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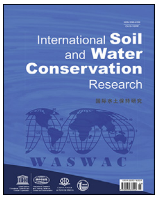

Original Research Article

Assessment of deforestation impact on soil erosion in loess formation using ^{137}Cs method (case study: Golestan Province, Iran)

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ABSTRACT

Golestan, a province in the North-East of Iran, is characterized by high coverage of loess deposits. Since 1963, the area has experienced approximately 200,000 ha deforestation due to land-use changes in agriculture and increasing demand for wood. Approximately, 110,000 ha of the clear-cut lands are under dry-farming, mainly for wheat cropping, and about 86,000 ha have been reforested. This IAEA funded project is the first attempt to use nuclear techniques in the East of Hircanian Forest for determination of on-site impacts of deforestation due to two land-use changes (i.e. dry farming and reforestation). Practicing long-term dry-farming led to 60% soil losses with a mean rate of 2 mm per year. The net erosion rate of croplands on loess deposits in the study area was 32.27 t ha^{-1} yr^{-1}. Reforestation, cultivation of even-aged Cypress trees since 1993, showed 13 to 60 percent effectiveness in soil conservation. Dry-farming land use resulted in the loss of 95 t ha^{-1} soil organic carbon (SOC) stock at a mean rate of 1.7 t ha^{-1} over 54 years. Cultivating Cypress trees successfully restored the SOC content by 100% compared with the SOC in original forests. The conversion of dry-farming lands to orchards of olive trees since 2004, brought more income for farmers but were less effective in soil conservation because of low canopy cover of olive trees. Our data provide key information and guidance for land users and decision-makers about implementing strategic and sustainable conservation practices to restore degraded land.

1. Introduction

Land-use changes such as clear-cutting of forests hasten soil degradation (erosion) in catchment areas worldwide (Gharibreza et al., 2013a, 2013b, , 2013c). Deforestation is known as one of the most unsustainable land-use changes that lead to a wide range of on-site and off-site negative impacts. These include soil and nutrient losses, increased emission of greenhouse gases (GHGs), loss of biodiversity, loss of habitats, migration of animals, and increased incidents of the landslide, debris flow, and floods which are well recognized on-site impacts of deforestation. Besides, increasing of sediment transport and sedimentation in reservoirs, wetlands, lakes, shoaling of coastal sedimentary environments, severe eutrophication and pollution of water and sediment resources, climate change and socio-economic impacts are the main results among off-site impacts (Mohamed Abd Elbasit et al., 2013; FAO, 2015, p. 253; Indarto, 2016; Tejaswi and Mutaqin, 2007, p. 49; Gharibreza & Ashraf, 2014). Besides, the short and long-term socio-economic effects of deforestation affected incomes which were dependent on the forest.

Land development projects, agriculture, mining, logging, urbanization and rural settlements, cattle ranching, transport, power plants, commercial oil palm plantations, and utilization of wood fuel are known as the main driving forces for deforestation (Kaimowitz & Angelsen, 1998, p. 153; Gharibreza & Ashraf, 2014; Gharibreza et al., 2013a, 2013b, b). Burning and clear-cutting are the most common destructive methods that have been applied during deforestation

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over the last decades. Alternative methods such as strip, shelterwood, and selective cutting were also used for wood harvesting around the world. On the other hand, silvicultural systems have been used for reforestation of cleared cut lands for industrial wood demands.

These systems reflect the type of forest structure remaining after the initial harvest. Two classes of silvicultural systems can be recognized; even-aged and uneven-aged. Even-aged systems generally create stands where the trees are approximately the same age or one age class. However, sometimes, even-aged systems can result in two distinct age classes of trees when some older trees are left behind after harvesting. Clear cutting, seed tree, and shelterwood are generally considered to be even-aged silvicultural systems. Uneven-aged systems, on the contrary, aim at creating or maintaining, by the selection, stands to consist of trees with several distinct age classes.

Degradation of the forest by converting forest land to dry-farming and silvicultural systems is common in Iran but their on-site impacts on soil redistribution are still unknown. The effects of these types of land use on soil redistribution rates were evaluated in this study.

Evaluation of empirical, conventional, and nuclear-based methods (Evans et al., 2017; IAEA, 1998) has resulted in the application of the nuclear technique of ^{137}Cs to estimate soil redistribution rates on deforestation-induced land uses in the study area. Therefore, the Technical Cooperation (TC) project between Iran and the International Atomic Energy Agency (IAEA), IRA 5013 was established to find out the effects of deforestation and afforestation on soil erosion in the North of Iran using fallout radionuclides (FRNs) techniques. The study method was supervised by the IAEA experts.

Cesium-137 (^{137}Cs) is a fission product and atomic bomb-derived radioisotope that has a half-life of 30.02 years and emits gamma rays with an energy of 661.6 keV (Poreba, 2006). This radionuclide was first used by Yamagata et al. (1963) and Rogowski and Tamura (1970) to estimate the rates of soil erosion. Analytical methods and models for estimating soil erosion using ^{137}Cs have remarkably improved over the last four decades. Ritchie (2007) reported that scientific publications on the ^{137}Cs technique started in 1961 and reached its maximum number in 1999. New models for estimating soil erosion have also been introduced by Robbins (1978), IAEA (1995, 1998), Rogowski and Tamura (1970), Walling and Quine (1990), Walling and He (1999), Walling et al. (1999), Zapata and Agudo (2000), and Poreba (2006). Mabit et al. (2008) have evaluated different models and noted the advantages and limitations of using ^{137}Cs and ^{210}Pb for assessing soil erosion. Therefore, ^{137}Cs and ^{210}Pb-based techniques can be applied both quickly and efficiently to estimate soil loss and redeposition. A PC-compatible software package by Walling et al. (1999) contains improved models, based on several empirical and theoretical approaches that are applicable to both cultivated and non-cultivated areas. The package includes the Proportional Model, the Mass Balance I, II, and III Models, the Profile Distribution Model, and the Diffusion and Migration, Models. Specific requirements are, however, needed in applying the models for the underlying assumptions, descriptions, and representation of temporal variation (Walling et al., 1999).

The objective of this research was to determine the soil redistribution pattern induced by deforestation along the representative transects of the dry-farming and afforested lands in the Golestan Province of Iran using the ^{137}Cs technique.

2. Materials and methods

2.1. The study area

The Hircanian Forests (HF) are located along the South of the Caspian Sea, in the North of Iran. Their distribution along the northern slopes of the Alborz Mountains, covers ca. 1.85 million hectares in Iran. The HF includes an important refugium of temperate broad-leaved trees. The HF stretch across a large area that comprises the three provinces of Guilan, Mazandaran, and Golestan (Fig. 1). Golestan Province has approximately 452,000 ha of forest coverage, from which 66% are productive, 18% are conserved, and 16% are degraded. A rapid increase in the human population associated with the development of wood industries led to extensive deforestation and a decline in coverage of HF between 1942 and 2005. Between 1976 and 1991, deforestation through wood harvesting occurred at a mean rate of 2.3 million m^3 per year. Afterward, this deforestation rate decreased to 300,000 m^3 per year; while since 1981, approximately 75,527 ha of cleared cut areas have been reforested.

The study area has a semi-humid climate with a mean temperature of 16.4 °C and annual precipitation between 700 and 1000 mm which mainly occurs in October and sometimes in July.

2.2. Site selection and sampling

A sampling strategy is a critical step for the success of the ^{137}Cs method in soil erosion and sedimentation studies (Fulajtar, 2017, p. 63). In this study, based on the research objectives and distribution of specific land-use changes across the Golestan province, an accurate sampling design was established. Field observations showed that the hillslopes located between 150 m and 500 m elevations and with a slope lower than 30% have been experiencing maximum deforestation over the last decades. The deforestation affected mainly the loess areas of Golestan Province. Loess is a sedimentary deposit composed largely of silt-size grains that are loosely cemented by calcium carbonate. Such deposits cover older geological formations and rock units with different thicknesses in the study area. Muhs (2007) reported that the loess deposits have been deposited during the Quaternary interglacial–glacial cycles. Therefore, the development of loess deposits in the Golestan Province in the eastern part of the Caspian Sea (CS) is correlated with sea-level variation periods and with the availability of a huge amount of silty and sandy sediments, eventually redistributed as aeolian sediments layers (loess). Kakroodi et al. (2012) recognized five CS level cycles after 3260 cal yr BP. Therefore, two major periods of cooling phases occurred, including the 2600–2300 cal yr BP high stand and the Little Ice Age, which had a strong impact on the CS water level (Gharibreza et al., 2018). Such cooling ages provided a suitable environment for aeolian mechanisms to accumulate loess at the toe of the Eastern Alborz Mountain range. This idea has been supported by a newly published work (Rahimzadeh et al., 2019) on the formation of aeolian deposits in the Eastern Caspian Sea. Sedimentological and dating information has stressed on the accumulation of loess and fossil dunes in the Early Holocene, probably following the so-called Mangyshlak regression. High erodibility of loess deposits especially in China has been proved by some authors (Yan et al., 2018; Mohamed Abd Elbasit, 2013) using conventional models. Therefore, another strategy of sampling in the present study was to estimate deforestation-induced erosion rates on loess deposits in the North-East of Iran.

The comprehensive field observations across the Golestan province resulted in the selection of five representative transects (Fig. 1). Site selection was conducted based on different land-use changes across the study area. Intensive deforestation and converting of the forest to dry-farming started in 1963 (Act 41, 1962) by relaxing the law for the nationalization of forests and sharing land with laborers and new farmers. Driving forces such as willingness to create new land ownership, agriculture, cattle ranching, and new demands for wood by industries have facilitated the deforestation.

A sampling strategy was designated to find out the proper reference sites in western and eastern parts of the Golestan province to estimate variations in the ^{137}Cs radioisotope inventory.

