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Determination of soil loss by ^{137}Cs fallout radionuclide in Ömerli watershed of İstanbul, Turkey

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Abstract: Soil erosion and sedimentation in watersheds are usually part of the information to be considered for soil and water conservation measures. Soil loss is generally estimated with models or measured with plot studies. Although fallout radionuclides (FRN)[#] methodology provides a powerful technique for predicting the impacts of proposed land management strategies on soil erosion and sediment yield within river basins and estimates erosion based on fallout radioisotopes (Cs-137, Pb-210, Be-7) radioactivity, it is rarely used in Turkey. The aim of this study was to determine soil losses from different land use types with FRN's methodology by using caesium-137 radionuclide in selected study sites around Paşaköy (shrub) and Esenceli (rangeland) villages in the environs of Ömerli watershed. Bulk and 2 cm-depth incremental soil core samples were collected from the reference and sloping areas in both study sites. Soil losses varied from 0.49 to 23.22 t ha^{-1} yr^{-1} for shrub-covered sites and from 0.44 to 7.23 t ha^{-1} yr^{-1} for rangelands. The data show that soil loss from shrub-covered site was greater than acceptable tolerance limit (10 t ha^{-1} yr^{-1}) for soils of the sites.

Key words: Caesium-137, Soil erosion, Land use, Ömerli watershed, Radionuclide

[#]**Abbreviations:** FRN, Fallout Radionuclide; IAEA, International Atomic Energy Agency; ISKI, İstanbul Water and Sewerage Administration; NPP, Nuclear Power Plant; TECDOC, Technical Document; TSMS, Turkish State Meteorological Service; UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation; USDA, United States Department of Agriculture.

Ömerli havzasında (İstanbul-Türkiye) toprak kayıplarının ^{137}Cs serpinti radyonüklidi ile belirlenmesi

Özet: Su havzalarındaki toprak erozyonu ve sedimentasyon genel olarak toprak ve su koruma önlemlerinin belirlenmesine yönelik olarak değerlendirilmektedir. Toprak kaybı genellikle modeller ya da parsel çalışmalarıyla belirlenmektedir. Serpinti radyonüklidlerinin (Cs-137, Pb-210, Be-7) radyoaktivitesini temel alan serpinti radyonüklidleri yöntemi (FRN); öngörülen arazi kullanım şekillerinin su havzalarının toprak erozyonu ve sediment verimi üzerindeki etkisini belirlemek için uygun bir yöntem olmasına karşılık, Türkiye'de az kullanılan bir metottur. Bu çalışmada amaç, değişik arazi kullanım şekillerinden meydana gelen toprak kayıplarını, sezyum-137 radyoaktivitesinden yararlanarak serpinti radyonüklidleri yöntemi ile belirlemektir. Bu amaca uygun olarak, araştırma alanları Ömerli havzasındaki

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Paşaköy (fundalık) ve Esenceli (mera) köylerinden seçilmiştir. Her iki çalışma sahasında seçilen referans ve eğimli alanlardan doğal yapısı bozulmamış silindir örnekleri ve 2 cm kalınlığında kesitler halinde toprak örnekleri alınmıştır. Toprak kaybının fundalık alanda 0.49 ile 23.22 t ha^{-1} $yıl^{-1}$ ve mera alanında da 0.44 ile 7.23 t ha^{-1} $yıl^{-1}$ arasında değiştiği belirlenmiştir. Bu bulgular fundalık alandaki toprak kaybının araştırma alanlarındaki topraklar için öngörülen tolerans değerinden (10 t ha^{-1} $yıl^{-1}$) büyük olduğunu göstermektedir.

