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An evaluation of the role of land use in soil erosion using ^{137}Cs inventory and soil organic carbon stock, in a mountainous catchment of western Iran.

Loghman Shirzadi [a],Jamal Rasouli [a] , Kazem Nosrati [b]*

[a]: *PhD students, Department of Earth Sciences, Shahid Beheshti University, Tehran, Iran*

b: Department of Physical Geography, Faculty of Earth Sciences, Shahid Beheshti University, G.C., 1983969411 Tehran, Iran

1. Introduction

Soil erosion has been recognized as one of the major forms of human-induced soil degradation. In addition, harmful sediment may cause downstream sedimentation as well as surface and groundwater pollution. Soils are the largest terrestrial C pools (IPCC, 2007) and any manipulation of this pool can significantly influence the concentration of atmospheric CO_2 (Poeplau and Don, 2013). Soil erosion is one of the most important environmental problems in Iran's catchments. Due to land-use changes in Iran, erosion has increased 800% between 1951 and 2002, calling for urgent action (Nosrati et al., 2011). The concentration and turnover of soil organic carbon (SOC) are usually the highest in the surface soil (Conant et al., 2001). Therefore, soil erosion influences the balance of SOC stock and hence may cause CO_2 emissions or sequestration. A global carbon sink of 0.12 (range 0.06 to 0.27) petagrams of carbon per year (pg yr $^{-1}$) occur as a result of erosion in the world's agricultural landscapes (Van Oost et al., 2007). Thus, the ability to predict SOC stocks and its changes can provide useful information on land degradation risk. This helps to select the best management actions to mitigate the effects of land degradation. It is therefore not surprising that changes in soil erosion and deposition have been suggested as an indicator of changes or disturbances of SOC. The most used tracer in soil erosion measurement is a radioactive isotope of caesium (^{137}Cs). ^{137}Cs was produced in the fallout of atmospheric testing of nuclear weapons from the 1950s to 1970s. Demonstrated that ^{137}Cs and SOC moved at the same rate with the same mechanism through soil erosion, indicating that the ^{137}Cs radionuclide could be used directly for quantifying dynamic SOC redistribution as the soil was affected by intensive soil erosion. It is therefore worthwhile to investigate the ^{137}Cs activity as a proxy for soil erosion and SOC release. Instead of employing the commonly used soil organic carbon (SOC) term to relate soil erosion, we used soil organic carbon stock (SOCS) related with soil erosion and ^{137}Cs activity. The reason for this change is because soil organic carbon stock is a function of the SOC concentration, and the bulk density of the soil that is more vulnerable to land use type and soil erosion. The main objectives of this study were to determine soil redistribution on the basis of the variation of ^{137}Cs radionuclide activity under different land uses in a mountainous catchment of western Iran. Also, the relationship between soil erosion and deposition rates, using ^{137}Cs inventory conversion models and storage and loss of soil organic carbon stocks was examined. To do this, ^{137}Cs activity and SOCS were measured in thirty-two sample sites from in cultivated and forested areas and four sediment samples were collected along the river catchment . The simplified mass-balance model and diffusion and migration model estimated. Finally were determined relative percent of each sediment sources.

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* Corresponding author. E-mail address: *Loghman.Shirzadi@gmail.com*

2. Material and methods

2.1. Study area

The study was conducted on the Nachi catchment as a sub catchment of Ghazalche Soo catchment located near the town of Marivan in western Iran (46° 7′ E, 35° 40′ N). The study site covered an area of 4.47 km2 and is conterminous with the eastern border of Iraq. The major land uses of the Nachi catchment are: residential rural area (8.4 ha, 1.9% of total area), forest including Quercus infectoria, Crataegus aronia, Pyrus spp., and Contoneaster vulgaris species (184.4 ha, 41.2% of total area) and crop field (254.5 ha, 56.9% of total area).

