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# Soil Erosion and Soil Organic Carbon in the Forest-Steppe Zone: *A Case Study in Baga Mukhar, West Khentei, Mongolia*

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**ABSTRACT**

Specifics and relationships between soil erosion and soil organic carbon in the Mongolian forest-steppe were studied in this research, in a case of Baga Mukhar catchment, west Khentei. Soil erosion was estimated by the Cesium-137 isotope tracing method. For estimation of soil redistribution rates from inventories of 137Cs, diffusion migration model used in grazing lands and mass balance model-2 used in cultivated land. In total, 38 soil samples were taken from 5 isosectors. The mean soil redistribution of the catchment was -3.67 t $ha^{-1}$ $y^{-1}$. In cultivated land, soil erosion was the highest with a value of -15.47 t $ha^{-1}$ $y^{-1}$ and it gets higher (-24.43 t $ha^{-1}$ $y^{-1}$) if we take into account that the cultivated land is located at the bottom of the valley where has deposition. Soil erosion in the south-facing slopes is 5.1 times higher than north-facing slopes, which shows slope differences significantly influence vegetation growth and soil erosion. The average soil organic carbon of the study area is 4.37 %. SOC was highest in the forest area (7.33 %) and the lowest in the agriculture field (2.48 %). SOC in the north facing slope was 2.4 times higher than the south facing slope. Isosectors mean value of soil redistribution and SOC is comparatively well corresponded ($r^2$=0.567). Soil erosion and soil organic loss in agriculture is a significant, it needs more appropriate management practice and soil conservation activities in the Mongolian forest-steppe.

***Keywords:*** *Cesium-137, forest-steppe, Mongolia, Soil erosion, Soil organic carbon*

## 1. INTRODUCTION

The forest-steppe zone of Mongolia is one of comparatively dense populated and intensive land use area of country. Negative impact on environment condition is increasing and soil degradation, soil organic carbon (SOC) loss issue is becoming serous. But not much research related to soil erosion and soil nutrition. Improper land management and environment protection activity due of lack of scientific based soil quality assessment.

Aim of our research is soil erosion study using fallout radionuclide technologies in forest-steppe zone in case of Baga Mukhar area of west Khentei mountain of Mongolia. Soil erosion impact on SOC is another aspect of our research. There are several investigation of soil erosion using isotope techniques in Mongolia and most of them in steppe area [1; 2; 3; 4]. This research is conducted under IAEA project “RAS5084-Assessing and Improving Soil and Water Quality to Minimize Land degradation and Enhance Crop Productivity Using Nuclear Techniques”.

## 2. STUDY AREA

Study area is located in western part of Khentei mountain ranges, administratively belong to the Bayangol sum of Selenge province (Figure 1). This is typical forest-steppe landscape of central-north Mongolia. There are low, middle mountains with forested north facing slopes. Dominated mainly mountain steppe and steppe, as a main pasture grazing land. Intermountain valley bottom plain areas mostly used by agriculture.

The soil study conducted in the Baga Mukhar catchment (106$^{O}$2’E, 49$^{O}$5’N). This is medium sized valley covering 15.1 $km^2$ or 1510 hectare area. From south-east to north-west stretching 7 km, and width about 2-3 km. Elevation ranging from 923 to 1494 meter above sea level and relative heights of mountain is 50-300 meter. The south-east or upper part valley is forested and in northern lowland or valley bottoms located agriculture fields. Small spring flowing from forest upper part of valley to the northward.

In Baga Mukhar catchment area dominated grazing land covering 8.5 $km^2$ (56.7 %) area, forest area is about 5.7 $km^2$ (38.0 %) and crop field area is 0.8 $km^2$ (5.3%).