Anahtar sözcükler: Sezyum-137, Toprak erozyonu, Arazi kullanımı, Ömerli havzası, Radyonüklid

Introduction

Land degradation induced desertification is one of the main threats towards humans. One major cause of desertification in Turkey is soil erosion that mostly advances parallel with loss of biodiversity, contamination, sealing and compaction, floods, and landslides. Additionally, soil erosion has a negative effect on water quality and quantity; hence sediment storage within a river basin can provoke environmental problems where sediment-associated pollutants accumulate in sediment sinks. Some reservoirs of Turkey have been subject to serious erosion events and suffered from siltation. The suspended sediment yield of Turkey is about 3 times greater than the world average (world average 1.82 t ha^{-1} yr^{-1}) (Hızal, 2004). According to the erosion map of Turkey, 86.0% of the soils of Turkey have been experiencing erosion in various intensities (Topraksu Genel Müdürlüğü, 1981). Moreover, the consequences of land degradation are resulting in considerable environmental damages and posing serious threats to human life in the country. Similar problems also take place in the Ömerli reservoir watershed in Riva basin. Although detailed historical land use information was not available for the Ömerli watershed, contacts with local villagers and related state services suggested that the general land use pattern has not changed significantly for periods. The whole watershed is forest-covered and land rehabilitation studies in the area are carried out by the Turkish Forest Service. The main effort of Forest Service is to protect soil from erosion with forestation. Preliminary results of these efforts show that these works could decrease erosion rates in the study site.

The need to understand, describe, predict and quantify soil erosion at all scales, and accurately define the influence of local ecological factors is important for the adoption of suitable erosion control measures. Among the main techniques used worldwide to measure soil erosion on different scales are plot experiments, surveys, and tracers. There is a paucity of long-term erosion rate data derived from direct measurements. Many of the problems associated with long-term monitoring of soil redistribution can be overcome by using the FRN's methodology to trace soil movement. Since the FRN's methodology provides accurate, quick, and efficient net soil flux measurements aggregated over different time scales for different land use types, it has been applied successfully in numerous studies throughout the world (Ritchie and Ritchie, 2007). The methodology and its important advantages are well explained by Walling and Quine (1993) and Zapata (2002). The global ^{137}Cs inventory map which does not include the Chernobyl Nuclear Power Plant (NPP) accident contribution shows that the ^{137}Cs inventory for Turkey is between 1600 and 2400 Bq m^{-2} (Agudo, 1998), and the average ^{137}Cs deposition density in countries or larger sub regions in Europe map (adopted from UNSCEAR, 1988) shows that the Chernobyl derived ^{137}Cs inventory for Turkey was smaller than 1 kBq m^{-2} (1000 Bq m^{-2}) (Figure 1a). In the light of this information and considering the limited number of erosion studies using the FRN's methodology in Turkey, long-term and spatially distributed data are essentially not available (Hacıyakupoğlu et al., 2003; Uğur et al., 2004; Haciyakupoglu et al., 2005; Saç et al., 2008). In this paper, an attempt has also been made to determine soil losses from different land use types in the environs of Ömerli reservoir in Riva basin by using caesium-137 (^{137}Cs) fallout radionuclide, which is artificial and has been introduced into the atmosphere by the detonation of fission nuclear weapons.

Materials and methods

Ömerli watershed and Study sites

The Ömerli watershed (40 ° 51 ′ N – 41 ° 07 ′ N and 29 ° 11 ′ E – 29 ° 40 ′ E) is located in the east part

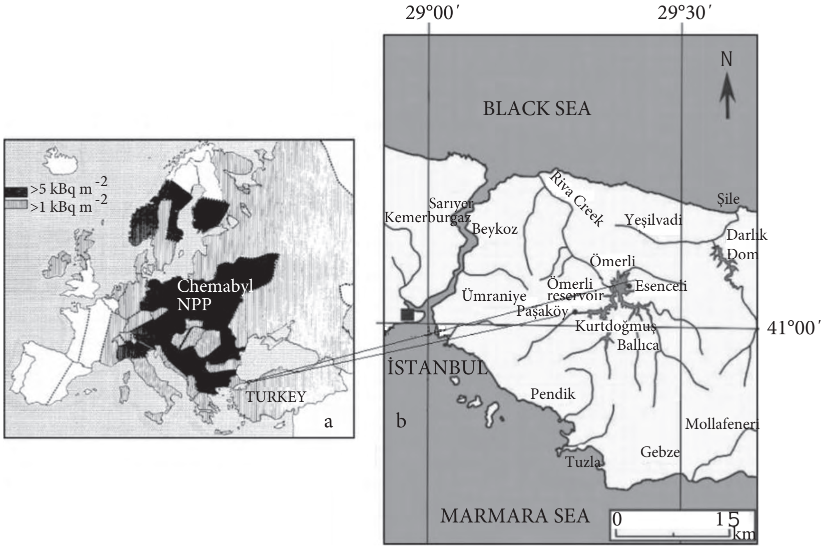

Figure 1. a) Average ^{137}Cs deposition density in countries or larger sub regions in Europe (adopted from UNSCEAR, 1988) b) Location of Ömerli reservoir and sampling sites.