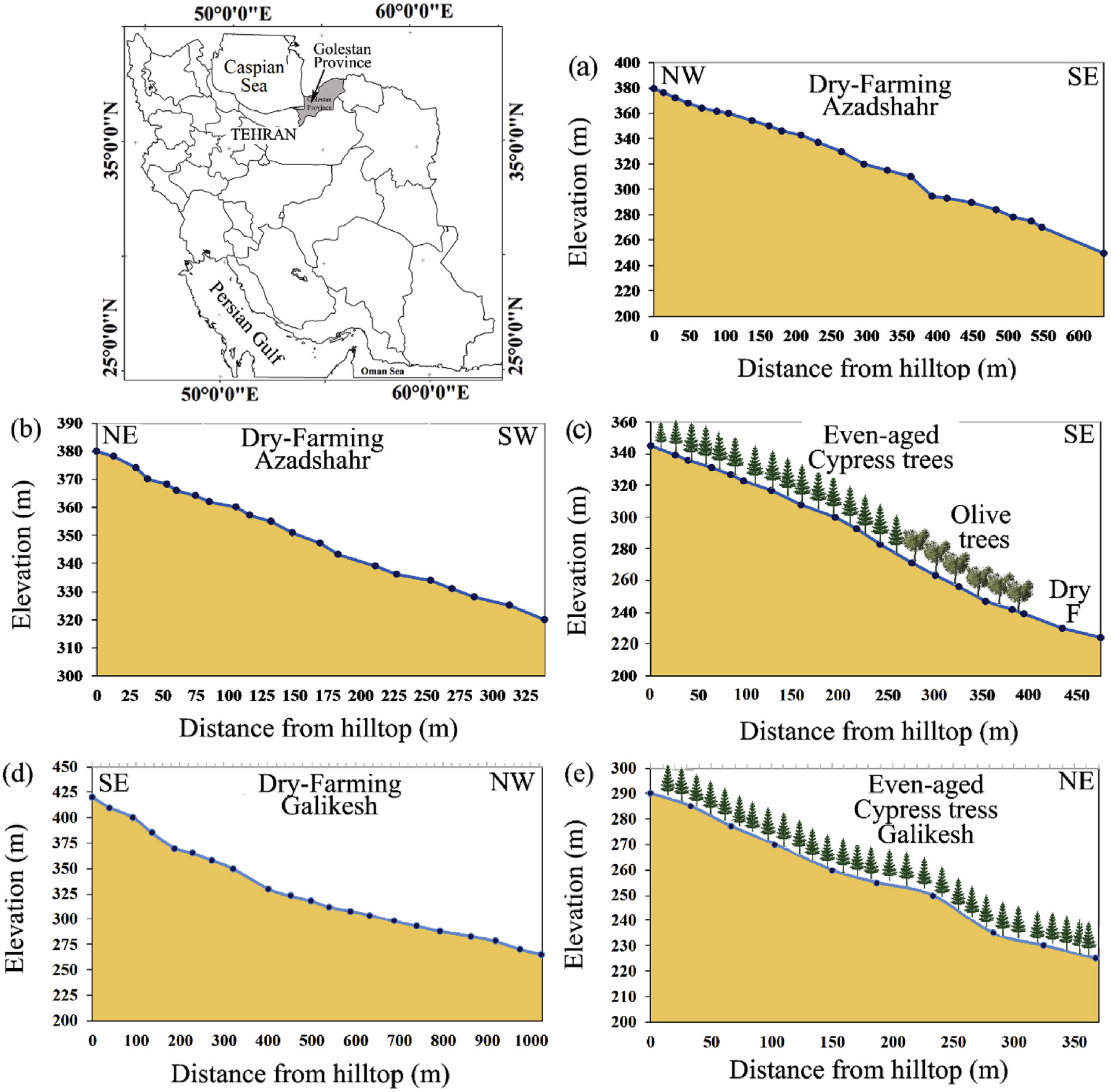


Fig. 1. Location of the study areas and profiles of sampled transects in representative sites of Golestan Province, Iran: a) Eastward Dry-farming transect, Azadshahr, b) Westward Dry-farming transect, c) Reforested by Cypress, Olive trees and Dry-farming transect Azadshahr, d) Dry-farming transect, Galikesh, and e) Reforested by even-aged Cypress trees, Galikesh.

Accordingly, two reference sites in the Kuhmian and Galikesh watershed were identified with the cooperation of an IAEA expert (IAEA, 1998) in August 2017. Both the reference sites are located in conservative parts of the watershed where original forests are protected by the Forest, Rangelands, and Watershed Management Organization of Iran. The Galikesh reference site was located 1.3 km from the study site at an elevation of 728 m, in the original forest. The Kuhmian reference site was located 1.1 km from the study site at an elevation of 420 m, in the original forest. A sampling of reference sites was carried out and 24 bulk samples and two incremental depth samples were collected. A scraper plate with a cutting edge and having a rectangular metal frame (surface area = 1292.71 cm^2) served to collect 2 sectioned cores samples (one for each site) at 2-cm intervals at a total depth of 30 cm. Both the Kuhmian and Galikesh watersheds included conservative and trading forests and deforested-induced land uses that gave opportunities to the project team to find out appropriate locations for reference sites and sampling transects.

Sampling strategy for such studies (IAEA, 1998) implies selecting the nearest location to the reference sites where a variety of sampling patterns could be implemented. Conducting sampling patterns with the catchment scale was not applicable because of the extensive sub-catchments and limitations in the number of sample analyses. Therefore, a transect approach was followed for sampling along hillslopes with representative land uses.

Accordingly, three of the transects were chosen to represent the effect of converting forest to dry-farming lands in two separate watersheds in the western and eastern parts of the Golestan

Province (Sites Azadshahr and Galikesh, Table 1 and Fig. 1). Two representative transects of dry-farming lands, located at the Kuhmian Watershed and west of Azadshahr (AZ) city, where clear-cutting of original forest focused on hilly and loess formations, between 150 m and 400 m elevations (Fig. 1). These sites have a uniform slope (22%), Southeast and Southwest aspect, and 340 m and 635 m 168 in length, respectively (Fig. 1 c, d).

In the case of transect "e" (Fig. 1), the presence of hedges (made by bushes and wood bunches) between the different farm owners represents a discontinuity along the slope, which was considered in the sampling activity. Therefore, the Southeast direction dry-farming land use was selected in such hillslopes with four farms to identify soil redistribution patterns.

Sampling in the study area consisted of 93 bulk samples collected along the five transects (Table 1 and Fig. 1). In this case, a handy core sampler of 11-cm diameter was used to a depth of 25 cm. Also, single samples from moved sediment at the catchment outlet (where deposition occurred) were collected to gain information on the particle size factor. In total, 21 and 24 samples were collected with about 20 m intervals from the Azadshahr westward and eastward dry-farming transects, respectively.

The third dry-farming land use transect with 1000 m length (Fig. 1 d) was located in the Galikesh Watershed, eastern Golestan Province. This transect has similar topographic conditions and cropping systems as compared to the transects of the Azadshahr city (Fig. 1a and b). Accordingly, 21 samples, 25 cm deep, were collected along this transect approximately 50 m from each other.

On the other hand, reforestation of converted forest lands was another land-use change in the study area. Cultivation of Cypress trees using an even-aged method was envisaged by the environmental Act71 (1992) in the Golestan Province in 1993. This law settled by the Parliament of the Islamic Republic of Iran aimed to perform appropriate practices to preserve natural resources. Therefore, two transects were chosen to explore the effectiveness of silvicultural practices in decreasing soil erosion in the study area. Transects with 500 m and 350 m length (Fig. 1 b, e), represent the implementation of even-aged silvicultural systems located near to dry-farming lands at Azadshahr and Galikesh, respectively. 19 and 10 samples were collected from the Azadshahr (Fig. 1 c) and Galikesh silvicultural (Fig. 1 e) transects with intervals of 25 m and 37 m, respectively. Therefore, 19 and 10 samples were collected from the Azadshahr and Galikesh silvicultural transects with intervals of 25 m and 37 m, respectively. The vicinity of transects provides conditions to compare the rate of soil erosion in different land uses.

2.3. Sample preparation and analysis

The soil samples were oven-dried at 105 °C and ground using mortar. Then, the samples were homogenized, weighed, and sieved. Portions finer than 2 mm were packed in special containers weighing 250 g. The ^{137}Cs activity was measured using a well-calibrated gamma-spectrometry based on high-purity germanium (HPGe) detectors in the laboratories of the Nuclear Science & Technology Research Institute (NSTRI), in Iran. The gamma-spectrometer model EGPC 80-200-R, (EURISYS MESURES) detector at NSTRI has a relative efficiency of 80% and full width at half maximum (FWHM) of 2.5 keV for ^{60}Co gamma-energy line at 1332 keV. The gamma-spectrometer was calibrated using multi-nuclides standard (POLATOM MIX SOURCE) solutions dispersed in soil homogeneously in the same sample–detector geometry (250 g Marinelli beaker). The lower limit of detection depends on efficiency, FWHM, and counting time, and thus, it differs from sample to sample. The IAEA reference materials were used for quality control of the gamma-detector.

A total of 119 samples were analyzed for finding out grain size distribution and bulk density values. The distribution of course and fine particle size portions was estimated using the ASTM 422 standard and the ASTM D7928 methods, respectively. Besides, to estimate the land degradation induced by deforestation, the total soil organic carbon (SOC) was measured using the Walkley and Black (1934) method. The soil organic carbon stock (SOCs) was estimated with the formula proposed by Hiederer and Martin (2011):

$$SOCs = SOCc \times BD \times \left(1 - \frac{VS}{100}\right) \times LD \times 10^2 \tag{1}$$

where:

SOC_S: the total amount of soil organic carbon to a given depth (t ha-1).
SOC_C: soil organic carbon content for given depth (%)
BD: dry bulk density (kg m^{-3}).
VS: volume of stones (%)
LD: depth of soil layer (m).

