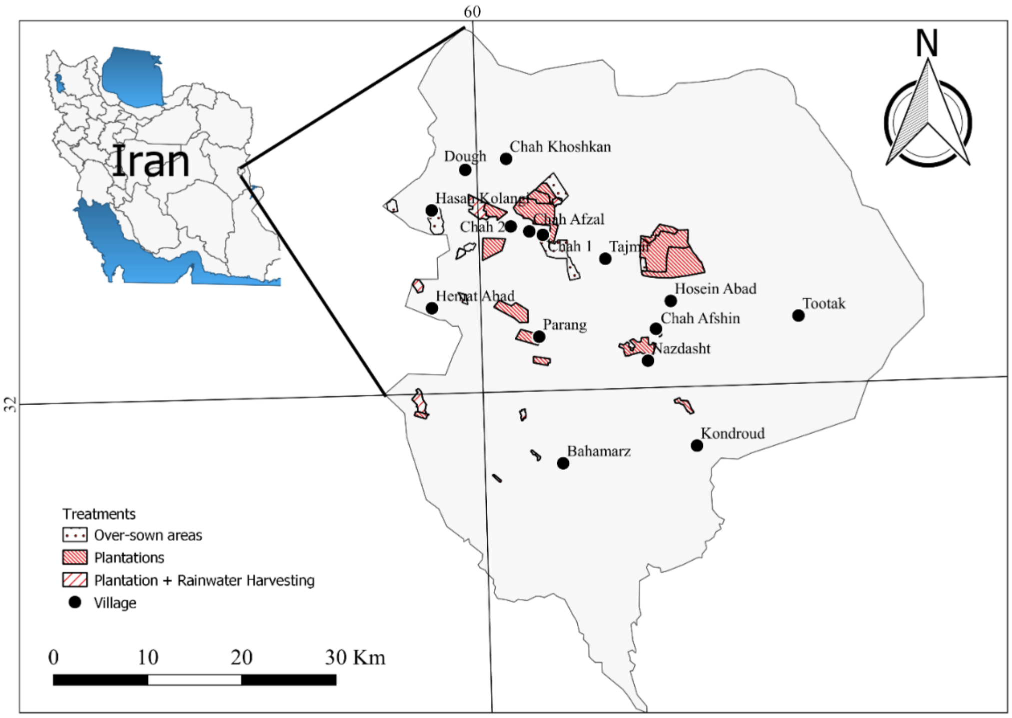


Fig. 1. Map of different vegetation rehabilitation sites in Hossein Abad region, South Khorasan Province, Iran

Assessment of water erosion using USLE model

In order to assess the amount of water erosion in this study, the USLE model was applied.

For measurement of water erosion, the general equation of the universal soil loss equation (USLE) was used as follows:

A = R.K.L.S.C.P (1)

Where:

A =the average annual soil loss (t. ha^{-1}. yr^{-1}, erosion classification in this model is presented in Table 1),

R =Rainfall Erosivity index (MJ. ha^{-1}. yr^{-1}),

K =the soil erodibility factor (t. ha. h. ha^{-1}. MJ^{-1}, mm^{-1}),

L =slope length,

S =the slope steepness,

C =cropping factor and

P = the conservation practices factor.

Below, each parameter of the USLE model is presented in more details:

Rainfall Erosivity Index (R) is the potential of precipitation for causing erosion, which is calculated based on the EI30 total precipitation energy (E) at 30-minute intensity (E30). Since the data of rainfall intensity are not available in the study area, the monthly precipitation of Sarbisheh station (2004-2005) was used to determine this parameter as follows (Wischmeier and Smith, 1978; Modified by Arnoldus, 1980):

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \log\left(P_i^2/P\right) - 0.08188\right)} \quad \text{(Equation 2)}$$

Where:

R =the rainfall erosivity factor in MJ. mm^{-1}. ha^{-1}.h^{-1}. yr^{-1},

P_i = the monthly precipitation in millimeters and

P = the annual precipitation in millimeters.

The Soil erosion factor K was calculated using the following equation (Wischmeier and Smith, 1978):

$$K = (2.1 \times 10^{-6} \times f_p^{1.14} \times (12 - P_{om}) + 0.0325(S_{struc} - 2) + 0.025(f_{perm} - 3) \quad (3)$$

Where:

$f_p = P_{silt} \times (100 - P_{clay})$ (4)

f_p=particle size parameter (dimensionless),

P_{om} =the percentage of organic matter (dimensionless),

S_{struc} = Soil structure index (dimensionless, which is considered to be 3 in this research for soils with a slightly developed structure) (Wischmeier and Smith, 1978),

f_{perm} =the soil permeability factor (dimensionless, which was considered to be 2 here) (Wischmeier and Smith, 1978) and

P_{clay} = the clay content (dimensionless).

Since there are no available data about the soil, the soil layers were obtained from the Global Gridded Soil Data project at soilgrids.org. On this website, soil information is presented from roughly 250 m to half a degree scales at various depths. The data used included the percentage of silt and clay and organic matter at the depth of 30 cm.

Topographical factor slope was determined based on the following equation (McCool *et al.*, 1987):

$L = (\frac{\lambda}{22.13})^m$ (5)

Where:

L = the slope length factor,

λ = the slope coefficient factor (m),

m = the dimensionless coefficient which depends on the slope and is given 0.5 for slopes above 5%, 0.4 for slope of 4% and 0.3 for slopes below 3%.

The slope percent was obtained using a digital elevation map. The 200-m cell size was used to investigate the slope length factor which is similar to that of many similar studies (Dabral *et al.*, 2008).