of İstanbul city, drains an area of 57800 ha. Its reservoir was built in 1972 and supplies a substantial portion of the fresh water consumed in İstanbul. Mean annual temperature in the site is around 12.8 °C, average annual precipitation is about 705 mm, which mainly falls in winter (41.2%) and autumn (29.1%) (TSMS, 1970). According to the Thornthwaite classification system, the climate of the watershed is humid, mesothermal oceanic with a moderate water deficit in summer months. Topography is fairly steep in watershed. 55.2% of the watershed has a slope equal or greater than 15% and soil texture ranges generally from sandy to loam. Deep to moderate (90 to 50 cm), stony and non-calcic Vertic Xerochrept soils (brown forest soils) are dominant in the watershed. The lithological parent material includes Silurian arkoses, Devonian schist, Triassic conglomerates, sandstones, gravel, limestone, Eocene limestone and covered deposits Neocene (Pliocene) sand, clay and gravel (Kızıltaş, 2007).

Vegetation cover of the Ömerli watershed is mainly composed of pine tree species and coppice vegetation including oak, beech, and shrub species; however, most of the watershed (34653 ha) is covered with forest vegetation. In addition, open areas (agriculture, urban, and industry) and water surfaces cover 23167 ha of the watershed (Hızal and Cesur, 1998). In order to protect reservoir from contamination and siltation, İstanbul Water and Sewerage Administration (ISKI) divided watershed into four protection zones starting from edge of the water body. In addition to the Forest Service, ISKI has also been making afforestration works with using some tree species such as willow, ash, cypress, maple and stone pine trees in the first and second degree protection areas, but the effectiveness of these works has not been measured. No systematic monitoring of soil and water conservation has been undertaken for agriculture and rangelands in the Ömerli watershed until now. Therefore, in the frame of study objective, Paşaköy (arkoses) and Esenceli (Devonian arkoses sandstone) sites were selected as representative of shrub land and rangeland, respectively according to data gathered from geological and topographic maps and forest management plans to assess soil redistribution (erosion) rates with using ^{137}Cs inventory by FRN's methodology in the watershed (Figure 1b).

Application of fallout radionuclide's methodology

The profile distribution and diffusion-migration models, developed for uncultivated soils by using

FRN's methodology have been successfully used in previous studies, where field erosion and sedimentation rates were estimated (Ritchie and Ritchie, 2007). The diffusion-migration model represents an improvement over the profile distribution model and takes into account the time-dependent behavior of both the ^{137}Cs fallout input and its subsequent redistribution in the soil profile. However, the reliability of the relevant parameters provided the use of profile distribution model in this study. Soil redistribution for study sites for the period of 1963 to January 2006 was derived from ^{137}Cs measurements with using profile distribution model:

$$Y = \frac{10}{(t - 1963)\,P} \times \ln\left(1 - \frac{X}{100}\right) \times h_0 \qquad (1)$$

where;

Y is the annual soil loss (t ha^{-1} yr^{-1}).

t is the year of the sample collection (yr).

P is the particle size correction factor, which assumes to take account of the grain size selectivity of erosion and sedimentation processes. For an eroding site, it is a function of the ratio of the ^{137}Cs concentration of mobilised sediment to that of the original soil. In order to estimate values for the particle size correction factor for eroding sites, information on the grain size (specific surface area) distribution of the soils and the mobilised sediment is needed. The particle size correction factor has no unit and is assumed to be 1.

X is the percentage of ^{137}Cs loss in total inventory in respect to the local ^{137}Cs reference value [defined as $(A_{ref} - A_u)\ 100 / A_{ref}$].