2.4. The conversion model to estimate soil redistribution rates from ^{137}Cs measurements

Some conversion models able to convert ^{137}Cs loss (or gain) into values of soil erosion (or deposition) are available in the literature (Walling et al., 2007). Considering the type of land-use changes and the current cultivation along the representative transects, the Mass Balance Model 2 (MBM2) was an appropriate choice (Walling et al., 2014). This model considers both the temporal variation in ^{137}Cs fallout input and the initial distribution of fresh fallout on the surface soil. In addition, transects with dry-farming land use have been plowed for more than 50 years, while two other selected transects have been plowed at least for 30 years before afforestation. The equation for the MBM2 can be written following the form proposed by Walling and He (1999 a, b):

$$A(t) = A(t_0)\, e^{-\int_{t_0}^{t} (PR/D + \lambda)\, dt'} + \int_{t_0}^{t} (1 - \Gamma) I(t')\, e^{-(PR/D+\lambda)\ (t-t')} dt' \tag{2}$$

where:

R = erosion rate (kg m^{-2} yr^{-1});
D = cumulative mass depth representing the average plow depth (kg m^{-2});

Table 1
Characteristics of the representative transects in the study area.

No.	Sample number	Slope %	Transect length (m)	Aspect	Land uses	Area
Transect a	23	22	580	East	Dry-farming	Azadshahr
Transect b	21	22	350	West	Dry-farming	Azadshahr
Transect c	19	22	480	Northwest	Even-aged Cypress trees, Olive trees and Dry-farming	Azadshahr
Transect d	20	20	1000	Northwest	Dry-farming	Galikesh
Transect e	10	20	380	Northeast	Even-aged Cypress trees	Galikesh

λ = decay constant for ^{137}Cs (yr^{-1});
I(t′) = annual ^{137}Cs or ^{210}Pb$_{ex}$ deposition flux (Bq m^{-2} yr^{-1});
Γ = percentage of the freshly deposited ^{137}Cs fallout removed by erosion before being mixed into the plow layer;
P = particle size correction factor;
t₀ (yr.) = year when cultivation started;
A(t₀) (Bq m^{-2}) = ^{137}Cs inventory at *t₀*.

If *A(t)* is greater than the local reference inventory $A_{ref,}$ at a sampling point, deposition may be assumed. In this case, the mean soil deposition rate *R′* can be calculated from the following equation:

$$R' = \frac{\int_{t_0}^{t} R'C_d(t')e^{-\lambda(t-t')}dt' \int_S RdS}{PP' \int_{t_0}^{t} dt' \int_S \left(I(t')\gamma\left(1-e^{-R/H}\right)/R + A(t')/D\right) dS} \tag{3}$$

where:

H is the relaxation mass depth of the initial fallout input;
C$_d$(t′) reflects the radionuclide content of sediment mobilized from all the eroding areas that converge on the aggrading point. Generally, *C$_d$(t′)* can be assumed to be represented by the weighted mean ^{137}Cs activity of the sediment mobilized from the upslope contributing area *S* (m^2);
P′ is a further particle size correction factor reflecting differences in grain size composition between mobilized and deposited sediment; γ is the proportion of the annual fallout susceptible to removal by erosion before incorporation into the soil profile by tillage. According to field observations, a tillage depth of D = 0.25 m has been assumed. The following values were used for the other input parameters: H = 4, γ = 1 (based on the relationship between the timing of cultivation and the rainfall regime), and calculated values of the P factor based on particle size analyses. The PC-compatible Excel Add-in, developed by Walling et al. (2007) was used to apply the model described above.

3. Results and discussion

3.1. *Soil physical properties and organic matter*

Particle size analyses confirmed the research hypothesis that the conversion of forest to dry-farming and silvicultural operations has led to an increase in erosion of loess deposits (see Table 2).

Soils with silty texture are the majority in the study area - up to 65% on average. In addition, at reference sites and dry-farming transects, the clay content is between 30 and 40 percent (Fig. 2 a, b).

According to Smalley and Smalley (1983), loess layers had generally unimodal, well-sorted, leptokurtic, and negatively-skewed particle-size population. The present research supports dominating palaeoclimate events in the study area and the consequent development of paleosols on the basis of granulometric results. The data showed a significant correlation to unimodal, well-sorted, and clayey loess deposits. This composition pointed to climate change and meteoric diagenesis by which loamification and soil formation on the loess developed. All evidence points out a very high sensitivity of altered loess and paleosols to soil erosion, especially when degraded by deforestation.

3.2. *$^{3.2.137}$Cs inventories at the reference sites*

The ^{137}Cs depth distribution of the two sectioned cores collected from the two reference sites (one for each location), showed an exponential decline with depth (Fig. 3 a, b). The shape of these profiles confirmed that 70–80% of the ^{137}Cs inventory were present in the top 12 cm. The ^{137}Cs inventory gained in the reference sites of Azahshahr and Galikesh was 3849 Bq m^{-2} and 4062 Bq m^{-2},

Table 2
Physical properties of representative transects in the study area.

Study area	Bulk Density (kg m^{-3})	SOC (%)	Clay (%)	Silt (%)	Sand (%)	Texture
Transect a (n = 23)						
Average	1494.6	1.24	35.67	59.63	4.67	Si - C - L[a]
STDEV	163	0.45	4.97	4.12	4.57	
CV	11	36	14	7	98	
Transect b (n = 21)						
Average	1431.7	1.32	33.76	60.67	5.57	Si - C - L
STDEV	119.28	0.25	2.43	3.31	3.76	
CV	8	19	7	5	68	
Transect c (n = 19)						
Average	1385.37	2.32	31.37	61.37	7.26	Si - C - L
STDEV	125	0.73	2.71	2.61	3.35	
CV	9	32	9	4	46	
Transect d (n = 20)						
Average	1429	2.2	33.14	60.24	6.62	Si - C - L
STDEV	112	0.6	2.03	2.81	3.25	
CV	8	30	6	5	49	
Transect e (n = 10)						
Average	1355	3.58	30.10	67.6	2.3	Si-L[b]
STDEV	96	0.83	5.86	4.5	4.69	Si - C - L
CV	7	23	19	7	200	
Reference Site1-Azadshahr (n = 12)						
Average	1400.8	3.7	40.38	56.62	2.09	S–C[c]
STDEV	92	0.53	7.7	4.61	0.83	Si - C - L
CV	6.6	25	19	8	40	
Reference Site2-Galikesh (n = 12)						
Average	1307	3.57	29	64.5	6.5	Si-L
STDEV	101	1.1	3.5	6.6	4.25	Si - C - L
CV	7	30	11	0.1	11	

[a] Silty-Clayey Loam.
[b] Silty Loam.
[c] Silty Clay.

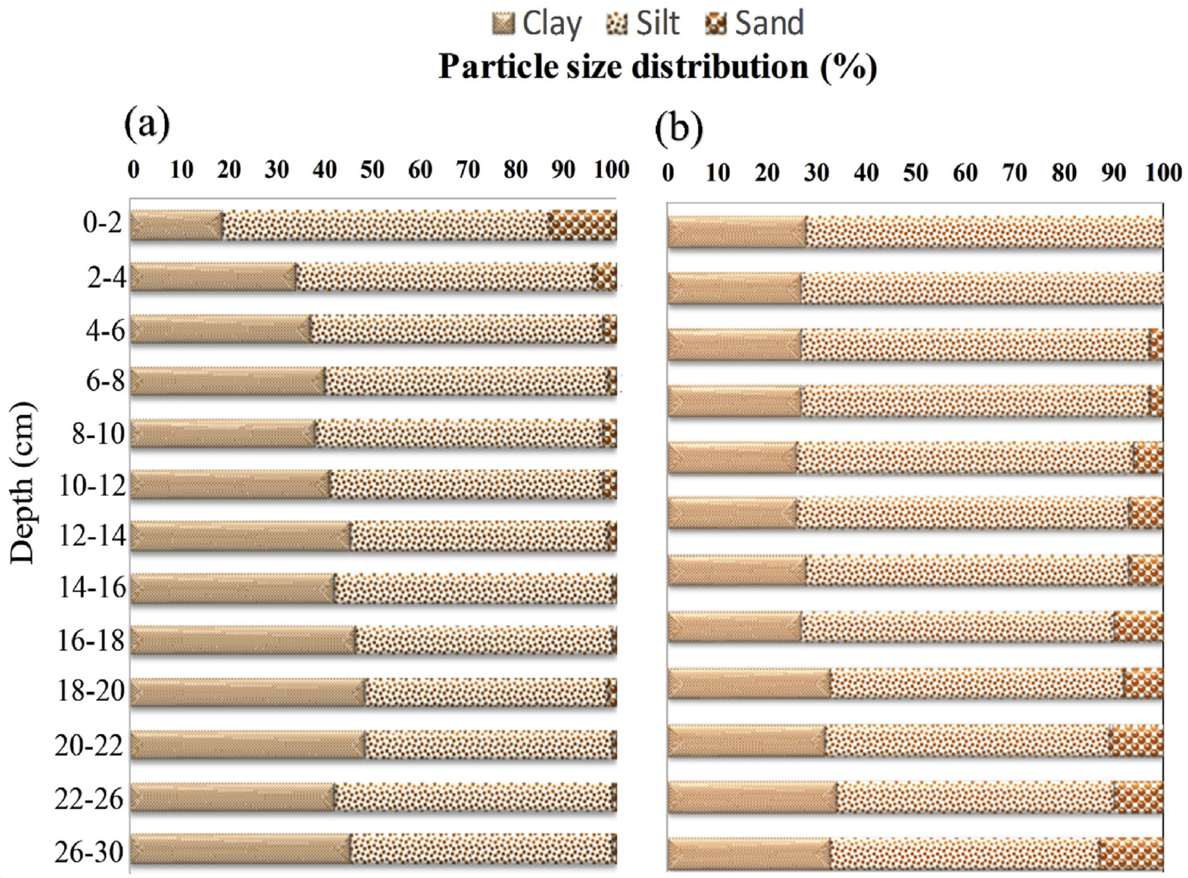
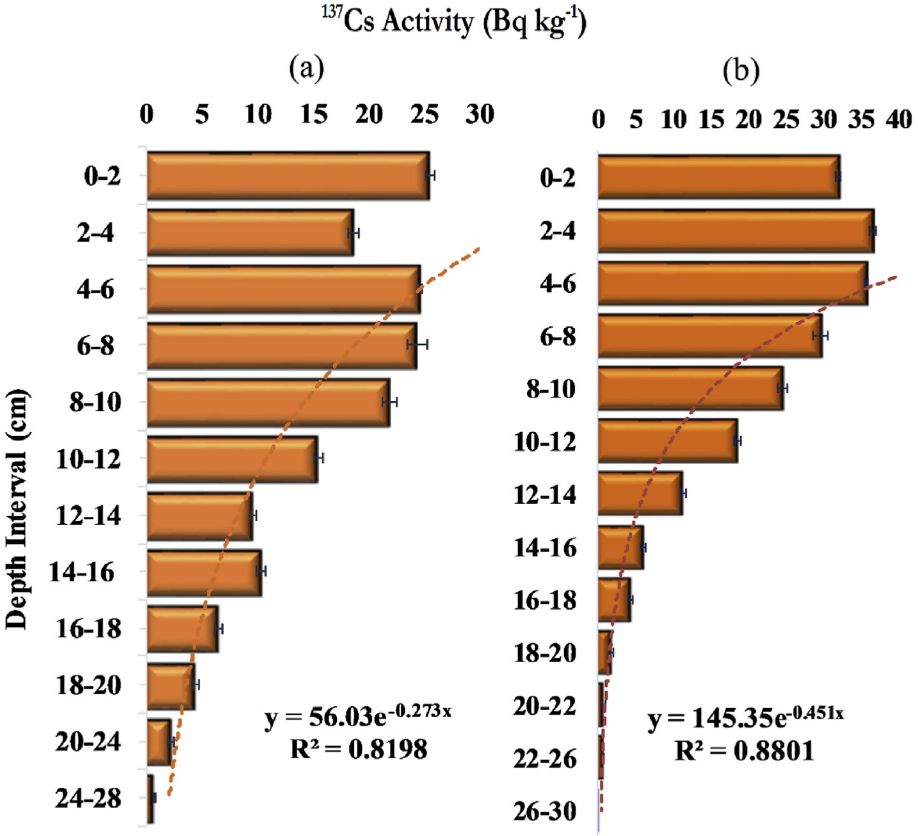