The slope gradient factor was obtained using the (McCool *et al.*, 1987) equation as follows:

$S = 10.8\sin(\Theta) + 0.03$ (6a)

$S = 16.8 sin\Theta - 0.50$ (6b)

Equation 6a is considered for slopes below 9% and equation 6b for slopes above 9%. In these two equations, S is the dimensionless gradient factor and Θ is the slope angle in degrees.

- Cover and management factors of vegetation status

Crop cover factor is referred as the loss of soil from arable land under specified conditions to the amount of erosion from a bare fallow plowed land at specific slope under the same rainfall condition.

In this study, MODIS Satellite data (2001 and 2013) were used. The area was divided into four classes of land covers (rangeland, settlements, plantations and shrub lands, croplands) and 0.4, 0.1, 0.1 and 0.20 were assigned as the corresponding coefficients (Dabral *et al.*, 2008), respectively for the crop protection factors. Crop management factor was also considered to be 0.25 for croplands, and 1 for other lands (Dabral *et al*., 2008).

After the estimation of erosion in different parts of the study area, the erosion classes were classified into five classes as mentioned in Table 1.

Table 1. Classification of erosion severity in USLE model (Dabral *et al.*, 2008)

Erosion severity class	*Model* USLE ($t.ha^{-1}.yr^{-1}$)
Negligible to slight	<6.7
Slight	6.7-11.2
Moderate	11.3-22.4
Severe	22.5-33.6
Very Severe	>33.6

The analysis was performed in ArcGIS environment and the paired t-test was used to compare the same plot over the study period between 2003 and 2016.

Assessment of wind erosion using IRIFR-E.A. model

Wind erosion was estimated using the Iranian Research Institute of Forest and Rangelands Ekhtesasi – Ahmadi model (IRIFR-E.A.) (Ahmadi *et al.* 2007); the first step in using the model is to prepare geomorphologic facies as work units. For this purpose, the geomorphologic facies was mapped by visual interpretation of the Google map images, and then in the ground trothing, the boundaries of these units were reviewed and corrected. In the field visit, for each facies, three rating forms were filled, and the scores were averaged to obtain a homogenous evaluation of erosion. The *IRIFR-E.A.* model has 9 factors that range from -5 to 20. These factors are presented in Table 2.

The sum of scores assigned to each facies indicates the amount and severity of wind erosion, which was determined by the weighted average. The wind erosion classes are given in Table 3.

Table 2. The factors of the IRIFR-E.A. model and their scoring interval (source: Ahmadi *et al.* 2007)

NO	Factors of wind erosion and sedimentation	Range
1	Lithology	0-10
2	Landform and terrain	0-10
3	Wind speed and conditions	0-20
4	Soil and soil surface cover	-5 to -15
5	Vegetation condition and density	-5 to -15
6	Signs of soil erosion at the surface	0-20
7	Soil moisture	0-10
8	Type and distribution of wind sedimentary accumulations	0-10
9	Land use and management	-5 to -15

Table 3. Annual sediment production and soil erosion classes in IRIFR-E.A. model (source: Ahmadi *et al.* 2007)

Wind erosion intensity classes	Annual sediment yield ($t\ km^{-2}\ yr^{-1}$)	*Wind erosion rate*
Very low (class 1)	<250	<25
Low (class 2)	250-500	25-50
Medium (class 3)	500-1500	50-75
High (class 4)	1500-6000	75-100
Very high (class 5)	>6000	>100

Results

Estimation of water erosion using USLE model

The rain erosivity factor was determined based on equation 2 as 96.7 $MJ.h^{-1}.ha^{-1}.yr^{-1}$. Two factors of slope length and intensity were computed using a digital elevation map with a 200-meter cell size (Dabral *et al.*, 2008). The soil erodibility factor which indicates the soil sensitivity to erosion was also calculated in the range of 0.19 to 0.25 and its spatial distribution was determined. Two factors of land management and crop protection were also prepared using the MODIS Satellite images. Given that the MODIS land cover data were only available until 2013 and researchers were not able to distinguish between the treated areas and the natural rangelands, the vector map of the treatments were converted into a 200-meter gridded raster and combined with the land cover map. Then, each of the classes of this map received its proportional coefficient and eventually two layers of land management and crop protection were prepared. By combining each of the six factors of rainfall erosivity, soil erodibility, slope length, slope steepness, crop protection and land management, the spatial distribution of soil erosion were computed in ArcMap software environment in a 200-meter cell size (Fig. 2). In view of the fact that the rainfall erosivity index was considered constant for the whole area, the amount of erosion seems to be influenced more by elevation and type of land management. Accordingly, minimum erosion rate occurred on plantations reaching at 6 $t.\ ha^{-1}.yr^{-1}$, and the highest erosion rate occurred in the East and South of the study area (up to maximum rate of 44 t. ha^{-1}. yr^{-1}) (data not shown). It seems that the treatments have been successful in reducing erosion, and thus need to be extended to other areas that are affected by erosion.

As shown in Fig. 2, there is a significant difference in erosion rate between the initiation and the termination of the project. According to the information presented in Fig. 3, a major part of the study area with an area of 1524.2 km^2 (65.2%) fell into range of slight to moderate erosion classes. The 'very severe' class with an area of 68.6 km^2 (2.9%) had the smallest contribution to the total soil erosion in the study area.