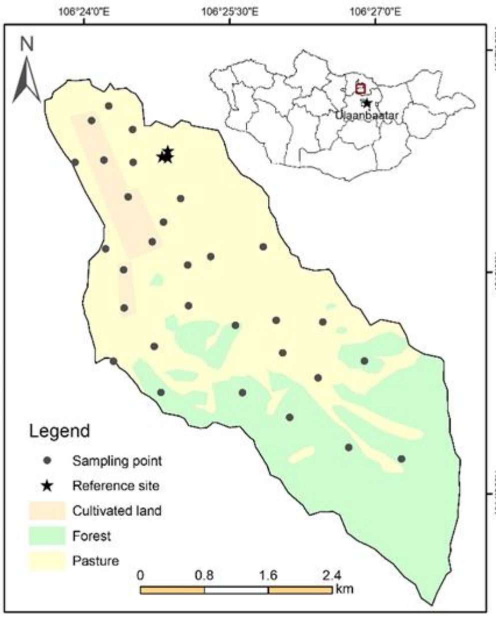


**Figure 1.** Study area and sampling points

According by Baruunkharaa (17 km from study area) climate station data (1950-2020 years), study area average air temperature is -0.6° C and mean annual precipitation is 290 mm. In last 70 years' air temperature increased by 3.07° C and annual precipitation no change or slightly increase by 10.6 mm.

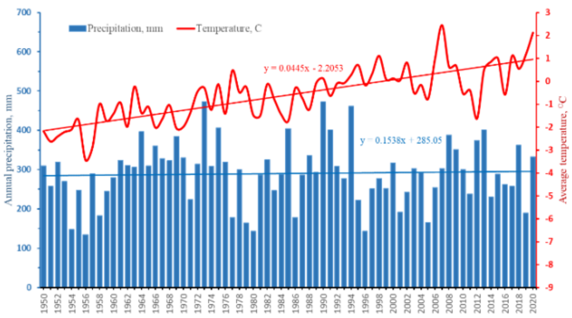


**Figure 2.** Annual precipitation and average air temperature (Baruunkharaa climate station between 1950-2020)

Livestock number of Bayangol soum is 168 828 in 2020 and within 30 years (1990-2020) increased by 4 times [5]. The goat is becoming dominant in composition of livestock, from 34 % in 1990 up to 70 % in 2020. Overgrazing impact is increasing and soil fertility is declining.

Agriculture area of Bayangol soum is 5295 hectare in 2020, mainly cultivated wheat. From 1990-s agriculture area declined and from 2008 increased due of "Atar-3" agriculture program of government. Population of Bayangol soum is 5500 in 2020, not much change since 1990, drop occur in 2002-2006 and then back to the previous level.

## 3. METHOD

To quantify erosion and sedimentation of the catchment using 137Cs, finding appropriate reference inventory sampling sites and finding sampling strategy/methods are very important. These processes were done based on the guidelines by Zapata [6] and FAO/IAEA [7].

Baga Mukhar catchment is relatively large for a transect sample. Therefore, we used the isosector [8] approach to take soil bulk samples. The purpose of the study is to examine soil erosion using Cs137 isotope in different land cover types and hill slope aspects (isosectors) and relation with soil organic carbon.

Totally 38 soil samples take a from study catchment area in 2018 according by isosectors approach. The land use types and hill slope aspects were considered as an isosector in this study.

Samples were collected from 6 major isosectors including natural forest, cultivated land, river valley, and 2 aspects of mountain hill slope includes northern and southern. Samples were taken from 15 cm depth by a metal core with a 10.7 cm internal diameter.

### *3.1. Reference site selection and sampling*

The reference site location was selected in a catchment with minimal slope and on the summit position. The selected site has permanent grass and had not been affected by soil erosion or deposition.

Three reference inventory samples were collected, 2 soil core samples and 1 depth incremental sample were taken. A scraper plate with an internal soil sampling area of 100 $cm^2$ was used to collect depth incremental samples. Samples were scraped from 0-2, 2-4, 4-6, 6-10, 10-15, 15-20, and 20-25 cm depths.

### 3.2. Laboratory analysis

Soil sample preparation involved the following steps: air drying, grinding large aggregates, sieving the soil (2 mm), and weighing both fine and coarse fractions. In the Soil Laboratory of Institute of Geography-Geoecology of Mongolian Academy of Sciences conducted soil organic matter, pH, EC, available phosphorus, available potassium, texture, gravel, and bulk density analysis.