A_u is the measured total ^{137}Cs inventory at the sampling point (Bq m^{-2})h_0 is the profile shape coefficient (kg m^{-2}), which describes the rate of exponential decrease in inventory or radioactivity with depth for a soil profile from an uncultivated site and is derived from measurements of the vertical distribution of ^{137}Cs in the soil profile at the reference site by fitting the following exponential function to those data:

$$A(x) = A(0) \times e^{-x/h_0} \quad \text{where;} \qquad (2)$$

A (x) is the activity of ^{137}Cs at depth x (Bq kg^{-1}).

A(0) is the activity of ^{137}Cs in the surface soil (Bq kg^{-1}).

x is the mass depth from soil surface (kg m^{-2}) and it is a function of surface area of soil core, soil density and depth from the soil surface downward (Collins et al., 2001; Zapata, 2002).

Soil sampling and preparation

Bulk and depth incremental soil core samples were collected from the selected reference and sloping areas according to the procedures for fallout radionuclide's methodology to compare soil losses, which are determined by activity of ^{137}Cs fallout radionuclide. For these purposes, reference areas were chosen from the flat sites which had not been subjected to erosion and deposition, nor cultivated.

To collect soil samples, two reference sites each having a size of approximately 100 m^2 in a square shape were chosen one from Paşaköy and other from Esenceli. In each reference site, 3 soil bulk samples were taken for each corner of the square in a triangle position with a motorized percussion corer with the corer diameter of 6.9 cm. Soil sampling depth varied from 16 to 50 cm. A total of 12 bulk soil samples were collected for estimating ^{137}Cs activity inventories for each reference site. Additionally, one soil section sample from each site was also collected with 2 cm increments to determine ^{137}Cs depth profile.

In order to collect soil samples from sloping sites (vulnerable to erosion), two transect lines with a slope of 17 ° in Paşaköy and four transect lines with a slope of 32 ° in Esenceli were established and sampling was done with an interval of 10 meters along the transect lines. Sampling depth was 48 cm in Paşaköy and 40 cm in Esenceli. Because of the differences in the topography of the study sites, numbers of transect lines and their lengths were different for both sites.

Soil samples were oven dried at 105 °C, grounded and passed through 2 mm sieve and each sample was weighed and sealed for gamma spectrometry analysis.

On the other hand, in order to determine some selected soil properties, which have an effect on vertical movement of radionuclides, soil samples were collected from reference and sloping areas in Paşaköy and Esenceli from the depths of 0-10 cm and 10-20 cm and analyzed for soil texture, pH and $CaCO_3$. Soil texture analyses were made on the basis of organic matter-free and oven-dry soil samples less than 2mm diameter using the Bouyoucus hydrometer method, pH was measured at 1/2.5 soil water ratio using glass electrode pH-meter, $CaCO_3$ was determined using Scheibler calcimeter and loss-on-ignition was determined at 700-800 °C by using a muffle furnace (Gülçür, 1974).

Radionuclide activity measurements

The measurements for ^{137}Cs activities were undertaken in the International Atomic Energy Agency (IAEA) Soil Science Unit Laboratories using lead shielding detector (GEM 100-PLUS coaxial p-type germanium detector, 100% efficiency for 1.3 MeV of ^{60}Co and 1.20 keV full width at half maximum for 122 keV of ^{57}Co), which had been calibrated using Amersham radionuclide standard (volume: 1.300 mL, density: 1.0 g cm^{-3}). Statistical confidence levels and counting times were adjusted to 2σ and 3 x 10^4 or 6 x 10^4 seconds, respectively. ^{137}Cs activity concentrations in the soil samples were determined by measuring the counts at 661.66 keV photo peaks using Vision-32 software program (Gamma-Ray Spectrum Analysis and MCA Emulator for Microsoft Windows 98, 2000, NT and XP - Software Version 6).

Statistical analysis

In order to compare ^{137}Cs activity inventories, erosion rates and sedimentation rates between shrub land and rangeland, ^{137}Cs data were analyzed using two-tailed t-test ($P < 0.05$) (Zar, 1996).