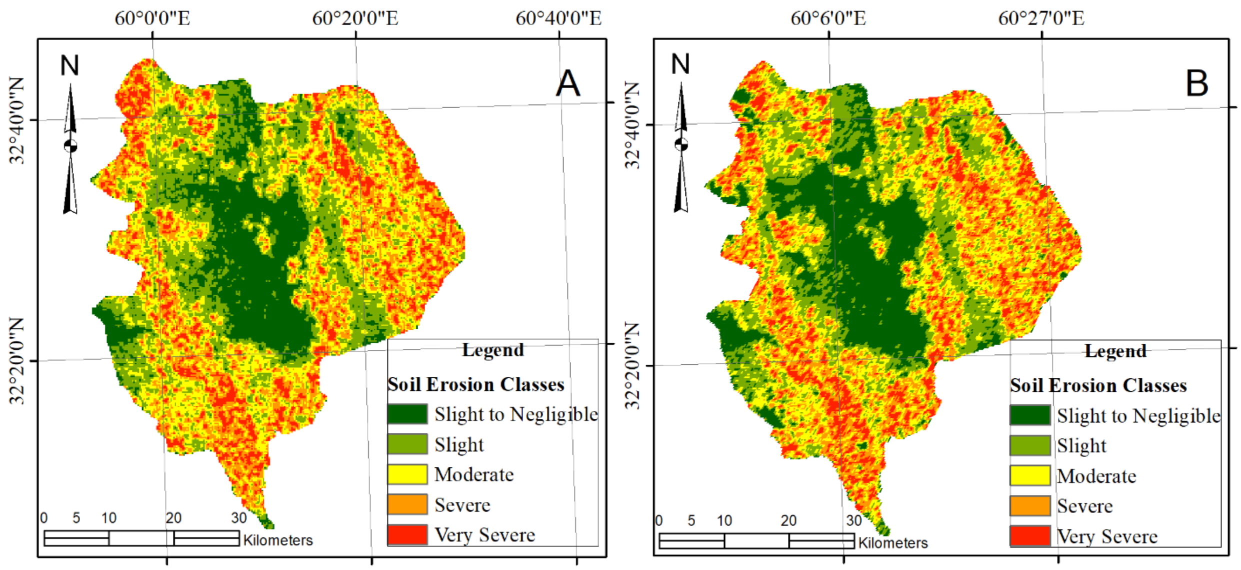


Fig. 2. Estimation of annual water erosion per hectare between 2004 (A) and 2016 (B) using the Universal Soil Loss Equation in the Hossein Abad area, South Khorasan Province

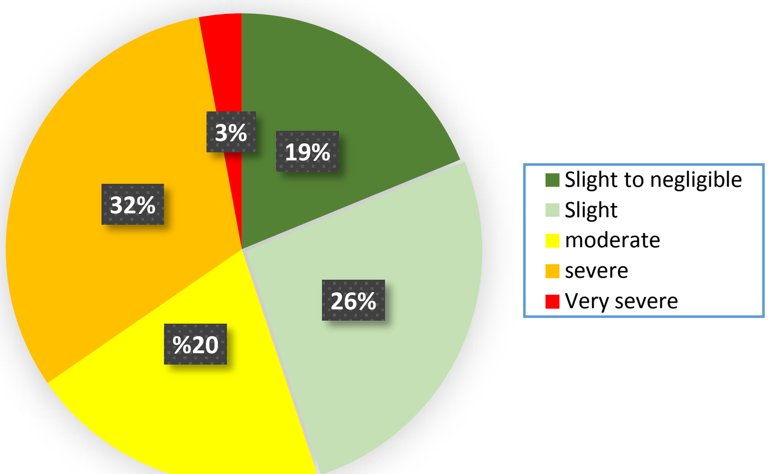


Fig. 3. Classification of water erosion based on severity using the Universal Soil Loss Equation in the Hossein Abad area of South Khorasan Province, Iran

Estimation of wind erosion using IRIFR-E.A. model

In this research, geomorphologic facies were considered as the work units for the assessment of wind erosion. To identify geomorphological facies, various facies were initially mapped onto Google Earth images. In the next step, new facies were added to the map after several field visits. Accordingly, in this region, 10 facies were identified as shown in Fig. 4 and Table 4. The largest portion of the area was covered with a very scarce vegetation. In most cases, the soil particles were eroded with only gravel and coarse particles remaining on soil surface. The salty and swollen land had the smallest area in the region with an average of 0.8% (Fig. 4, Table 4).