137Cs activity (Bq $kg^{-1}$) was measured on the fine fractions (0-2 mm) by gamma spectroscopy. Gamma spectrometry analysis was done in the Nuclear Laboratory of Ulaanbaatar, Mongolia.

### 3.3. Calculation of soil loss and deposition rates

To quantify soil erosion/deposition rates, the radionuclide loss or gain was computed by comparing radionuclide inventories at sampling sites to a reference inventory was converted into soil loss or gain using conversion models.

For estimation of soil erosion and deposition rates from radionuclide inventories of 137Cs in grazing lands used Diffusion Migration Model [9]. Under certain circumstances, the redistribution of 137Cs in uncultivated soils can be represented using a one dimensional diffusion and migration model characterised by an effective diffusion coefficient and migration rate. 137Cs concentration Cu (t) (Bq $kg^{-1}$) in surface soil with time t (yr) may be approximated as:

$$C_u(t) = \frac{I(t)}{Y} + \int_0^{t-1} \frac{I(t')e^{-R/H}}{\sqrt{D\pi(t-t')}} e^{-V^2(t-t')/(4D)-\lambda(t-t')} dt' \quad (1)$$

D is the diffusion coefficient ($kg^2$ $m^{-2}$ $yr^{-1}$); V is the downward migration rate of 137Cs in the soil profile (kg $m^{-2}$ $yr^{-1}$).

For an eroding point, if sheet erosion is assumed, then the erosion rate R may be estimated from the reduction in the 137Cs inventory Als(t) (Bq $m^{-2}$) [defined as the 137Cs reference inventory Aref less the measured total 137Cs inventory Au (Bq $m^{-2}$)] and the 137Cs concentration in the surface soil Cu(t) given by according to:

$$\int_0^t PRC_u e^{-\lambda(t-t')} dt' = A_{ts}(t) \quad (2)$$

For cultivated area soil erosion estimation used Mass Balance Model -2 [10].

$$\frac{dA(t)}{dt} = (1-\Gamma)I(t) - (\lambda + P\frac{R}{d})A(t) \quad (3)$$

A(t) is the cumulative 137Cs activity per unit area (Bq $m^{-2}$); R is the erosion rate (kg $m^{-2}$ $yr^{-1}$); d is the cumulative mass depth representing the average plough depth (kg $m^{-2}$); λ is the decay constant for 137Cs ($yr^{-1}$); I(t) is the annual 137Cs deposition flux (Bq $m^{-2}$ $yr^{-1}$); Γ is the proportion of the freshly deposited 137Cs fallout removed by erosion before being mixed into the plough layer; P is the particle size correction factor.

For statistical data analysis we used SPSS-23 software.

## 4. RESULTS

In study area dominated Kastanozem soil this is typical steppe soil of Mongolia. In forest area distributed high organic content Umbrisols. Study area soil organic content is high, average SOC is about 4.1 % and forest soils SOC is up to 8.54-.11.15 %. SOC is higher in the forested - south part of the study area and lower in cultivated land and the south slope of the mountain (Figure 3).

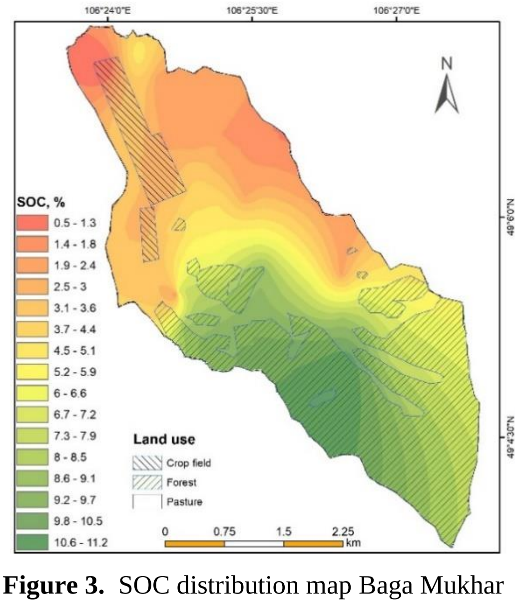


**Figure 3.** SOC distribution map Baga Mukhar catchment area

Soil reaction slightly acid (pH-6.5). Calcium carbonate in the sampling top soils not existed only one sampling point in south facing slopes $CaCO_3$ is 6.54 % evidence of soil erosion and removal of top organic horizon. Electrical conductivity is very low and soils not contain salts. Available phosphorus ($P_2O_5$) is medium and available potassium is high average is 23.7 mg 100 $g^{-1}$. Soils low gravelly, bulk density is about 1.12 g cm$^{-3}$, dominated sand (2.-0.05mm) fraction, silt (0.05-0.002 mm) is 35.4 % and clay (<0.002 mm) content is 13.2 %.