Fig. 2. Particle size distribution along the incremental samples collected in the references sites of a) Azadshahr, b) Galikesh.



Figs. 3. ^{137}Cs depth distribution from the sectioned cores collected at two reference sites, a) Galikesh, b) Azadshahr.

respectively. A very low difference (ca. 10%) between the ^{137}Cs inventory of the two reference sites, testifies a similar distribution of the ^{137}Cs fallout in the study area. A recent work by Tagami et al. (2019), assessing the geographical distribution of the ^{137}Cs inventory in India and other areas with similar latitude and longitude, reports ^{137}Cs inventories of ca 4000 Bq m^{-2} and confirms the reliability of the reference values found in our study areas.

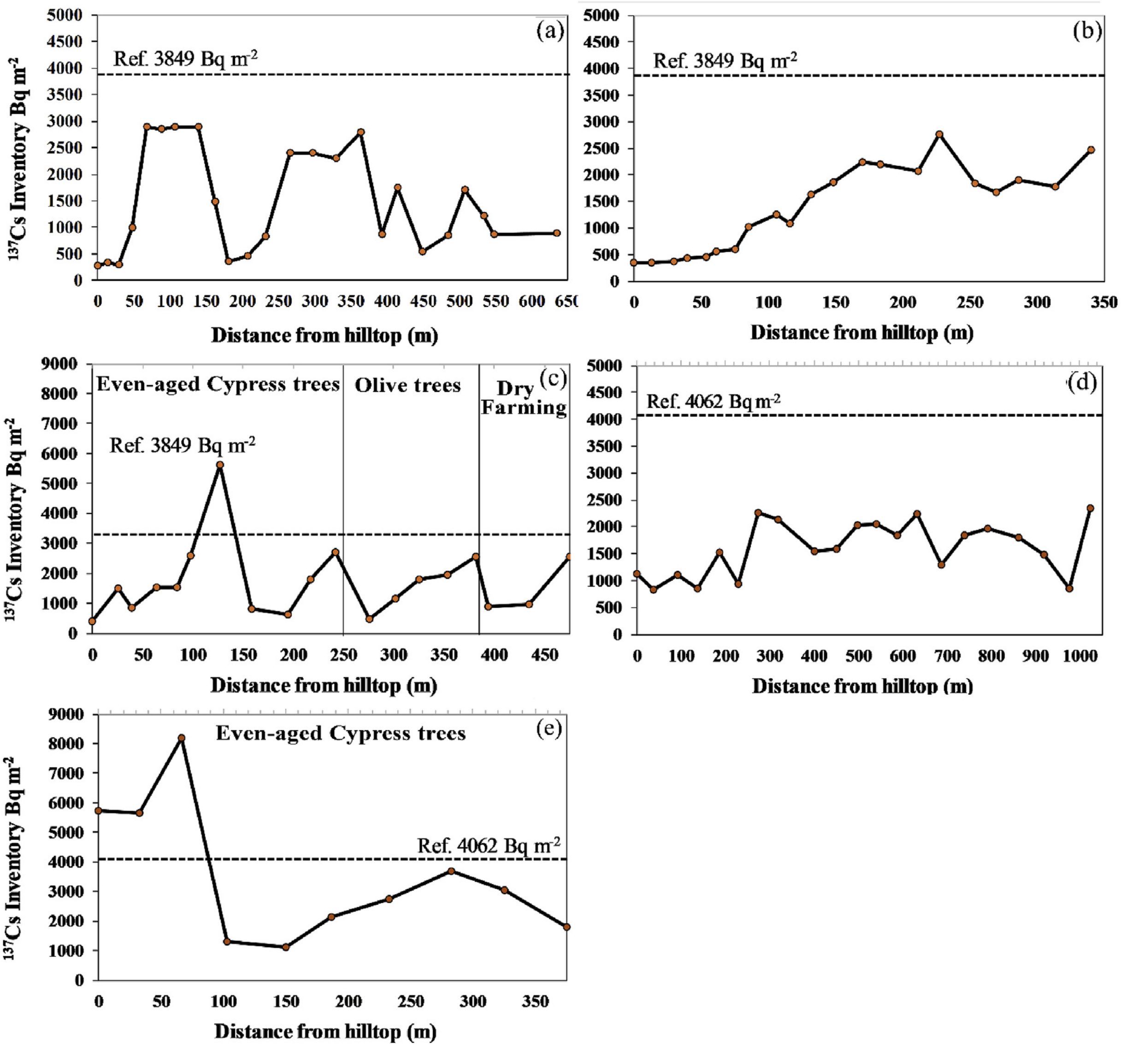
3.3. ^{137}Cs inventories within the study area

The ^{137}Cs inventory along the representative transects by distance from the top of the hillslope is represented in Fig. 4, together with the measured distances from the top hill. More specifically, the ^{137}Cs measurements in the two characterized dry-farming land uses at Azadshahr area (Fig. 4 a and b), represented the mean ^{137}Cs inventory of ca. 1421.77 Bq m^{-2} with single values ranging from 271.2 Bq m^{-2} to 2896.4 Bq m^{-2} with a CV about ca. 60%.

Further, the Galikesh representative dry-farming land use transect showed the mean value of the ^{137}Cs inventory of ca. 1600.91 Bq m^{-2} with single values ranging from 833.6 Bq m^{-2} to 2340.4 Bq m^{-2} and a CV equal to ca. 31%. As mentioned in Table 1, the Azadshahr representative mixed land use transect consists of cultivation of Cypress trees under even-aged silviculture, cultivation of olive trees, and dry-farming section. Under these land uses, the mean ^{137}Cs inventory is ca. 1703.04 Bq m^{-2} with single values ranging from 401.26 Bq m^{-2} to 5608.95 Bq m^{-2} and a CV equal to ca. 71% (Fig. 4 c). There are not any convex and concave forms along these transects and variation in ^{137}Cs inventory represents a redistribution pattern. Further, the ^{137}Cs inventory along the Galikesh silviculture land use transect represented an approximately 3544.31 Bq m^{-2} with single values ranging from 1119.7 Bq m^{-2} to 8265.45 Bq m^{-2} and a CV equal to ca. 65% (Fig. 4 e). Variations of ^{137}Cs inventory in single points of samples in both disturbed and undisturbed forest areas can be expected because of differences in canopy covers and ages of trees. All single inventory values in both sites of the dry-farming land are lower than the corresponding reference value.

The soil redistribution trend shown in Fig. 4 provides useful information for farmers and decision-makers to understand which part of the farm needs to be modified for soil and nutrient resources.

Variability on the ground and land use (see Fig. 1) have caused



Figs. 4. ^{137}Cs inventory variation along the transects related to the dry-farming land use of (a) Eastward Dry-farming transects, Azadshahr, b) Westward Dry-farming transect, c) Reforested by Cypress and Olive trees transect Azadshahr, d) Dry-farming transect, Galikesh) and e) Reforested by even-aged Cypress trees in Galikesh.

variations in the trend of the ^{137}Cs single inventory along the hillslope (Fig. 4). Correlation between the ^{137}Cs single values and distance from the hilltop of the Azadshahr westward transect of dryland farming (Fig. 4 b), using the Mann-Kendall test showed a correlation coefficient of 0.733 which is significant at the 0.01 level. Dividing hillslopes to small farms is the most common feature in the study area. Therefore, the Azadshahr eastward dry-farming transect was selected along such a hillslope where it has been divided into four farms by stakeholders. Accordingly, there is no significant correlation between the ^{137}Cs and the distance from the hilltop (Fig. 4 a). Instead, statistics of each four sections point to meaningful correlations. For instance, at the first farm (0–163 m), the correlation coefficient of 0.667 was gained which is significant at the 0.05 level. The second farm (163–363 m), the correlation coefficient of 0.714 which is significant at the 0.05 level was obtained. Similarly, there are two consecutive farms along the third dry-farming transect at the Galikesh area (Fig. 4 d). Correlation between the ^{137}Cs single values and distance from the hilltop at the first section (0–640 m) of transect "d" using the Mann-Kendall test showed a correlation coefficient of 0.538, which is significant at the 0.01 level. The statistical test showed no significant correlation between ^{137}Cs value and the distance from the top of the hill from 640 m onward.