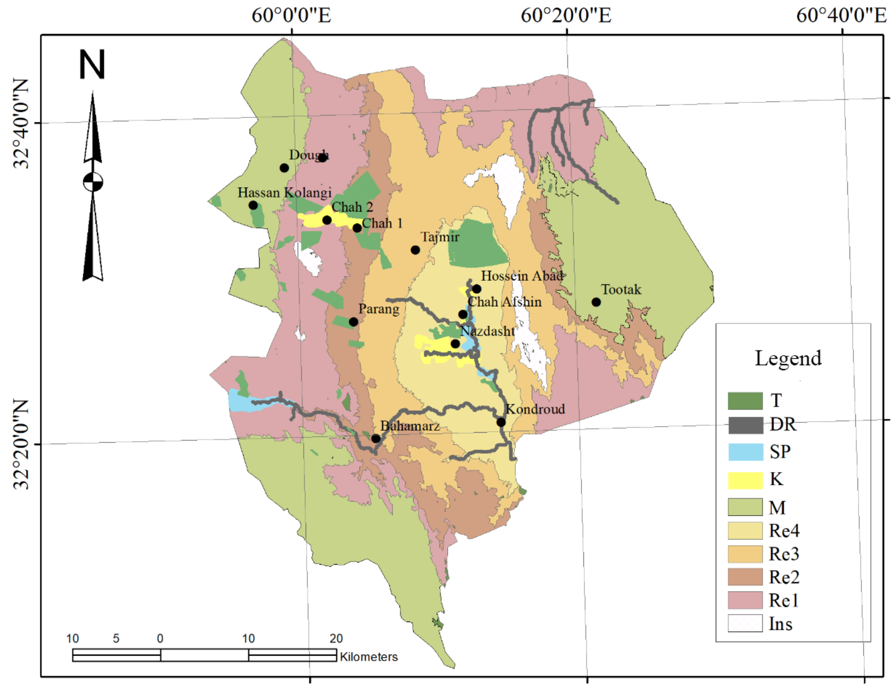


Fig. 4. Geomorphologic facies identified in the carbon sequestration project for the Hossein Abad Watershed, South Khorasan Province (abbreviations used are described in Table 4)

Table 4. Areal coverage of facies identified in the carbon sequestration project for the Hossein Abad plain, South Khorasan Province

Name of the facies	Area (km^2)	%	Codes on map
Croplands	27.52	1.2	K
Salty lands and wetlands	20.0	0.8	SP
Dry river beds	55.58	2.3	DR
Desert pavement with a moderate particle size and planted vegetation cover	88.05	3.7	T
Mountain unit and rock outcrops	633.33	27.2	M
Desert pavement with very severe water erosion and coarse particles	288.33	12.4	Re1
Desert pavement with severe water erosion and coarse particles and low vegetation cover	440.62	18.8	Re2
Desert pavement with moderate water erosion and medium-sized particles and low vegetation cover	264.84	11.4	Re3
Desert pavement with low water erosion and vegetation cover with coarse-grained sand particles	465.23	19.9	Re4
Inselberg	53.48	2.3	Ins
Total	2337	100	

In Table 5, the scores assigned to each facies in Hossein Abad plain based on nine factors involving lithology, topography, wind speed and direction, soil vulnerability to erosion, vegetation cover, signs of wind erosion, soil moisture, existence of wind-blown deposits and land management are presented. The calculated scores are the total scores assigned to each facies based on the judgments of two experts. According to Table 5, the highest amount of annual sedimentation was found on salty lands and wetlands, which also form the smallest portion of the area. The lowest amount of wind erosion occurred in desert pavements with a medium-sized particles and in planted areas by 29 $t.ha^{-1}.yr^{-1}$, which falls in the very low erosion class (with annual sedimentation of less than 25 $t.ha^{-1}.yr^{-1}$). Mountain and inselbergs are also in the moderate class of erosion due to lack of surface soil and high resistance of volcanic rocks to agents of erosion. Most of the area is covered with desert pavements with moderate water erosion and medium-sized particles which gives an indication that soil particles are worn out by the wind. These plains have a very scarce vegetation cover with decreasing its density from the mountainside toward the plain. Also, desert pavements close to the mountainous area generally show severe erosion and active to semi-active fans with coarse coatings. Therefore, wind erosion in this unit was less than lower elevations with more gentle desert pavements. The spatial distribution of wind erosion is presented in Fig. 5.

Table 5. Scores assigned to each facies within the project site in Hossein Abad Plain, South Khorasan Province based on the IRIFR-E.A. Model

Facies Names	1	2	3	4	5	6	7	8	9	Total score	Severity class
Croplands	8.1	8.1	20	5.3	1.2	1.2	5	1.1	-3	48.8	2
Salty and wetlands	9.5	8.9	20	12.3	15	18.2	5.6	5.6	15	110.1	5
Dry river beds	8	7.9	20	10.2	14.2	11.4	4	3.9	15	94.6	4
Desert pavement with medium sized particles and planted vegetation cover	4.8	4.2	20	2.2	-5	1.2	4.2	1.5	-5	29	2
Mountain unit, rocky deposits, rock outcrops	0	1.1	20	-5	13	0	9.5	0	10	48.6	2
Desert pavement with very severe water erosion and coarse particles	1.8	2.3	20	1.2	3.5	1.4	6.8	2.5	1.2	45.2	2
Desert pavement with severe water erosion and coarse particles and low vegetation cover	2.2	5.3	20	5.9	6.2	5.5	6.5	4.2	3.1	58.9	3
Desert pavement with moderate water erosion and medium-sized particles and low vegetation cover	4.2	8.2	20	6.3	7.3	6.8	5.9	5.8	4.5	69	3
Desert pavement with low water erosion and vegetation cover with coarse-grained sand particles	7.2	8.6	20	10.1	9	10.8	3.8	9.1	7.5	77.5	4
Inselberg	1.1	1.9	20	1.2	12	4.1	8.7	1.5	13.5	64	3

Numbers 1-9 stand for lithology, topography, wind speed and direction, soil vulnerability to erosion, vegetation cover, sings of wind erosion, soil moisture, existence of wind-blown deposits, land management