**Table 1.** Study area soil properties mean, standard deviation, coefficient variation (n=38)

| Properties | Unit | Mean | STD | CV% |
|---|---|---|---|---|
| $^{137}Cs$ | Bq kg$^{-1}$ | 10.8 | 6.5 | 60.2 |
| SOC | % | 4.1 | 2.6 | 62.5 |
| pH | | 6.5 | 0.4 | 6.1 |
| $CaCO_3$ | % | 0.18 | 1.09 | 600.0 |
| El. cond. (EC) | dS m$^{-1}$ | 0.06 | 0.02 | 40.0 |
| Avialable $P_2O_5$ | mg 100g$^{-1}$ | 2.2 | 1.8 | 82.3 |
| Avialable $K_2O$ | mg 100g$^{-1}$ | 23.7 | 13.8 | 58.5 |
| Gravel (> 2mm) | % | 4.7 | 6.1 | 129.2 |
| Bulk Density | g cm$^{-3}$ | 1.12 | 0.34 | 30.0 |
| Sand | % | 51.4 | 11.0 | 21.4 |
| Silt | % | 35.4 | 9.3 | 26.2 |
| Clay | % | 13.2 | 3.6 | 27.0 |

Figure 4 presents 137Cs depth profiles and its inventories for reference sampling location. A large quantity of 137Cs activity (~73%) was concentrated in the upper 4 cm layer of soil and decreases with depth until 15 cm. The mean value of 137Cs inventory of the depth incremental sample at reference site was 1639.7 Bq m$^{-2}$. Also, we took 2 core samples from the reference site and its inventory was 1601 Bq m$^{-2}$ and 1774 Bq m$^{-2}$, respectively. The coefficient of variation (CV) of total 137Cs inventory for the reference three sites was 4.4% with a mean value of 1671.7 Bq m$^{-2}$, which is similar to other studies in Mongolia with 1668 Bq m$^{-2}$ [3] and 1889 Bq m$^{-2}$ [10].

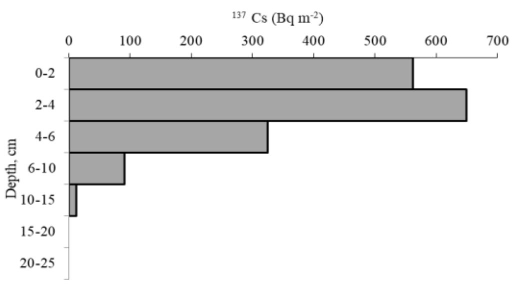


**Figure 4.** Depth distribution profiles for 137 Cs inventory in reference site

Table 2 shows descriptive statistics of Cs 137 inventory (Bq m$^{-2}$) of 6 isosectors. In the bottom of the valley, an inventory of 137Cs was the highest among others with a mean value of 1871.2 Bq$^{-2}$. Also, the bottom of the valley has the lowest CV with 10.4 %. On the other hand, the south slope of the mountain has the lowest value of inventory with 1029.1 Bq m$^{-2}$. Inventory in the forested area, cultivated land, and the north slope of the mountain was 1645.5 Bq m$^{-2}$, 1103 Bq m$^{-2}$, and 1453.6 Bq m$^{-2}$, respectively (Table 2).