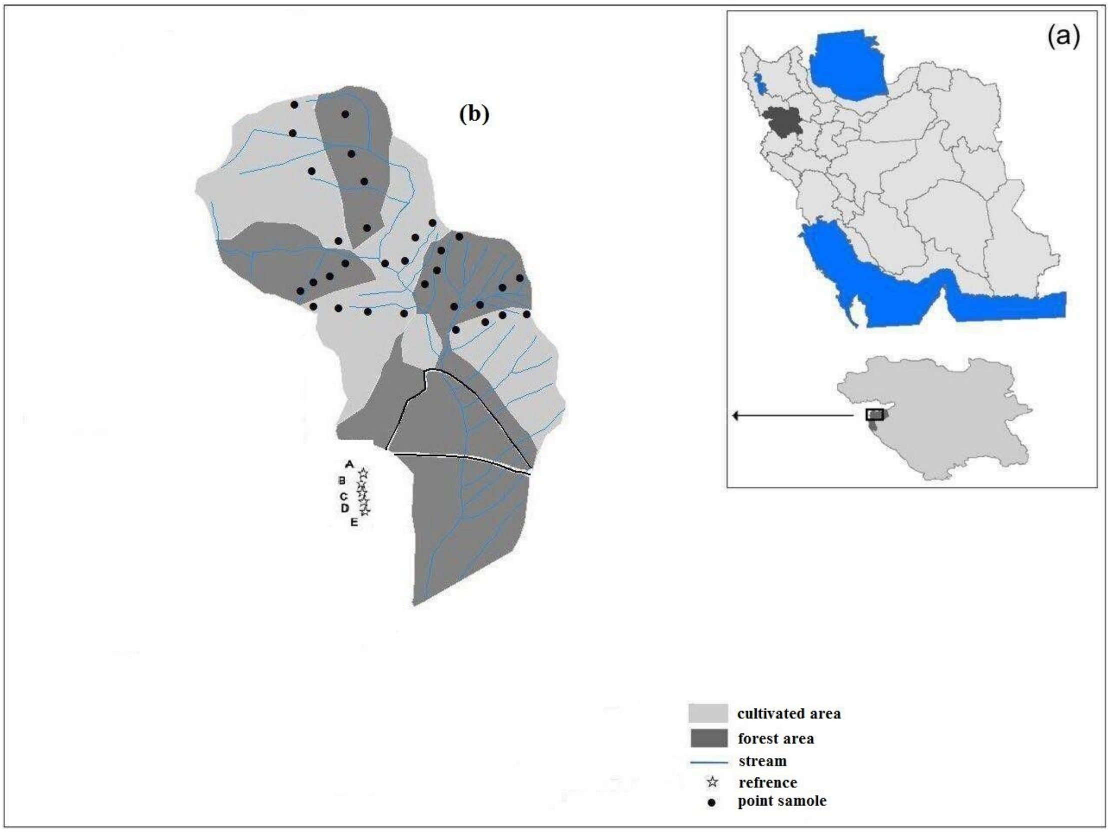

Fig.1. Map of Nachi catchment showing the location of catchmentand reference and sampling sites

2.2. Reference location soil sampling and measurements

Reference locations were selected based on the guidelines by Walling and Quine (1993). who suggested sites with minimal slope, within or very close to the catchment, and without erosion and deposition. An appropriate location for reference sampling, on the basis of site selection criteria, was located out of the catchment at eastern side (~700 m distance from catchment border) (Fig.1). Then, five reference sampling sites made accurate estimates of erosion/deposition rate. soil core samples were taken ranging from 5 to 30 cm deep in order to establish a ^{137}Cs distribution profile. A scraper plate was used to collect depth incremental samples (Loughran et al., 1992; Walling and Quine, 1993). The coefficient of variation (CV) of total 137Cs inventory for all five sites was 10.26% with mean value of 7405 Bq m $^{-2}$ and standard deviation of 759.9. Minimum number of reference samples with less than 10% error at the 95% confidence level and coefficient of variation of 10% is four (See Pennock et al., 2008) .The ^{137}Cs concentrations were measured at 662 keV by gamma spectrometry with a high-resolution germanium detector (count times ~86,000 s). The mean value of ^{137}Cs inventory collected from the five reference sites was 2428.8 and 150.4 Bq m $^{-2}$ for upper (0–5 cm) and lower layers (25–30 cm), respectively, which is consistent with another study from western Iran with 2339 Bq m $^{-2}$ (Kalhor, 1998) and 2130 Bq m $^{-2}$ (Abbaszadeh Afshar et al., 2010) inventory for upper layer of soils.

2.3. Soil sampling and measurements

Samples were collected from two major land use types including natural forests (undisturbed area) and cultivated land. Composite sampling procedure is needed to reduce soil properties variability as a result of processes such as micro topography, especially in forest land uses (Be'langer and Van Rees, 2008). soil bulk density using the method proposed by Forster (1995) was measured for each sample. As samples were collected using a narrow core, there will be some variability associated with sample collection. It is suggested that the magnitude of such sampling variability is a function of the surface area over which samples are collected. The larger the surface area involved, the smaller the variability associated with sampling (Owens andWalling, 1996). The spatial variability can be statistically overcome by measuring replicate independent samples from each landuse unit, or simply composite them and then measuring the concentrations for faster measurement with minimal cost (Zhang, 2014; Zhang et al., 2015). To measure the bulk density, undisturbed soil cores were collected using a 6 cm diameter corer. As the volume of soil samples from corer is not sufficient for gamma spectrometer measurements, a trowel was used to collect samples (size ~1000 g) from the upper soil layer adjacent to the corer sampling locations. An area of 100 cm^2 with 10 cm depth was used to collect the samples. fallout radionuclide ^{137}Cs activity (Bq kg^{-1}), and inventory (Bq m^{-2}).