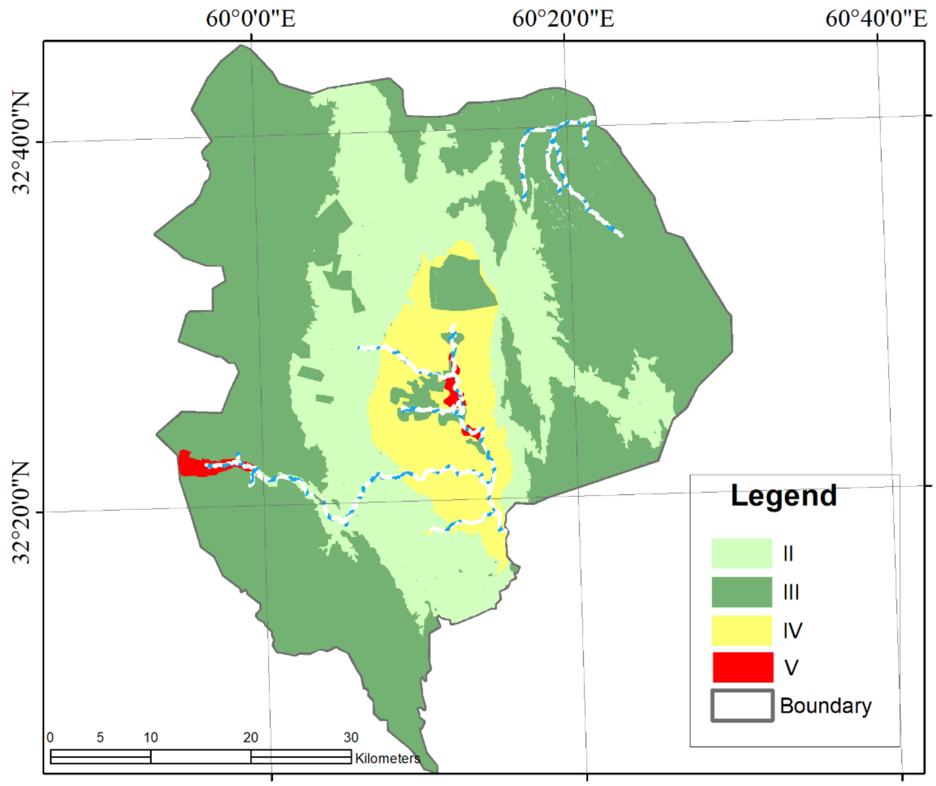


Fig. 5. Project site sensitivity to wind erosion (Hossein Abad plain, South Khorasan Province, Iran). Greek letters II, III, IV and V respectively stand for 25-50, 50-75, 75-100 and >100 t. ha^{-1}. yr^{-1} sedimentation potential

The comparison between wind erosion in 2004 (the first year of project implementation) and in 2016 is shown in Fig. 6. Accordingly, during this time period, the studied area has experienced an improvement in wind erosion class in a way that classes 3 and 4 improved to class 2. Therefore, it can be concluded that vegetation treatment has been successful in controlling wind erosion.

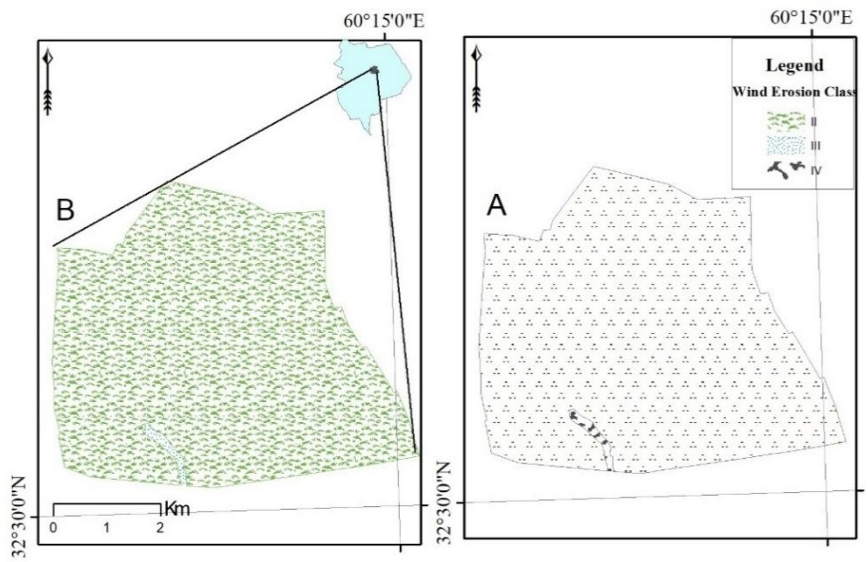


Fig. 6. Differences between wind erosion classes in IRIFR-E.A. model in Hossein Abad area. The study areas in 2004 (A) and 2016 (B) are the same Greek letters II, III, IV respectively stand for 25-50, 50-75, 75-100 t. ha^{-1}. yr^{-1} sedimentation potential

Impact of carbon sequestration project on water and wind erosion

In order to study the effect of carbon sequestration project in Hossein Abad area, water and wind erosion were evaluated in two-time intervals using USLE and IRIFR-E.A. models. The present results from the general survey of water erosion in two time periods using the USLE model (Fig. 2) indicated a reduction in erosion by different treatments (Table 6). Accordingly, the greatest reduction occurred in over-sown areas (5.92 m^3. ha^{-1}. yr^{-1}) and the minimum erosion rate occurred in afforestation areas (3.0 m^3.ha^{-1}.yr^{-1}). Therefore, given the total area of all treatments, the implementation of this project has reduced water erosion by 47,000 tons (Fig. 2).The study of wind erosion changes during 2004 and 2016 also indicated a reduction in wind erosion on treated areas compared with the untreated areas. Since soil erosion was only studied for a limited area in the region in 2004, same treatment was considered in 2016 (Fig. 6). Accordingly, wind erosion rate was improved from classes 3 and 4 in 2005 (moderate and high) to 2 in 2016. Therefore, it can be concluded that not only in terms of the project's duration, both water and wind erosions in the region have reduced, but there has also been a significant difference between the treated and untreated areas.