**Table 2.** Descriptive statistics of Cs137 inventory (Bq m$^{-2}$)

| | Mean | Max | Min | STD | CV,% |
|---|---|---|---|---|---|
| Forest *(5)* | 1645.5 | 1967.8 | 1258.5 | 276.9 | 16.8 |
| Cultivated land *(6)* | 1103.0 | 1404.0 | 574.6 | 328.9 | 29.8 |
| North slope *(6)* | 1453.6 | 1742.8 | 1112.3 | 285 | 19.6 |
| South slope *(6)* | 1029.1 | 1686.6 | 390.6 | 535.2 | 52.0 |
| Bottom of valley *(6)* | 1871.2 | 2161.7 | 1556.9 | 193.8 | 10.4 |

## 5. DISCUSSION

Baga Mukhar catchment area statistical data of soil redistribution rates (t ha$^{-1}$ yr$^{-1}$) of 4 undisturbed (forest, north and south slope of the mountain, valley bottom) and cultivated isosectors shown in table 3. Forest area have soil deposition with mean redistribution rate is 1.75 t ha$^{-1}$ y$^{-1}$, coefficient variables is high. Valley bottom area soil have highest soil deposition rate 8.96 t ha$^{-1}$ y$^{-1}$ (Figure 5). In the cultivated land, the soil erosion rate was the highest with a mean value of –15.5 t ha$^{-1}$ yr$^{-1}$.

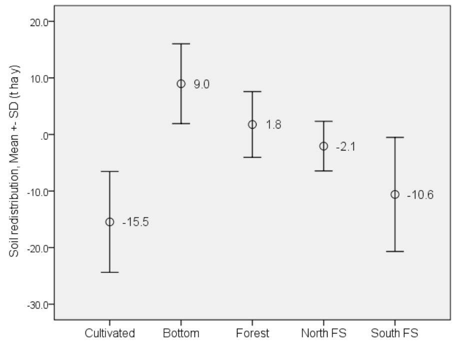


**Figure 5.** Soil redistribution mean value by isosector

**Table 3.** Soil redistribution and SOC statistics by Isosector

| Isosectors | Soil redistribution, (t ha$^{-1}$ y$^{-1}$) | | | SOC, % | | |
|---|---|---|---|---|---|---|
| | Mean | SD | CV% | Mean | SD | CV% |
| Forest *(n=5)* | 1.75 | 5.81 | 332.7 | 7.33 | 3.43 | 46.8 |
| North slope *(n=6)* | -2.07 | 4.39 | 211.9 | 5.34 | 2.43 | 45.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| South slope *(n=6)* | -10.60 | 10.09 | 95.3 | 2.18 | 0.18 | 8.4 |
| Bottom of valley *(n=6)* | 8.96 | 7.05 | 78.7 | 5.00 | 2.16 | 43.2 |
| Cultivated land *(n=6)* | -15.47 | 8.94 | 57.8 | 2.48 | 1.09 | 43.9 |
| Total (n=29) | -3.67 | 11.39 | 310.6 | 4.37 | 2.73 | 62.4 |

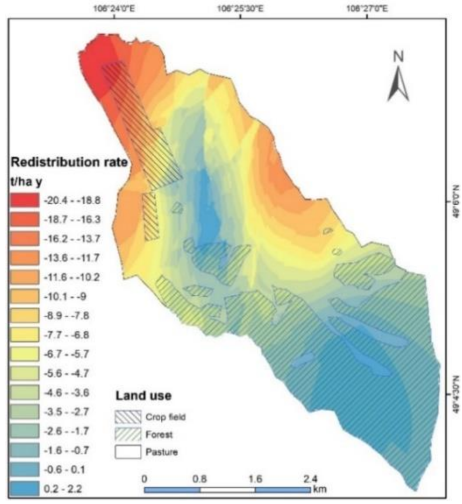


**Figure 6**. Soil redistribution in Baga Mukhar catchment

According to soil redistribution map of Baga Mukhar catchment area south forest and north-central valley bottom area dominated deposition (Figure 6). Cultivated field and slope areas dominated erosion. Forest located in slope areas but mainly soil deposition is prevailing. In some points of forest have soil erosion.

Land use, slope aspect isosectors areas mean value of soil redistribution and SOC is comparatively well corresponds ($r^2$=0.567), but all data is not so good related (Figure 7).