The multiple land use along the Azadshahr transect (Fig. 4 c) resulted in a low correlation between the ^{137}Cs inventory and the distance from the hilltop. There are two unexpected downward decreases in the ^{137}Cs inventory of silviculture even-aged Cypress trees. Meanwhile, the correlation coefficient of 0.905 was obtained which is significant at the 0.01 level for this section. The Mann-Kendall test showed a correlation coefficient of 1.000 which is significant at the 0.01 level for olive trees that points to a real downward increasing in the ^{137}Cs values because of soil redistribution.

Clear variability between the ^{137}Cs sing values and distance from the hilltop was observed in the Galikesh silviculture transect (Fig. 4 e), which points to unexpected correlation. This transect is located beneath the dry-farming land - some portions of eroded soil moved to the first 100 m of this transect and this caused an increase in ^{137}Cs inventory. As a result, the first 100 m of the transect enriched by ^{137}Cs in comparison with the local reference value, while the rest of the transect shows a downward increase of inventory because of soil redistribution.

3.4. Estimating erosion and deposition rates at the sampling points

As mentioned above, the rates of soil loss or deposition associated with the individual sampling points in comparison with the local reference value, have been obtained using the Mass Balance Model II (Eq. (2) and Eq. (3)). The overall results showed that soil erosion was the dominant process compared with the deposition along the hillsides since the beginning of ^{137}Cs fallout in the mid-1950s. The land-use history of the study area (Bobek, 2005) documents that extensive deforestation has occurred before the maximum radionuclide fallout (1954–1963). This activity reflects the lower values of ^{137}Cs inventory in the study areas if compared with the corresponding reference values. Therefore, the trend of soil erosion and the amount of soil and nutrients losses can be considered as the main indicators of anthropogenic activities and susceptibility of loess deposits to land degradation.

Maximum, minimum and mean values of soil erosion rates along the AZ-East direction transect were 81.25, 7.63 and 35.86 t ha^{-1} yr^{-1} (Table 3; transect a) respectively, while the similar values for the AZ-West direction transect were calculated to be 69.68, 8.66 and 34.87 t ha^{-1} yr^{-1}, respectively (Table 3; transect b). The maximum, minimum and mean values of soil erosion rates along the Galikesh-Northwest direction transect were 48.4, 15.8, and 29.19 t ha^{-1} yr^{-1} (Table 3; transect d). Besides, the hillslope under silviculture and horticulture practices in the Azadshahr area shows a mean value of erosion rate equals to 31.7 t ha^{-1} yr^{-1}, with single values ranging from 71.9 t ha^{-1} yr^{-1} (erosion) to 11.6 t ha^{-1} yr^{-1} (deposition) (Table 3; transect c). Such situations in the Galikesh area indicate a net erosion rate of 10.01 t ha^{-1} yr^{-1} with single values ranging from 39.8 t ha^{-1} yr^{-1} (erosion) to 20.9 t ha^{-1} yr^{-1} (deposition) (Table 3, transect e).

Table 3
Soil loss and net erosion along the representative transects.

Transects	Soil loss (%)	Net Erosion (t ha^{-1} y^{-1})
Transect a (n = 23)		
Average	*60.24*	*35.86*
Max	*92.95*	*81.25*
Min	*24.75*	*7.63*
Transect b (n = 21)		
Average	*64.28*	*34.87*
Max	*90.78*	*68.68*
Min	*28.16*	*8.66*
Transect c (n = 19)		
Average	*55.75*	*31.7*
Max	*89.57*	*71.9*
Min	*45.75*[b]	*11.6*[a]
Transect d (n = 20)		
Average	*60.59*	*29.19*
Max	*79.47*	*48.39*
Min	*42.38*	*15.8*
Transect e (n = 10)		
Average	*12.74*	*10.01*
Max	*72.43*	*39.8*
Min	*102*[b]	*20.9*[a]

[a] Soil Accumulation.

[b] Deposition.

The net erosion rate of dry-farming lands of the East and West of Golestan Province was calculated to be 35.86 t ha^{-1} yr^{-1} and 29.19 t ha^{-1} yr^{-1}, respectively (Table 3; transects a, b). Therefore, the mean rate of soil erosion of the whole province for loess soil type is 32.27 t ha^{-1} yr^{-1}, on average. Results pointed out that ca. 160.6 kg m^{-2} (or ca. 10.97 cm) and ca. 150.6 kg m^{-2} (or ca. 10.29 cm) of soil have been eroded from the AZ-Westward and the AZ-Eastward transects, respectively. Resultant data has been obtained based on the mean rate of soil loss along the Azadshahr transects (64.24% and 60.24%), the mean bulk density of 1463 kg m^{-3}, and the tillage depth of 250 kg m^{-2} (or ca. 25 cm). Considering the elapsed time of 54 years between deforestation and the present research, soil erosion along these transects has occurred with the rate of 2 mm yr^{-1} and 1.9 mm yr^{-1}, respectively.

Results suggest 151.47 kg m^{-2} (or ca. 10.59 cm) of soil eroded from dry-farming land use (transect d). Similarly, these data were calculated based on the mean rate of soil loss along the Galikesh transect (60.59%), the mean bulk density of 1429 kg m^{-3}, and the tillage depth of 250 kg m^{-2} (or ca. 25 cm). Therefore, a long-term rate of soil erosion of 1.96 mm yr^{-1} has been obtained along this transect by considering the elapsed time (54 years) between deforestation and the present research.

Soil loss based on the amount of the reduction in ^{137}Cs inventory from the silvicultural, horticultural, and dry-farming parts of the Azadshahr mixed land use transect (c) was calculated to be 52.8%, 58.62%, and 61.67%, respectively. In such a situation, these sections eroded by the mean rate of 1.8 mm yr^{-1}, 1,8 mm yr^{-1}, and 2.1 mm yr^{-1}, respectively. Although the upper part of this transect has experienced the dry-farming land use for about 30 years, the silvicultural practice using even-aged Cypress trees resulted in 15% effectiveness in soil conservation since 1993. Similarly, the cultivation of olive trees in the second section (≈150 m) of the transect, caused - since 2004 - a 5% soil loss in comparison to the remaining dry-farming land use.

In general, afforestation of dry-farming land in Galikesh results in a higher effectiveness in soil erosion control (ca. 34%) as compared to the adjacent dry-farming land (Table 3; transect e). A long-term volumetric soil loss of ca. 31.85 kg m^{-2} (or ca. 2.38 cm) with a rate of 0.4 mm yr^{-1} has been recorded along this transect. This rate was obtained using key resultant data of soil loss (12.74%), the mean bulk density (1355 kg m^{-3}), and the tillage depth of 250 kg m^{-2} (or ca. 25 cm).

In Fig. 5, the trend of soil redistribution along the transects are presented. The severe soil erosion occurring in the upper part ($\approx$25% of transect b), covered with dry-farming land use, is considerably higher than the rest of the transect. Interpretation of satellite images (Sentinel-2A, 10 m resolution) and comprehensive field observations documented very low fertility of such farms because of soil and nutrients loss and confirms the above assumption. On the contrary, the annual range of soil erosion along the rest of transect "b" documents value lower than 20 t ha^{-1}.

Intensive soil erosion in the upper section of the transect with silvicultural and horticultural practices was also observed (Fig. 5, c). The division of the slope into sections with different land use seems to be useful in reducing soil erosion. In each section, the upper part has a high erosion rate and the lower part has a much lower erosion rate.

Preventing soil erosion and collection of eroded soils under silvicultural practices (with rates of 10–20 t ha^{-1} yr^{-1}) is the dominant process in the Galikesh transect (Fig. 5, e), even if severe soil erosion (up to 40 t ha^{-1} yr^{-1}) can be observed in the middle of the transect e. It is difficult to explain such a situation, but it is certainly related to the complex land-use history as a result of a general alternation of clear-cutting and long-term dry-farming before cultivation (Fig. 5, e).