Results

Results showed that soils in Paşaköy and Esenceli study sites have acidic soil reaction with pH values lower than 6 with no carbonate reaction. Soil in the Paşaköy site has sandy loam texture whereas soil in the Esenceli site has silt loam texture. Measured properties of soils in the study sites were presented in Table 1.

^{137}Cs inventories and depth distribution

The mean activities were about 7.50 ± 0.77 Bq kg^{-1} for the Paşaköy reference study site and 1950.16 ± 198.52 Bq m^{-2} for the local ^{137}Cs fallout reference inventory while they were about 5.33± 0.48 Bq kg^{-1} for the Esenceli reference study site and 1440.04 ± 129 Bq m^{-2} for the local ^{137}Cs fallout reference inventory. Furthermore, ^{137}Cs mass depth profiles show that Paşaköy and Esenceli have convenient conditions for reference sites (Figure 2).

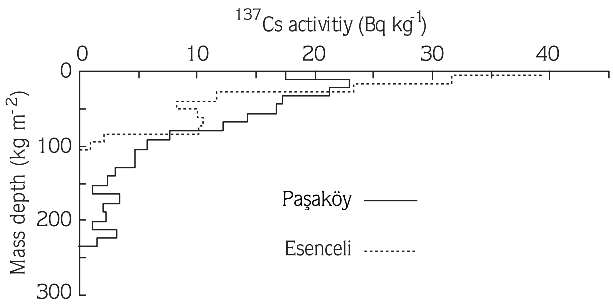

Figure 2. Mass depth distribution of ^{137}Cs within soil profiles for the Paşaköy and Esenceli reference sites.

Soil redistribution rates

Inventories from Paşaköy and Esenceli reference sites were used for determining soil redistribution rates in Paşaköy and Esenceli study sites. To parameterize the profile distribution model, equation (2) has been fitted to the vertical distribution of ^{137}Cs activities for the two reference sites to obtain values for A (0) and h_0. For this reason, A(0) and h_0 factors were estimated from straight regression equation

Table 1. Measured properties of soils in the study sites.

Sample location	Depth (cm)	Texture (%) Clay	Silt	Sand	Textural class names	pH (1/2.5 H_2O)	$CaCO_3$ (%)	Loss on ignition (%)
Paşaköy	0-10	15.0	27.0	58.0	sandy loam	5.8	None	6.7
	10-20	17.0	31.0	52.0	sandy loam/loam	5.5	None	5.4
Esenceli	0-10	3.0	63.0	34.0	silt loam	5.3	None	7.1
	10-20	2.0	58.0	40.0	silt loam	5.2	None	6.9

which was established by taking logarithmic transformation of equation (2). Based on this equation, A (0) and h_0 factors were estimated and found to be 309.358 Bq kg^{-1} and 78.74 kg m^{-2} for Paşaköy and 511.373 Bq kg^{-1} and 33.33 kg m^{-2} for Esenceli reference sites, respectively (Figure 3). Finally, fitting curves were drawn by using related A (0) and h_0 values for the equation (2).

^{137}Cs activity inventory and soil redistribution data obtained with using Addin software from sloping areas in Paşaköy and Esenceli were shown in Table 2 (Kızıltaş, 2007). As seen from the Table 2, soil losses varied from 0.49 to 23.22 t ha^{-1} yr^{-1} for Paşaköy and from 0.44 to 7.23 t ha^{-1} yr^{-1} for Esenceli whereas deposition rates varied between 0.6 and 38.33 t ha^{-1} yr^{-1} for the soils in Paşaköy and between 0.43 and 4.77 t ha^{-1} yr^{-1} for the soils in Esenceli.

Statistically significant differences in soil loss and deposition rates between two sites were determined ($P < 0.05$). Average soil losses were 10.12 t ha^{-1} yr^{-1} and 2.97 t ha^{-1} yr^{-1} while soil depositions were 12.83 t ha^{-1} yr^{-1} and 2.37 t ha^{-1} yr^{-1} for Paşaköy and for Esenceli, respectively (Table 3). On the other hand, these two sites were significantly different in terms of average ^{137}Cs activity inventories only for soil deposition, which were 3283.465 Bq m^{-2} for Paşaköy, and 1880.748 Bq m^{-2} for Esenceli (Table 3).