Table 6. Effect of different treatments on water erosion evaluated by USLE model over 2004 and 2016 in Hossein Abad area. The values provided for erosion are in m^3. ha^{-1}. yr^{-1}

Treatment	water erosion (m^3. ha^{-1}. yr^{-1})		No. of pixels	Total Area (ha)	Total Reduction ($t.ha^{-1}.yr^{-1}$)
	Year 2004	Year 2016			
Over-sown areas	10.42^a	4.50^b	340	1645	5.92
Afforestation + Rainwater Harvesting	12.50^a	6.31^b	189	914	6.19
Afforestation	8.04^a	3.0^b	1313	6354	5.04

Different letters in each rows indicate significant difference at the level of 95% using t test

Discussion and Conclusions

The carbon sequestration project in the Hossein Abad plain of Southern Khorasan Province has been implemented with the aim of improving soil properties through vegetation rehabilitation and soil organic carbon improvement. The project's executing team also aimed at reducing soil erosion in the area. Alongside, the improvement of the environmental conditions, the empowerment of the people and the improvement of biological conditions were also the agendas to prevent from the migration of the villagers. Thus, except a number of reports on the short-term project outcomes, a comprehensive assessment of the project achievements has not been made available or published. Therefore, the effectiveness of this project which has been implemented by receiving national and international supports has been studied with USLE, and IRIFR-E.A. models. These models have been evaluated in several cases in the country and have provided reliable results. Due to the harsh environmental conditions (high temperature and low precipitation), the study area has a very scattered vegetation cover which is an important factor contributing to erosion (Zadsar and Azimi, 2016). The scarcity of rainfall which rarely exceeds 160 mm annually greatly reduces the likelihood of water erosion. Lack of soil organic matter due to low vegetation cover has made the condition susceptible to water and wind erosion. Li *et al.* (2017) also pointed out low organic matter and reduced aggregate formation as major factors contributing to soil erosion. Rotich *et al.* (2018) also believe that land management by affecting soil organic matter content could affect soil and land quality. Therefore, the implementation of the carbon sequestration project can make an important contribution to reduce erosion by increasing soil organic carbon content. According to the findings, implementation of this project has reduced water erosion in the area by greater than 19.9 tons per ha per year which is a significant result. Likewise, wind erosion has also been reduced significantly on treated plots, as previously indicated by the improvement in wind erosion rate in one of the afforested areas. The estimation of wind erosion in the region using the IRIFR-E.A. model indicated severe erosion on fine-grained desert pavements in the center of the area, dried river beds, and wet salty plains. Hossein Abad is exposed to the persistent of harsh weather due to the local winds of so called “120-days Winds” during summer time. Thus, erosion risk is high in this area. By moving towards higher elevations and increasing the proportion of coarse-grained particles and rocks, erosion risk also decreases. Gholami (2014) also used the IRIFR-E.A. model to study the rate of wind erosion in the Sarbisheh plain of Southern Khorasan Province. Authors argued that crop lands had less wind erosion rates than other land-uses. In this connection, river beds also showed to have the lowest degree of erosion, which is not consistent with the results of this research. According to the field survey, the river beds are shallow and wide with very poor vegetation which may have been due to the high salinity of runoff in these rivers. The relevant substrate is rich in fine-grained elements that is contributing to wind erosion with apparent signs of severe wind erosion.

By summing up the results of the two models, Hossein Abad plain is subject to severe wind erosion and slight water erosion. This finding can be supported by low activity of waterways in the foothills and the effects of wind-blown particles in the flat plains. Short and severe rainfalls during winter and spring, recent drought and reduced vegetation, heavy grazing, and salinity have contributed to the increase in the severity of wind erosion. Obviously, on the foothills, due to the removal of fine particles by the wind, mainly coarse particles have remained on the surface that can protect the soil from erosion in the future.

Major lithological formations of the study area are volcanic which can hinder vegetation cover establishment due to the increase in the temperature of the surrounding environment. Therefore, it seems that it is the main problem in flat areas of the plain. However, given the large area of the project site, the undertaken measures seem to be insufficient. Based on field observations, there was a significant reduction in wind erosion on treated sites. The assessment of the overall erosion rate in the area also showed a significant reduction in water and wind erosion mainly on treated areas. Therefore, implementation of this project has temporally and spatially improved wind erosion condition of the region. Thus, according to the findings of this research, it seems that vegetation rehabilitation should be further pursued in the plain and a special attention should be paid to dried river beds. The results indicate that carbon sequestration project implemented in the form of afforestation, over-sowing and afforestation along with rainwater harvesting have been able to significantly reduce the severity of erosion in the area. Indeed, the implemented measures had less effects on water erosion due to low annual precipitation in the area. The results obtained from the USLE model is also consistent with this claim. On the other hand, the implemented project has been able to significantly reduce the severity of wind erosion on treated areas. In general speaking, researchers believe that the implementation of the carbon sequestration project in Hossein Abad area was successful.

Acknowledgments

Researchers hereby acknowledge the efforts of the project team to provide the opportunity to visit and stay in the region. Moreover, they would like to thank Gorgan University of Agricultural Sciences and Natural Resources for its support.

References

Ahmadi, H, Ekhtesasi, M. R., and Hemati, N. A., 2007. Estimation and comparison of water and wind erosion sedimentation potential by MPSIAC and IRIFR-E.A. models in semi-arid regions (Case study: Nematabad Watershed in Birjand). Iranian J Nat. Res. 60(1): 1-11

Akbari, M., Ownegh, M., Asgari, H. R., and Khosravi, H., 2016. Soil erosion risk assessment using the CORINE Model (Case Study: Semi-Arid Region in Golestan Province, Iran). Des. Ecos. Eng. J., 5(12), 63-78.