Using Diffusion and Migration Model calculated gross, net erosion rates. Baga Mukhar catchment area gross erosion rate is -11.8, net erosion rate is -9.0, sediment delivery ratio is 76 %.

Soil erosion deposition rate and soil organic carbon is related. The generally soil organic carbon decline due of the soil erosion. The concentration and turnover of soil organic carbon (SOC) are usually the highest in the surface soil [11]. The SOC may be affected by different factors including climate, hydrology, soil type, land use, and geomorphology [12].

Cultivated area soil erosion is highest, if account that cultivated area located in valley bottom soil erosion in cultivated area become more higher -24.43 t $ha^{-1}$ $y^{-1}$. South facing slopes soil erosion is 5.1 times higher than north facing slopes. Slope exposition differences significantly influence vegetation growth further more in soil erosion.

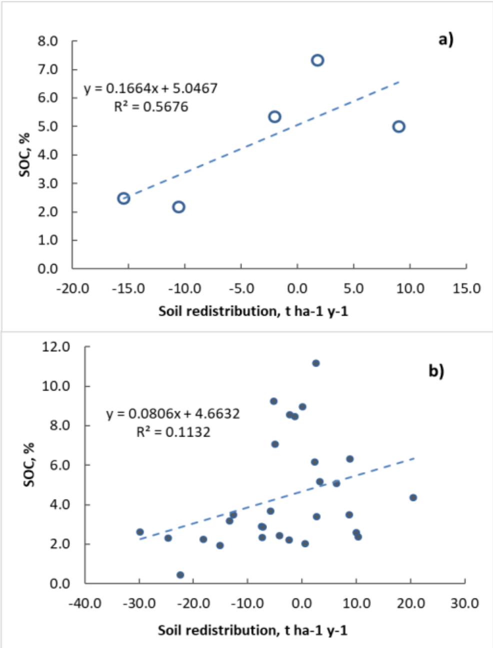


**Figure 7.** Relationship between soil redistribution and SOC, a) Isosector mean b) all data

In the scatter plot figure 8 showing highest soil erosion in cultivated field, south facing slopes consequently lowest SOC. Opposite condition is soil deposition in bottom of valley, forest with high SOC 5.00 % and 7.33 % (Table 3).

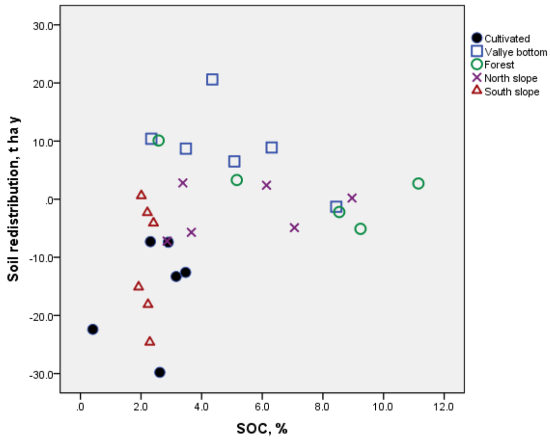


**Figure 8.** Scatter plot of Soil redistribution

Forest-steppe zone of Mongolia considered comparatively high soil fertility part of country with concentration of agriculture and animal husbandry. But in this area soil erosion, soil organic loss is increasing due of human impact and climate warming. Need to improve land management practice and promote soil conservation activities.

## 6. CONCLUSION

Specifics and relationships between soil erosion and soil organic carbon in the Mongolian forest-steppe were studied in this research, in a case of Baga Mukhar catchment, west Kehntei. Soil erosion was estimated by the Cesium-137 isotope tracing method. For estimation of soil redistribution rates from inventories of 137Cs, diffusion migration model used in grazing lands and mass balance model-2 used in cultivated land. In total, 38 soil samples were taken from 5 isosectors. The mean soil redistribution of the catchment was -3.67 t $ha^{-1}$ $y^{-1}$. In cultivated land, soil erosion was the highest with a value of -15.47 t $ha^{-1}$ $y^{-1}$ and it gets higher (-24.43 t $ha^{-1}$ $y^{-1}$) if we take into account that the cultivated land is located at the bottom of the valley where has deposition. Soil erosion in the south-facing slopes is 5.1 times higher than north-facing slopes, which shows slope differences significantly influence vegetation growth and soil erosion. The average soil organic carbon of the study area is 4.37 %. SOC was highest in the forest area (7.33 %) and the lowest in the agriculture field (2.48 %). SOC in the north facing slope was 2.4 times higher than the south facing slope. Isosectors mean value of soil redistribution and SOC is comparatively well corresponded ($r^2$=0.567).