Discussion

Most classical methods for estimating soil erosion are based on measuring soil loss from erosion plots and mathematical models. But these approaches have some limitations because sometime they give biased measurements of actual soil movement and do not address spatial patterns of erosion and deposition at any location on the landscape. In contrast to classical erosion measurement techniques and mathematical models, many studies showed that FRN's methodology using ^{137}Cs redistribution rate has the potential to provide the necessary type of data for researchers to measure soil loss at any location on the field where other erosion data are not available and where long-term experiments have not, nor cannot be, established (Zapata, 2002; Ritchie and Ritchie, 2007).

This study proved that soil erosion takes place in Ömerli watershed and annual soil loss varies from 2.97 to 10.12 t ha^{-1} yr^{-1} and the results are consistent with results found in other studies. For instance,

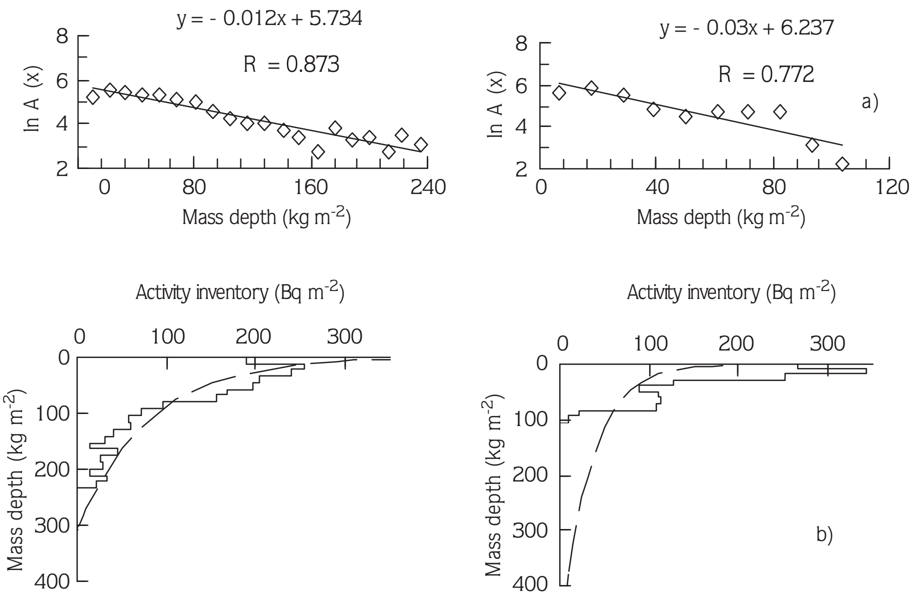

Figure 3. Simple regression equations and exponential ^{137}Cs mass depth distributions for the reference sites at a) Paşaköy b) Esenceli.

Table 2. ^{137}Cs activity inventories and soil redistribution from sloping areas in Paşaköy and Esenceli according to profile distribution model (ns; not sampled).

Sample	^{137}Cs activity inventory (Bq m^{-2})		Soil redistribution rate (t ha^{-1} yr^{-1}) †	
No	Paşaköy	Esenceli	Paşaköy	Esenceli
1	1899.590	1850.101	-0.49	2.21
2	1333.047	2188.227	-7.13	4.03
3	565.229	1066.100	-23.22	-2.33
4	2394.576	1795.729	4.28	1.92
5	1428.592	1847.727	-5.83	2.2
6	3109.927	1932.459	11.16	2.65
7	5244.996	1086.137	31.71	-2.19
8	1123.203	2326.778	-10.34	4.77
9	4696.198	1721.431	26.42	1.52
10	801.627	1869.421	-16.67	2.31
11	5933.511	566.515	38.33	-7.23
12	4418.921	1072.006	23.76	-2.29
13	2588.474	1360.921	6.14	-0.44
14	2886.050	938.367	9.01	-3.32
15	2686.155	1829.346	7.08	2.1
16	2012.697	1519.593	0.6	0.43
17	2578.429	1973.804	6.05	2.87
18	2396.501	1714.365	4.3	1.48
19	2867.799	ns	8.83	ns
20	2154.270	ns	1.96	ns
21	968.003	ns	-13.13	ns
22	1562.977	ns	-4.15	ns

† Negative and positive values indicate soil loss and soil deposition, respectively.