Arnoldus, H. M. J., 1980. An approximation of the rainfall factor in the Universal Soil Loss Equation. In (pp. 127-132). Chichester: John Wiley and Sons Ltd.

Astorga, R. T., de los Santos Villalobos, S., Velasco, H., Domínguez-Quintero, O., Cardoso, R. P., dos Anjos, R. M., and Mabit, L., 2018. Exploring innovative techniques for identifying geochemical elements as fingerprints of sediment sources in an agricultural catchment of Argentina affected by soil erosion. Env. Sci. Pol. Res., 25(21), 20868–20879.

Bayramin, I., Basaran, M., Erpul, G., Dolarslan, M., and Canga, M. R., 2009. Comparison of soil organic carbon content, hydraulic conductivity, and particle size fractions between a grassland and a nearby black pine plantation of 40 years in two surface depths. Env. Geo. 56(8), 1563-1575.

Ben, R., Hermassi, T., and Habaieb, H., 2018. Water erosion modeling in a Mediterranean semi-arid catchment using USLE/GIS (El Gouazine, Central Tunisia). J. New Sci., 50, 3071-3081.

Dabral, P. P., Baithuri, N., and Pandey, A., 2008. Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Res. Manage., 22(12), 1783-1798.

De Roo, A. P. J., 1996. Soil erosion assessment using GIS. In Geographical information systems in hydrology (pp. 339-356). Dordrecht, Netherlands: Springer.

Esrey, S. A., and Habicht, J. P., 1988. Maternal literacy modifies the effect of toilets and piped water on infant survival in Malaysia. Am. J. Epidemiol., 127(5), 1079-1087.

Flanagan, D. C., and Nearing, M. A., 1995. USDA-Water Erosion Prediction Project: Hillslope profile and watershed model documentation (Vol. 10). NSERL report.

Fryrear, D. W., and Bilbro, J. D., 2018. Mechanics, modeling, and controlling soil erosion by wind. In Advances in Soil and Water Conservation (pp. 39-49). New York, USA: Routledge.

Fryrear, D. W., Sutherland, P. L., Davis, G., Hardee, G., and Dollar, M., 1999. Wind erosion estimates with RWEQ and WEQ. Paper presented at the Proceedings of Conference Sustaining the Global Farm, 10th International Soil Conservation Organization Meeting, May 24-29, 1999, Purdue University.

Gholami, M., 2014. Comparison of Wind Erosion Potential in Agricultural and Non-Agricultural Lands Using IRIFR Model in the Mokhtaran Plain Sarbisheh. (M.Sc.), University of Zabol, Iran. 132 pages. (In Persian)

Hosseinalizadeh, M., and Seyedalipour, H., 2009. Temporal changes of wind erosion a case study of the site of an international carbon sequestration project in Hossein Abad Ghinab. Paper presented at the 5th National Conference on Watershed Management Sciences and Engineering, 23-25 May, 2009, Karaj, Iran. (In Persian)

Ildermi, A. R., and Moradi, M., 2016. Assessment of wind erosion severity using the IRIFR-EA model (in Ghahavand Plain of Hamedan Province). J. Geog. Plan., 21(60), 43-60.

Ildermi, A. R., Moradi, M., and Ghorbani, M., 2018. Invest the Effect of the Intensity of Wind Erosion and Desertification on the Destruction of the Habitat of Hamedan Region. J. Geog. Plan., 29(1), 21-42.

Kitahara, H., Okura, Y., Sammori, T., and Kawanami, A., 2000. Application of universal soil loss equation (USLE) to mountainous forests in Japan. J. For. Res., 5(4), 231-236.

Li, Z., Liu, C., Dong, Y., Chang, X., Nie, X., Liu, L., and Zeng, G., 2017. Response of soil organic carbon and nitrogen stocks to soil erosion and land use types in the Loess hilly–gully region of China. Soil Till. Res., 166, 1-9.

Lovrić, N., and Tošić, R., 2018. Assessment of soil erosion and sediment yield using erosion potential method: case study-Vrbas River basin (B&H). Bull. Serb. Geog. Soc., 98(1).

McCool, D. K., Brown, L. C., Foster, G. R., Mutchler, C. K., and Meyer, L. D., 1987. Revised slope steepness factor for the Universal Soil Loss Equation. Trans. ASAE, 30(5), 1387-1396.

Munro, R. N., Deckers, J., Haile, M., Grove, A. T., Poesen, J., and Nyssen, J., 2008. Soil landscapes, land cover change and erosion features of the

Central Plateau region of Tigrai, Ethiopia: photo-monitoring with an interval of 30 years. Catena, 75(1), 55-64.

Pandey, A., Chowdary, V. M., and Mal, B. C., 2009. Sediment yield modelling of an agricultural watershed using MUSLE, remote sensing and GIS. Paddy Water Env., 7(2), 105-113.

Rezaei, M., Sameni, A., Shamsi, S. R. F., and Bartholomeus, H., 2016. Remote sensing of land use/cover changes and its effect on wind erosion potential in southern Iran. Peer J, 4, e1948.

Rotich, H., Onwonga, R., Mbau, J., and Koech, O., 2018. Soil Organic Carbon Content and Stocks in Relation to Grazing Management in Semi-Arid Grasslands of Kenya. J. Rang. Sci., 8(2), 143-155.