3.5. Relations between soil erosion and soil organic carbon losses

The rates of soil loss provided by the ^{137}Cs technique must be seen as the first important step to point out some of the on-site effects caused by soil erosion. In this respect, loss of nutrients can be considered one of the most important consequences of land degradation that can be observed after land-use changes. FAO and IPCC (FAO, 2017; IPPC, 2019) have emphasized negative trends in land conditions, caused by direct or indirect human-induced processes

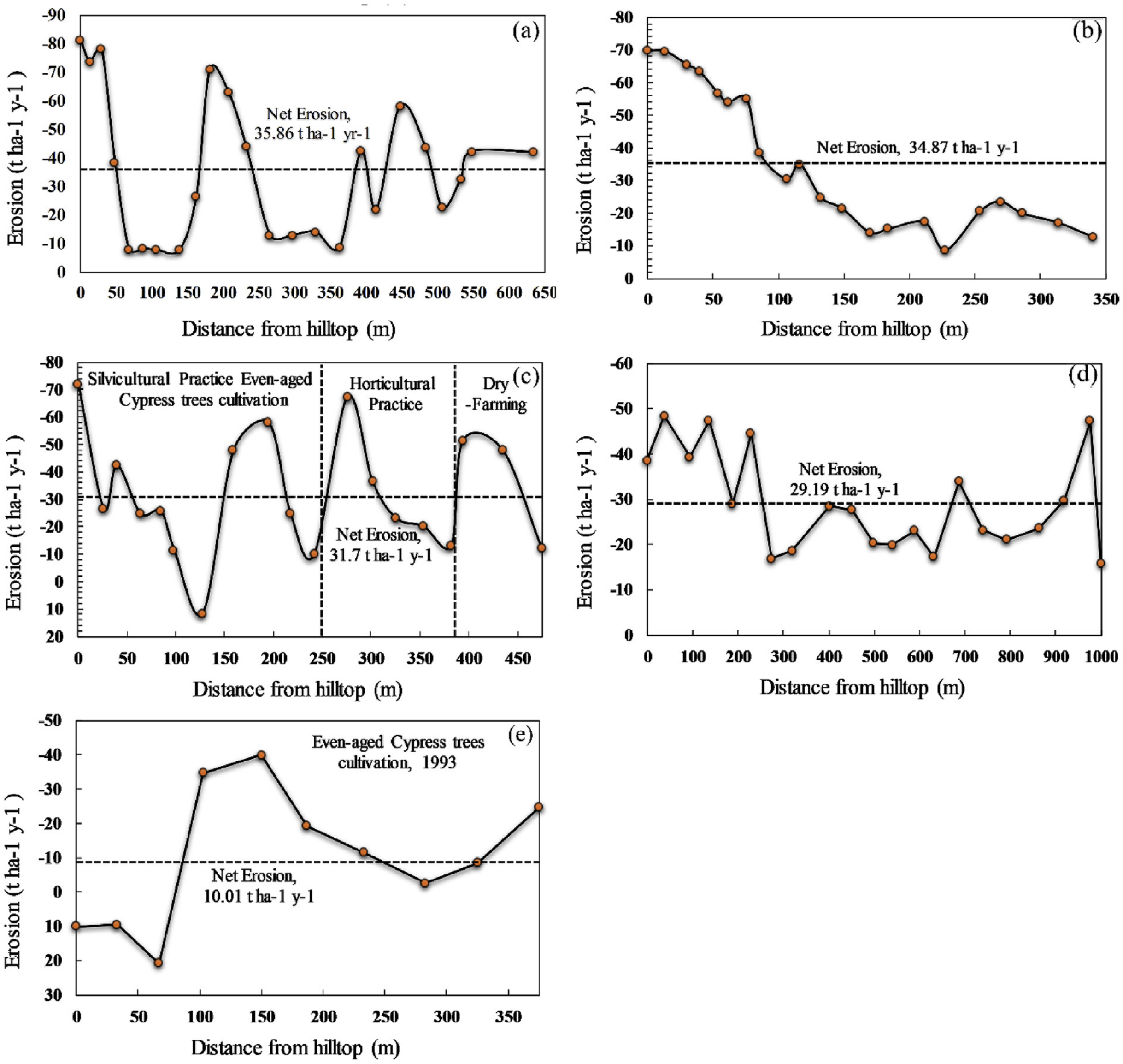


Fig. 5. Trends in soil redistribution along the transects (a) Eastward Dry-farming transects, Azadshahr, b) Westward Dry-farming transect, c) Reforested by Cypress and Olive trees transect Azadshahr, d) Dry-farming transect, Galikesh) and e) Reforested by even-aged Cypress trees in Galikesh.

including anthropogenic activities and climate change, expressed as a long-term reduction or loss of at least one of the following aspects: biological productivity, ecological integrity or value to humans. In forested areas, these aspects can be evaluated if the information on soil organic carbon is available. Normally, soil carbon is in steady-state equilibrium in the natural forest, but as soon as deforestation (or afforestation) occurs, the equilibrium will be affected.

Accordingly, the present study highlights the aspects of land degradation in terms of loss of soil organic carbon (SOC) followed by the conversion from forest to dry-farming land use. Measurements of SOC allowed to explore the existing relation between loss of SOC and soil erosion and provided useful information on the status of soil after a change in land use. Azadshahr and Galikesh reference sites presented SOC values of 3.57 ± 1.1% and 465 3.7 ± 0.53%, respectively. According to the bulk density values (1400 kg m^{-3} and 1300 kg m^{-3}), sample thickness (30 cm), and coarse grains content (2% and 6.5%) of the reference samples, the carbon stock was calculated to be ca 147 t ha^{-1} and 135 t ha^{-1} for original forests of the study area. The Azadshahr and Galikesh dry-farming transects (Fig. 6 a, b, d) presented SOC values of 1.24 ± 0.45% and 1.32 ± 0.25%, and 2.02 ± 0.62%, respectively, on average. Clear cutting of forest to develop dry-farming lands have contributed mainly to a carbon stock loss of ca. 93.55 t ha^{-1}, 93.83 t ha^{-1} in Azadshahr transects and ca. 54.14 t ha^{-1} in the Galikesh transect over the last five decades. Afforestation, particularly on degraded soils with low organic matter contents, can be an important way to mitigate this impact by long-term carbon sequestration both in biomass and in soil (FAO, 2017). In the Golestan Province, for example, silvicultural practices through the cultivation of Cypress trees since 1993 in highly eroded parts of the hillside have resulted in the restoration of SOC content by up to 100% effectiveness

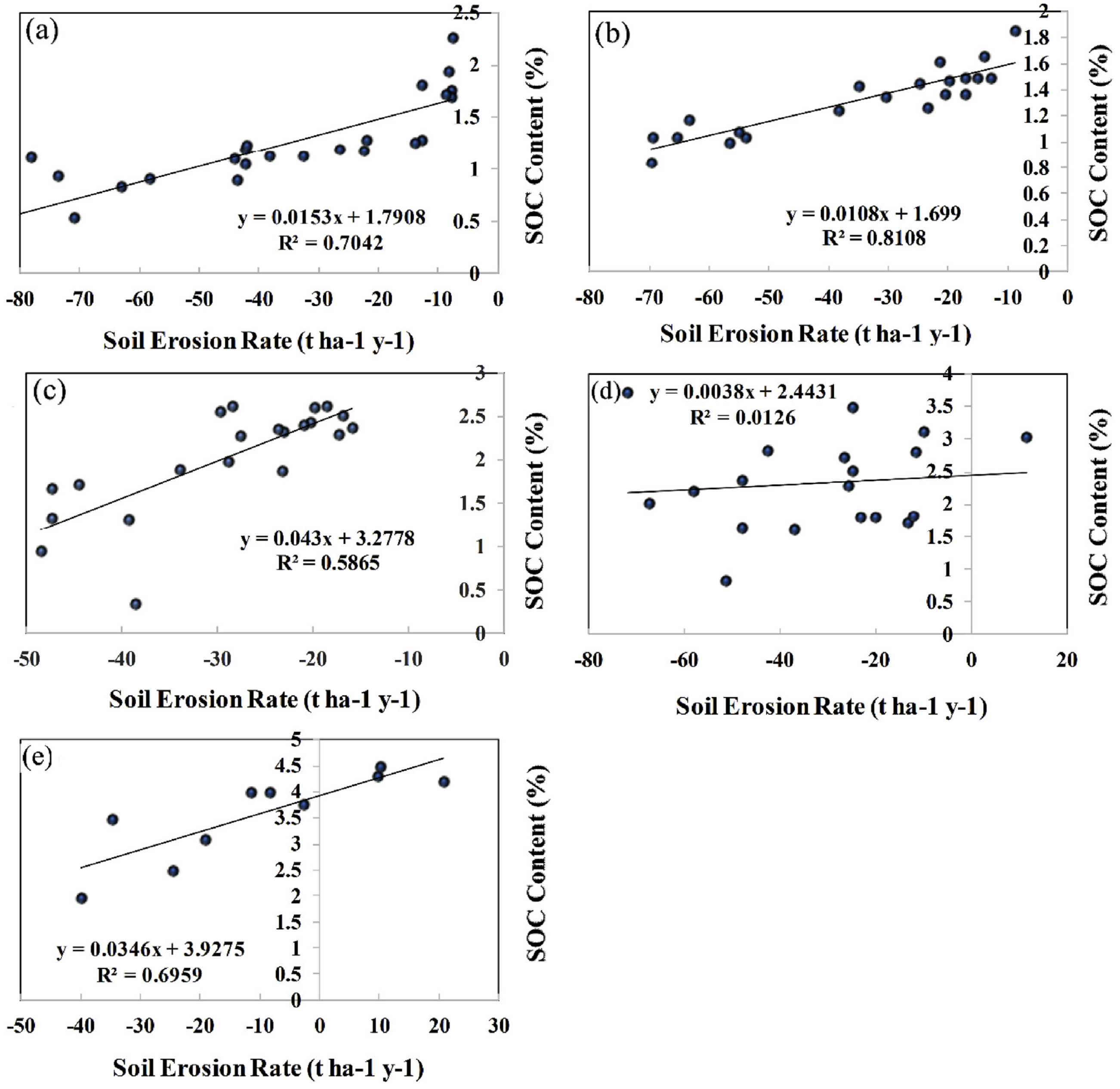


Fig. 6. Correlation between the rate of soil and nutrient loss along the transects (a) Eastward Dry-farming transects, Azadshahr, b) Westward Dry-farming transect, c) Reforested by Cypress and Olive trees transect Azadshahr, d) Dry-farming transect, Galikesh) and e) Reforested by even-aged Cypress trees in Galikesh.

in comparison to the adjacent dry-farming lands. Accordingly, this practice has increased the SOC content from 1.4% to 2.82% which corresponds to a carbon stock restored from 53.28 t ha^{-1} to 114 t ha^{-1}.

The present study has highlighted the remarkable effectiveness of silvicultural practices in the Galikesh area (Fig. 6 e), where the carbon stock increased to 143 t ha^{-1} by 5% in comparison to the SOC stock of the corresponding reference site (135 t ha^{-1}).