2.4. Calculation of soil loss and deposition rates

To quantify soil erosion/deposition rates, the radionuclide loss or gain which was computed by comparing radionuclide inventories at sampling sites to a reference inventory was converted into soil loss or gain using conversion models. In all conversion models, a site with a total ^{137}Cs inventory (Bq m $^{-2}$) less than the local reference inventory (Bq m $^{-2}$) was assumed to be an eroding site, while sites with inventories higher than the reference inventory were assumed to be depositional sites. Empirical and theoretical conversion models were used to calculate erosion and sedimentation rates from radionuclide inventories developed in previous studies for both cultivated and undisturbed soils. Models developed by Elliott et al(1990) and Loughran and Campbell (1995). were among the successful derivation of empirical relationship between erosion and radionuclide inventories in disturbed (cultivated) soils. Also, theoretical conversion models including the proportional model (Walling and Quine, 1990), gravimetric approach (Lowrance et al., 1988), simplified (Zhang et al., 1990) and improved (Walling and He, 1999) mass-balancemodelswere suggested to improve estimation of soil erosion in cultivated soils. Theoretical models such as profile-distribution models (e.g. Porto et al., 2001; Walling and Quine, 1990; Zhang et al., 1990) and diffusion-migration models (He and Walling, 1997; Knatko et al., 1996) were used to predict soil erosion in undisturbed soils.
For eroding sites, mean annual soil loss (t ha^{-1} yr^{-1}) was calculated based on percentage reduction in total ^{137}Cs inventory using relative difference of local reference inventory and sampling site inventory. For estimating the particle size correction factor P for erosion, two suspended sediment samples were collected during flood events from the outlet of a sub-catchment with cultivated area and their ^{137}Cs activity concentration was measured. Both mass balance model and diffusion and migration model were included in the software developed by Walling et al. (2007). To calculate soil organic carbon stocks (SOCS), soil organic carbon using the Walkley–Black method (Skjemstad and Baldock, 2008) and soil bulk density using the method proposed by Forster (1995) was measured for each sample.

2.5. Data treatment and statistical analyses

Two-way ANOVA test were used to investigate the effect of land use types on the ^{137}Cs activity and inventory, SOCS and erosion/deposition. Before performing a two-way ANOVA, the mentioned variables were subjected to the Kolmogorov– Smirnov test for normality and a Levene test for homogeneity of variance. When homogeneity of variance was not reached, the data were transformed using natural logarithm (Dytham, 2011). A Fisher's LSD post-hoc test was used to identify important contrasts within the

^{137}Cs activity and inventory, SOCS and erosion/deposition terms. All statistical analyses were performed using STATISTICA V.6.0 (StatSoft, 2008).

3. Conclusions

Erosion and sedimentation rate, determined using ^{137}Cs inventory measurements and conversion models, shows remarkably higher erosion in cultivated than undisturbed soils.The results of this study show that the relative contribution of the agricultural sector in the production of sediment is %95.34 and the relative contribution of the forestry sector has been% 4.66.This emphasizes that land use changes from forested and undisturbed soils to cultivated and disturbed soils significantly increases erosion showed were changing land use (human interference) which remarkably intensifies soil erosion in the catchment. Therefore, soil erosion influences the balance of SOC stock and hence may cause CO_2 emissions or sequestration. ^{137}Cs and SOCS concentrations of soils were significantly correlated in both forested and (undisturbed soils) cultivated areas (disturbed soils). This suggests that those carbon and ^{137}Cs radionuclides are moving along similar physical pathways in the Nachi catchment. Then, the values of SOCS could be an index of soil redistribution (erosion or deposition) rates. In addition, with increase in soil organic carbon stock (SOCS), erosion in both cultivated and undisturbed soils was decreased. This illustrates the ability of SOCS to enhance soil stability and maintain soil structure by forming stable aggregates and emphasizes the importance of management actions to enhance sequestration of carbon in the ecosystems. The results demonstrate that ^{137}Cs could be used directly for quantifying the dynamics of SOC in soil redistribution relationship as affected by soil erosion. Land use types affect variability of soil ^{137}Cs activity and inventory and SOCS. Accurate estimates of the factors contributing to soil erosion, sediment loading, and SOCS variability in mountainous catchment of the western Iran could provide useful information in exerting appropriate management actions to reduce excessive soil erosion and accelerated sedimentation.

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