Sadoddin, A., Akhzari, D., and Sheikh, V., 2011. Prediction of the vegetation management impacts on reduction of wind erosion risk in the southern parts of the Varamin Plain, Iran. Desert, 16(2), 131–140.

Sheikh, V. B., Jafari Shalamzari, M., Farajollahi, A., and Fazli, P., 2016. Soil erosion under simulated rainfall in loess lands with emphasis on land-use, slope and aspect. Ecopersia, 4(2), 1395–1409.

Tangestani, M. H., 2006. Comparison of EPM and PSIAC models in GIS for erosion and sediment yield assessment in a semi-arid environment: Afzar Catchment, Fars Province, Iran. J. Asian Earth Sci., 27(5), 585–597.

Walling, D. E., and He, Q., 1999. Improved models for estimating soil erosion rates from cesium-137 measurements. J. Env. Qual., 28(2), 611-622.

Wischmeier, W. H., and Smith, D. D., 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: Guide for selection of practices for soil and water conservation (Vol. 282). Washington, USA: Agricultural Research Service, US Department of Agriculture Washington DC.

Wischmeier, W. H., and Smith, D. D., 1978. Predicting rainfall erosion losses-a guide to conservation planning. Maryland, USA: USDA, Science and Education Administration.

Zadsar, M., and Azimi, M., 2016. Using SWAT Model to Investigate the Impact of Rangeland Management Practices on Water Conservation (Case Study: Gorganroud Watershed, Golestan, Iran). J. Rang. Sci., 6(4), 309-319.

Zhang, Y., Degroote, J., Wolter, C., and Sugumaran, R., 2009. Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS framework to assess soil erosion risk. Land Deg. Develop. 20(1), 84-91.

کاهش فرسایش خاک بر اثر اجرای پروژه ترسیب کربن در شرق ایران

عاطفه غلامی[الف*]، امیر سعدالدین[ب]، مجید اونق[ج]، محسن حسینعلیزاده[د]، علیرضا یاری[ه]

[الف] دانشجوی دکتری، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گروه مدیریت اراضی بیابانی، گرگان، ایران

[ب] دانشیار، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گروه آبخیزداری و مدیریت مناطق بیابانی، گرگان، ایران

[*](نویسنده مسئول)، پست الکترونیک: amir.sadoddin@gmail.com

[ج] استاد، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گروه آبخیزداری و مدیریت مناطق بیابانی، گرگان، ایران

[د] استادیار، دانشگاه علوم کشاورزی و منابع طبیعی گرگان، گروه آبخیزداری و مدیریت مناطق بیابانی، گرگان، ایران

[ه] مدیر اجرایی پروژه بین المللی ترسیب کربن، دفتر مرکزی استان خراسان جنوبی، بیرجند، ایران

چکیده. در این پژوهش، اثر اجرای پروژه ترسیب کربن بر وضعیت فرسایش آبی و بادی در دشت حسین آباد غیناب خراسان جنوبی مورد بررسی قرار گرفت. این منطقه به دلیل قرار داشتن در معرض بادهای صد و بیست روزه و کمبود بارش سالانه شرایط اقلیمی بسیار دشواری دارد. به همین دلیل از سال ۱۳۸۴، تیمارهای مختلفی (شامل نهالکاری، بذرپاشی و نهالکاری با کمک هلالی‌های آبگیر) جهت حفاظت از خاک اجرا شده است. اهمیت این تحقیق در آن است که تاکنون ارزیابی جامعی از چگونگی تأثیر این پروژه بر فرسایش منطقه منتشر نشده است. بنابراین، در این پژوهش اثرگذاری پروژه ترسیب کربن بر فرسایش خاک در بازه زمانی سال های ۱۳۸۴ تا ۱۳۹۶ مورد بررسی قرار گرفت. برای ارزیابی فرسایش آبی و بادی به ترتیب از مدل جهانی فرسایش خاک (USLE) و مدل پیشنهادی موسسه تحقیقات مراتع و جنگل‌ها اختصاصی ـ احمدی (IRIFR-E.A.) استفاده شد. نتایج حاصل از مدل USLE نشان دهنده کاهش بیش از ۱۹/۹ تن در هکتار در سال فرسایش آبی در هر سال در کل منطقه می باشد (در سراسر منطقه مطالعاتی با مساحت بیش از ۲۳۰۰ کیلومتر مربع). در همین راستا، تمام تیمارها بر کاهش فرسایش تأثیر معنی‌دار داشته‌اند، در حالی که بیشترین کاهش فرسایش در مناطق بذرپاشی شده مشاهده شده است (۵/۹۲ تن بر هکتار در سال) و کمترین فرسایش نیز در مناطق نهال‌کاری شده دیده شد (۳ تن بر هکتار در سال). از نظر کاهش فرسایش بادی در این دوره (۱۳۹۶-۱۳۸۴) نیز کلاس فرسایش بادی از متوسط تا شدید به کلاس فرسایش کم بهبود یافته است. بر اساس نتایج بدست آمده از دو مدل USLE و .IRIFR-E.A به نظر می‌رسد اجرای پروژه ترسیب کربن به صورت موثری فرسایش خاک را در منطقه مورد مطالعه کاهش داده است. بنابراین، پیشنهاد می‌شود که نه تنها تیمارهای اجرا شده ادامه یابند، بلکه در کنار آن‌ها برنامه‌های ترویجی جهت توانمندسازی جوامع محلی نیز در نظر گرفته شوند.

کلمات کلیدی: فرسایش، ترسیب کربن، نهالکاری، بذرپاشی، استحصال آب