In this respect, it is important to note the clear relation between rates of soil erosion and loss of SOC content under dry-farming land use and silvicultural areas (Fig. 6). In transects a, b and d, the high value of R^2 coefficients ($R^2 \approx 0.81$, $R^2 \approx 0.70$, and $R^2 \approx 0.58$) (Fig. 6 a, b, d) show a significant correlation between soil erosion and SOC loss along the representative transects under dry-farming land use. This is likely due to plowing and the consequent decomposition and oxidation of soil organic matter as compared to the original forest where the soil remained undisturbed. Besides, in the dry-farming lands, a very small amount of biomass is left in the fields after harvesting. In addition, a high R^2 coefficient ($R^2 \approx 0.69$) was also found between the SOC amount and ^{137}Cs inventory in the afforested dry-farming in the Galikesh area. These data stressed the high affinity of ^{137}Cs with SOC content and clay particles showing a similar long-term fate (Fig. 7). Similar to the soil loss trend, an expected downward decline in the rate of nutrient loss was found along all the studied transects.

4. Discussion

The new findings of the present research can be compared with the results of similar studies carried out in Golestan Province and around the world. Erodibility of loess deposits in the Golestan Province has been studied by several authors (see Hosseinalizadeh et al., 2018; Najafinejad et al., 2018; Jafari et al., 2015; Hosseinalizadeh et al., 2018; and; Khormali & Ajami, 2011). A specific contribution by Seyed-Alipour et al. (2014) has reported rates of soil erosion in loess deposits using the ^{137}Cs technique. These authors document a mean rate of soil loss equal to 10.78 t ha^{-1} yr^{-1} that is lower than those obtained in our study. However, because of the different sampling strategy adopted (based on random samples without a specific trend), the reported rate is not comparable with the present research in method and assumption. The mean rate of soil erosion for loess deposits of the Golestan Province was estimated by Hosseinalizadeh et al., 2018 using the WEPP model. He reported rates of soil loss equal to 27.26 t ha^{-1} yr^{-1} and 37.11 t ha^{-1} yr^{-1} for a buffer strip with and without vegetation along the hillsides, which is coherent with our results. A recent study by Poręba et al. (2019) documents rates of soil erosion in loess deposits of Poland using radionuclides (^{137}Cs and ^{210}Pb). In that case, a similar approach to that used in our study has been employed and the mean soil erosion rates of 33.5 t ha^{-1} yr^{-1} and 21.8 t ha^{-1} yr^{-1} have been calculated using Mass Balance I and II, respectively. The loess deposits in Poland have been exposed to agriculture because of deforestation and are coherent with our results in terms of geomorphic context and range of soil loss. Another previous work aimed at estimating soil erosion on loess deposits using the ^{137}Cs technique has been carried out by Pennockl et al. (1995) in Canada. Their results remarkably stressed the high sensitivity of the loess deposits to erosion with rates of soil loss ranging between 20 t ha^{-1} yr^{-1} and 40 t ha^{-1} yr^{-1}.

Additional contributions aimed at characterizing loess deposits of the Golestan Province have also been provided by Ayoubi et al. (2011); Jafari Honar et al. (2015); Khormali and Ajami (2011); Khormali et al. (2009); Kiani et al. (2007) in terms of effects of deforestation, land-use changes and soil erosion features on soil properties. Specifically, Ayoubi et al. (2011) stated that deforestation-induced croplands led to a decrease in SOM by 71.5% over the last five decades. On the other hand, this work highlighted the effectiveness of horticultural and silvicultural practices through the cultivation of olive trees and Cypress trees, which restored the SOM by about 49% and 72%, respectively. The overall results provided by Ayoubi et al. (2011) are in good agreement with the findings of the present research, in which forest clearing followed by the cultivation of the loess hill slopes resulted in a general decline of the soil quality attributes (SOC content) over 54 years with a rate of soil loss equal to 93 t ha^{-1} in Azadshahr transects and 54.14 t ha^{-1} in the Galikesh area. Similar information on soil properties of deforestation-induced croplands in the Golestan Province is reported by Khormali et al. (2009). These authors document an increase of silt particle size up to 65%, and a general decrease of the SOC content and clay particle size to 1% and 21%, respectively. These results compare very well with the findings obtained in our study in

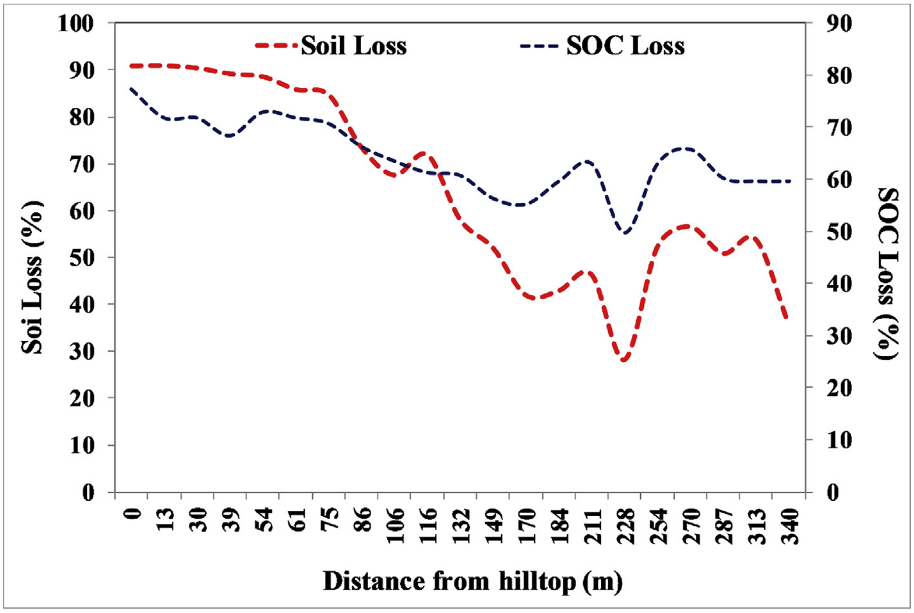


Fig. 7. Correlation between rate of soil and nutrient loss along the dry-farming land use, Azadshahr-West slope direction.

terms of the method applied (usage of transect approach), topographical conditions (similar slope), driving forces, and emphasize the negative effect of deforestation.

5. Conclusions

Soil redistribution following the conversion of original forests to croplands and croplands to reforested lands in the East of the Hircanian Forest has been estimated, for the first time in Iran, using the ^{137}Cs technique supervised by the IAEA. The research assumption was tested and the study objectives were achieved successfully. The research points to almost 110,000 ha of hilly lands, ranging in elevation from 100 m to 500 m, having experienced deforestation, dating back to the 1960s when maximum fallout of radionuclides has been received in original forests. Therefore, the elapsed time of 54 years was assumed between the period of maximum clear cutting (1963) and the date of sampling (2017). Agriculture, cattle ranching, and a variety of wood demands are the major driving forces of deforestation on loess deposits in the North East of Iran, which sped up soil and nutrients resources loss. Previous studies around the world suggested the mean rate of soil erosion using radioisotopes (^{137}Cs and ^{210}Pb) inducing through deforestation on loess deposits ranges from ca 20 t ha^{-1} yr^{-1} to 40 t ha^{-1} yr^{-1}. The highest impacts on land degradation appeared on the converted original forest to dry-farming lands. Present research concludes that loess hilly slopes in the Golestan Province, North-East of Iran have been eroded by the mean rate of 32.27 t ha^{-1} yr^{-1} over the last five decades. Under such conditions, soil and nutrient losses account for ca. 25 cm of superficial soil with a rate of $\approx$2 mm yr^{-1}. Also, resultant data demonstrated the loss of ca 93 t ha^{-1} of the carbon stock from croplands over 54 years in comparison to the original Hircanian Forest. Further, the present study has highlighted the effectiveness of soil conservation practices implemented since 1993 and 2004 (for olive groves) and has led to a successful decrease in soil erosion and nutrient loss. Cultivation of even-aged Cypress trees seems to be one of the best silvicultural methods for reducing soil erosion. Accordingly, results suggest a decline of soil loss from 16% to 60% in comparison with adjacent dry-farming lands, and up to 100% efficiency in the restoration of carbon stock in comparison with the original Hircanian Forests. Although the cultivation of olive trees documented the effectiveness of only 13% (because of its low canopy cover) in soil erosion control, it has produced a general increase (ca. five times) in the annual income of farmers. The research outcomes have recommended the application of radioisotope techniques as a reliable method in measuring some of the on-site impacts of deforestation and specific land uses especially on loess deposits. The present study has contributed greatly to highlighting the sensitivity of soil erosion in such an ecologically important region of Iran and has provided key information for Iranian and international decision-makers to fulfill soil conservation practices.

Acknowledgments

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References

Act41. (1962). *Forest and rangelands nationalization law*. Tehran: The national parliament of Iran.

Act71. (1992). *The law on conservation and protection of natural resources and forest resources of the country*. Tehran: The Parliament of Islamic Republic of Iran.

Ayoubi, S., Khormali, F., Sahrawat, K. L., & Rodrigues de Lima, A.c. (2011). Assessing impacts of land use change on soil quality indicators in a loessial soil in golestan province, Iran. *Journal of Agricultural Science and Technology A, 13*, 727–742.

Bobek, H. (2005). *Historical view of natural forests and Iran's trees* (Vol. 1). Tehran: Geographic Organization of the Armed Forces.

Evans, R., Collins, A. L., Zhang, Y., Foster, I. D. L., Boardman, J., Sint, H., & Griffith, B. A. (2017). A comparison of conventional and 137Cs-based estimates of soil erosion rates on arable and grassland across lowland England and Wales. *Earth-Science Reviews, 173*, 49–64. https://doi.org/10.1016/j.earscirev.2017.08.005

FAO. (2015). *Global forest resources assessment*. Rome: Food and Agriculture Organization of the United Nations.

FAO. (2017). *Land degradation assessment in small island developing states (SIDS)*. Rome, Italy: Land and Water Division.