General negative impact on environment and soil condition is climate warming and dryness. According by climate data of nearest located Baruunkharaa station last 70 years air temperature is increased by $3.07^{O}$ C, this is 3 times higher than world average. Annual precipitation is not much changed. Soil drying, organic decay accelerating and soil erosion is increasing. Another negative impact in soil cover is overgrazing. Livestock of study area increased about 4 times in last 30 years.

Soil erosion and soil organic loss in agriculture is a significant, it needs more appropriate management practice and soil conservation activities in the Mongolian forest-steppe.

## REFERENCES

[1] Norov, N., Davaa, S., & Shagjjamba, D., 1998. Studies on the Soil Radioactivity in Some City Using Gamma-Ray Spectrometer. Mongolian National University. Physical Electronical School. 5(138): 19-26. (Mongolian)

[2] Kato, H., Onda, Y., Tanaka, Y., Tsujimura, M., Davaa, G., & Oyunbaatar, D. 2006. Evaluating soil erosion history using fallout radionuclides in semi-arid grassland, Mongolia. Geophysical Research Abstracts, Vol. 8, Europ. Geosciences Union.

[3] Batkhishig, O., 2013. Human Impact and Land Degradation in Mongolia. Chapter 12. In the volume “Dry land East Asia: Land Dynamics Amid Social and Climate Change”. Editors: Chen, et al., Ecosystem Science and application. The Higher Education Press, 265-282 p.

[4] Hirose, K., Kikawada, Y., Igarashi,Y., Fujiwara, H., Jugder. D., Matsumoto,Y., Nomura,N., Oi, T., 2017. Plutonium, 137Cs and uranium isotopes in Mongolian surface soils. Journal of Environmental Radioactivity 166: 97-103. DOI: https://doi.org/10.1016/j.jenvrad.2016.01.007

[5] Statistics. 2021. Mongolian Statistical Information Service- www.1212.mn

[6] Zapata, F. (2002). Handbook for the Assessment of Soil Erosion and Sedimentation Using Environmental Radionuclides. Vienna, Austria: Kluwer Academic Publishers. DOI: https://doi.org/10.1007/0-306-48054-9

[7] FAO/IAEA. (2017). Use of 137Cs for soil erosion assessment. Food and Agriculture Organization of the United Nations, Rome, Italy. 64 p.

[8] Mabit, L., Chhem-Kieth, S., Dornhofer, P., Toloza, A., Benmansour, M., Bernard, C., Fulajtar, E., Walling, D.E, 2014. 137Cs: A widely used and validated medium-term soil tracer. Guidelines for using fallout radionuclides to assess erosion and effectiveness of soil conservation strategies. FAO/IAEA. Vienna. 42.

[9] 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”. FAO/IAEA. Vienna. 125-148.

[10] Kato, H., Onda, Y., Tanaka, Y. 2010. Using 137Cs and 210Pbex measurements to estimate soil redistribution rates on semi-arid grassland in Mongolia. Geomorphology, 114(4), 508-519. DOI: https://doi.org/10.1016/j.geomorph.2009.08.009

[11] Conant, R.T., Paustian, K., Elliott, E.T., 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecol. Appl. 11 (2), 343–355. DOI: https://doi.org/10.1890/1051-0761(2001)011[0343:GMACIG]2.0.CO;2

[12] Hancock, G.R., Murphy, D., Evans, K.G., 2010. Hillslope and catchment scale soil organic carbon concentration: an assessment of the role of geomorphology and soil erosion in an undisturbed environment. Geoderma 155 (1–2), 36–45 DOI: https://doi.org/10.1016/j.geoderma.2009.11.021