Table 3. Comparison of average values of ^{137}Cs activity inventory for soil losses and soil deposition for Paşaköy and Esenceli sloping sites (n is number of used cores).

^{137}Cs activity inventory for soil loss (Bq m^{-2})		Soil loss (t ha^{-1} yr^{-1})	
Paşaköy	Esenceli	Paşaköy	Esenceli
1210.284^{b}† ± 433 (n = 8)	1015.008^{b} ± 260 (n = 6)	10.120^{c} ± 7.362 (n = 8)	2.967^{d} ± 2.287 (n = 6)
P-value: 0.349		P-value: 0.042	
^{137}Cs activity inventory for soil deposition (Bq m^{-2})		**Soil deposition (t ha^{-1} yr^{-1})**	
3283.465^{e} ± 1250 (n = 14)	1880.748^{f} ± 213 (n = 12)	12.831^{g} ± 12.031 (n = 14)	2.374^{h} ± 1.146 (n = 12)
P-value: 0.001		P-value: 0.006	

† Average values with different superscript letters are statistically significant at alpha level of 0.05 between two sites for the same parameter.

Özyuvacı (1978) reported that soils developed from arkoses parent material in the same watershed have the highest dispersion and erosion rates and are susceptible to erosion. Another research carried out by Köy Hizmetleri Genel Müdürlüğü (1987) indicated that the selected study sites are under the influence of severe water erosion.

The results clearly indicated that the rate of soil loss was higher in shrub-covered areas (average 10.12 t ha^{-1} yr^{-1}) than that of rangeland (average 2.97 t ha^{-1} yr^{-1}). Lower soil loss might be expected generally from shrub areas as compared to rangeland areas. But this study showed that although soils developed from the same parent material in both shrub and range covered areas, shrub land had greater erosion and higher soil deposition rates as compared to rangeland. This evidence could be a result of sparse distribution of shrub species creating wide bare ground in the inter-canopy spaces and absence of grazing in the rangeland. Also, soil erosion rates less than 10 t ha^{-1} yr^{-1} is acceptable for deep brown forest soils in Turkey according to soil loss tolerance limits (Doğan and Güçer, 1976). Those values greater than 10 t ha^{-1} yr^{-1} mean that soil erosion is a serious problem at the site and necessary measures must be taken to prevent soil loss due to erosion. Although rangeland had a steeper slope than shrub land soil loss in the rangeland was less than that in the shrub land. This result shows that land use is a major impact on soil and water conservation. According to results of this study, it seemed that priority in soil and water conservation measures should be given areas having similar site conditions to shrub-covered land in the watershed.

Cations (including ^{137}Cs too) could be leached with percolating water into the deeper part of the soils with acidic reaction. Moreover, shrub covered area in Paşaköy has moderately coarse textured soils which affect water movement within the soil profile that could result in redistribution of radionuclides in the soil.

On the other hand, reference inventory for two study sites in the Ömerli watershed (in eastern outskirts of İstanbul) was estimated to be 1950 and 1440 Bq m^{-2}. These numbers indicate that radioactivity concentration is high enough to use FRN's methodology to estimate soil erosion in the watersheds of İstanbul. In fact, same method was applied in Büyükçekmece reservoir (in western outskirts of İstanbul) and reference inventory was estimated to be 1620 Bq m^{-2} (Hacıyakupoğlu et al., 2005).

Present study contributes new data for spatial radio-contamination in the study site soils for the global distribution of ^{137}Cs and shows the potential of using FRN's methodology in a watershed containing different land-use types. Further researches to implement the methodology with other fallout radionuclides (such as ^{7}Be and $^{210}Pb_{ex}$) having different half-life are still needed to predict various time scale of soil erosion. Considering spatial variations in topography and soil movement over very small distances, the effect of various land-use types in different time scales also needs further detailed studies over larger areas.

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