Fulajtar, M., Mabit, L., Renschler, C. S., & Lee Zhi Yi, A. (2017). *Use of ^{137}Cs for soil erosion assessment*. Rome: Food and Agriculture Organization of the United Nations (Soil and Water Management & Crop Nutrition Section, Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, Vienna, Austria).

Gharibreza, M., & Ashraf, M. A. (2014). *Applied limnology*. Tokyo, Heidelborg, New York, Dordrecht, London: Springer.

Gharibreza, M., Nasrollahi, A., Afshar, A., Amini, A., & Eisaei, H. (2018). Evolutionary trend of the gorgan bay (southeastern Caspian Sea) during and post the last Caspian Sea level rise. *Catena, 166*, 339–348. https://doi.org/10.1016/j.catena.2018.04.016

Gharibreza, M., Raj, J. K., Yusoff, I., Ashraf, M. A., Othman, Z., & Tahir, W. Z. W. M. (2013a). Effects of agricultural projects on nutrient levels in lake bera (tasek bera), peninsular Malaysia. *Agriculture, Ecosystems & Environment, 165*, 19–27.

Gharibreza, M., Raj, J. K., Yusoff, I., Ashraf, M. A., Othman, Z., & Tahir, W. Z. W. M. (2013b). Effects of agricultural projects on nutrient levels in lake bera (tasek bera), peninsular Malaysia. *Agriculture, Ecosystems & Environment, 165*, 19–27. https://doi.org/10.1016/j.agee.2012.12.004

Gharibreza, M., Raj, J. K., Yusoff, I., Othman, Z., Tahir, W. Z. W. M., & Ashraf, M. A. (2013c). Land use changes and soil redistribution estimation using 137Cs in the tropical Bera Lake catchment, Malaysia. *Soil and Tillage Research, 131*, 1–10.

Hiederer, R., & Martin, K. (2011). *Global soil organic carbon estimates and the harmonized world soil database (vol. EUR 25225 EN - 2011* (p. 79). Italy: Institue for environment sustainability, JRS European Commission.

Hosseinalizadeh, M., Kariminejad, N., Campetella, G., Jalalifard, A., & Alinejad, M. (2018). Spatial point pattern analysis of piping erosion in loess-derived soils in Golestan Province, Iran. *Geoderma, 328*, 20–29. https://doi.org/10.1016/j.geoderma.2018.04.029

IAEA. (1995). *Use of nuclear techniques in studying soil erosion and siltation TECDOC-828* (Vol. 828). Vienna: International Atomic Energy Agency.

IAEA. (1998). *Use of Cs137 in the study of soil erosion and sedimentation TECDOC-0828* (Vol. 1028). Vienna: International Atomic Energy Agency.

Indarto, J., & Mutaqin, D. J. (2016). An overview of theoretical and empirical studies on deforestation. *Journal of International Development and Cooperation, 22*(1), 107–120, 0.15027/39231.

Jafari Honar, A., Kiani, F., & Khormali, F. (2015). Effect of climates different on variation of loess soil erodibility indices in golestan province. *Journal of water and soil conservation (journal of agricultural sciences and natural resources), 22*(1), 49–70.

Kaimowitz, D., & Angelsen, A. (1998). *Economic models of tropical deforestation A review*. Bogor, Indonesia: Center for International Forestry Research.

Kakroodi, A., Kroonenberg, S., Hoogendoorn, R., Khani, H. M., Yamani, M., Ghassemi, M., & Lahijani, H. (2012). Rapid Holocene sea-level changes along the Iranian Caspian coast. *Quaternary International, 263*, 93–103.

Khormali, F., & Ajami, M. (2011). Pedogenetic investigation of soil degradation on a deforested loess hillslope of Golestan Province, Northern Iran. *Geoderma, 167–168*, 274–283. https://doi.org/10.1016/j.geoderma.2011.07.030

Khormali, F., Ajami, M., Ayoubi, S., Srinivasarao, C., & Wani, S. P. (2009). Role of deforestation and hillslope position on soil quality attributes of loess-derived soils in Golestan province, Iran. *Agriculture, Ecosystems & Environment, 134*(3), 178–189. https://doi.org/10.1016/j.agee.2009.06.017

Kiani, F., Jalalian, A., Pashaee, A., & Khademi, H. (2007). Effect of deforestation, grazing exclusion and rangeland degradation on soil quality indices in loess-derived landforms of golestan province. *Journal of Water and Soil Science, 11*(41), 453–464.

Mabit, L., Benmansour, M., & Walling, D. W. (2008). Comparative advantages and limitations of the fallout radionuclides ^{137}Cs, ^{210}Pbex and ^{7}Be for assessing soil erosion and sedimentation. *Journal of Environmental Radioactivity, 99*, 1799–1807.

Mohamed Abd Elbasit, A., Shekhar Prasad Ojha, C., Jinbai, H., Yasuda, H., Kimura, R., & Ahmed, Z. (2013). Relationship between rainfall erodibility indicators under arid environments: Case of liudaogou basin in Chinese loess plateau. *Journal of Food Agriculture and Environment, 11*(2), 1073–1077.

Muhs, D. R. (2007). *Loess deposits, origins and properties quaternary stratigraphy: Lithostratigraphy*. USA: U.S. Geological Survey, CO.

Pennockl, D. J., Lemmen, D. S., & de Jong, E. (1995). Cesium-l37 measured erosion rates for soils of five ;parent-material groups in southwestern Saskatchewan. *Canadian Journal of Soil Science*, 205–210.

Poreba, G. J. (2006). Cesium-137 as a soil erosion treacer: A review. *Journal on methods and applications of Absolut Chronology, 25*, 37–46.

Poręba, G., Śnieszko, Z., Moska, P., Mroczek, P., & Malik, I. (2019). Interpretation of soil erosion in a Polish loess area using OSL, ^{137}Cs, ^{210}Pbex, dendrochronology and micromorphology – case study: Biedrzykowice site (s Poland). https://doi.

org/10.1515/geochr-2015-0109, 46(1), 57.

Rahimzadeh, N., Khormali, F., Gribenski, N., Tsukamoto, S., Kehl, M., Pint, A., & Frechen, M. (2019). Timing and development of sand dunes in the golestan province, northern Iran—implications for the late-PleisSOCene history of the Caspian Sea. *Aeolian Research, 41*, 100538. https://doi.org/10.1016/j.aeolia.2019.07.004

Ritchie, J. C., Ritchie, C. A., Ritchie, J. C., & Ritchie, C. A. (2007). *Bibliography of publications of ^{137}Cesium studies related to erosion and sediment deposition*. USDA–ARS Hydrology and Remote Sensing Laboratory Occasional Paper HRSL-2007-01.

Robbins, J. A., Edgington, D. N., & Kemp, A. L. W. (1978). Comparative ^{210}Pb, ^{137}Cs, and pollen geochronologies of sediments from lakes ontario and erie. *Quaternary Research, 10*(2), 256–278.

IPPC. (2019). In J. M. M. Rodriguez, & C. Vera (Eds.), *Land degradation* (p. 186). the United Nations: IPCC SRCCL.

Rogowski, A. S., & Tamura, T. (1970). Erosional behavior of cesium-137. *Health Physics, 18*, 467–477.

Seyed-Alipour, H., Feiznia, S., Ahmadi, H., Zare, M., & Hosseinalizadeh, M. (2014). Comparison of soil erosion by 137CS and RUSLE-3D for loess deposits North-East of Iran (study area: Aghemam catchment). *Journal of Water and Soil Conservation, 21*(5), 27–47.

Smalley, I. J., & Smalley, V. (1983). Loess material and loess deposits: Formation, distribution and consequences. In M. E. Brookfield, & T. S. Ahlbrandt (Eds.), *Developments in sedimentology* (Vol. 38, pp. 51–68). Elsevier.

Tagami, K., Tsukada, H., & Uchida, S. (2019). Quantifying spatial distribution of 137Cs in reference site soil in Asia. *Catena, 180*, 341–345. https://doi.org/10.1016/j.catena.2019.05.009

Tejaswi, G. (2007). *Manual on deforestation, degradation, and fragmentation using remote sensing and GIS*. Rome: Forestry Department , Food and Agriculture Organization of the United Nations.

Walkley, A. I., & Black, A. (1934). An examination of the degtjareff method for determining organic carbon in soils: Effect of variations in digestion conditions and of inorganic soil constituents. *Soil Science, 63*, 251–263.

Walling, D. E. (1999). Linking land use, erosion and sediment yields in river basins. *Hydrobiologia, 410*, 223–240, 0.

Walling, D. E., & He, Q. (1999). Using fallout lead-210 measurements to estimate soil erosion on cultivated land. *Soil Science Society of America Journal, 63*, 1404–1412.

Walling, D. E., & Quine, T. A. (1990). Calibration of caesium-137 measurements to provide quantitative erosion rate data. *Land Degradation and Rehabilitation, 2*, 161–175.

Walling, D. E., Zhang, Y., & He, Q. (2007). *Models for converting Measurements of environmental radionuclide inventories (^{137}Cs, excess ^{210}Pb, and ^{7}Be) to Estimates of soil Erosion and deposition rates (including Software for model implementation)*. Exeter: University of Exeter.

Walling, D. E., Zhang, Y., & He, Q. (2014). Conversion models and related software. In *Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies* (pp. 125–148). Vienna: IAEA. Vol. IAEA-TECDOC-1741.

Yamagata, N., Matsuda, S., & Kodaira, K. (1963). Run-off of caesium-137 ans strontium-90 from rivers. *Nature, 200*, 668–669.

Yan, R., Zhang, X., Yan, S., & Chen, H. (2018). Estimating soil erosion response to land use/cover change in a catchment of the Loess Plateau, China. *International Soil and Water Conservation Research, 6*(1), 13–22. https://doi.org/10.1016/j.iswcr.2017.12.002

Zapata, F., & Garcia-Agudo, E. (2000). Future prospects for the ^{137}Cs technique for estimating soil erosion and sedimentation rates. *Acta Geologica Hispanica, 35*(3–4), 197–205.