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Research Article

Estimating Soil Erosion Using Fallout Caesium-137 and Lead- 210 in Cultivated Land of Micro Catchment in Dolosbage, Sri Lanka

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Abstract

Dolosbage, Sri Lanka lies between Latitude - 7.08°, Longitude - 80.47° (790 m-890 m above sea level). It belongs to up country wet zone and the average annual rainfall is about 4585.0mm. There were four main land uses such as marginal tea, well grown tea, home gardens and grasslands in this catchment. Uncultivated flat grassland of the hill top which had not been subjected to erosion and deposition was selected as a reference site for the comparison of fallout radionuclide inventory. Activity concentrations of ^{137}Cs & ^{210}Pb were measured by HPGe detector with the relative efficiency of 32.6%. Soil redistribution rates induced by water erosion were calculated by Mass Balance Model II for ^{137}Cs measurements and Mass Balance Model I for ^{210}Pbex (WALLING, et al., 2001). ^{137}Cs inventories, ^{210}Pbex inventories and soil redistribution rates were obtained for 24 bulk cores collected from the cultivated field. For the reference site, the vertical distributions associated with both radionuclides were similar with exponential decrease with depth. According to the ^{137}Cs inventories, highest soil erosion was recorded in marginal tea lands (37.36 t $ha^{-1}yr^{-1}$) followed by grassland (6.4 t $ha^{-1}yr^{-1}$) and home gardens (5.31 t $ha^{-1}yr^{-1}$). Well grown tea recorded the lowest soil erosion rate. According to the ^{210}Pbex inventories all the land uses studied in the catchment recorded the net soil deposition. Highest deposition rate was observed in grassland (16. 90 t $ha^{-1}yr^{-1}$) followed by well grown tea (3.61 t $ha^{-1}yr^{-1}$). Marginal tea recorded the lowest deposition rate (2.17 t $ha^{-1}yr^{-1}$).

Introduction

Sri Lanka is a tropical island located near to the southeast tip of India. The country lies in the between longitudes 79° 39' - 81° 53' East and latitudes 5° 54' - 9° 52' North. It consists of 64,453.6 km^2 of land area and 1,156.2 km^2 of inland waters. Extensive faulting and erosion over time have produced a wide range of topographic features, making Sri Lanka one of the most scenic places in the world (Annual Performance Report of Meteorology Meteorology, 2018).

Climate features of the country are basically determined by the geographical location of the country in the equatorial belt and its position in the inter tropical convergence zone. The chief determinants of the climate in Sri Lanka are rainfall and temperature. The mean temperature is 27.5°C over low lands. The oceanic influence helps to reduce temperature in the lowlands by sea breezes. The temperature decreases at a steady rate of about 6.5°C for each 1000 meters rise and in the Montana (Annual Performance Report of Meteorology, 2018).

The Central Highlands of Sri Lanka plays an important role in the economy of the country, producing a considerable amount of world class Tea, Rubber, Spices, vegetables and contributing around 7% of the national GDP. Soil erosion in agricultural and non-agricultural lands in central highlands caused serious onsite and offsite impacts on sustainable land productivity, environmental stability and national economy of Sri Lanka.

There are about 103 river basins covering 90% of the island, originated from Central Highlands. All the five major hydropower reservoirs in Sri Lanka, which contribute to the 31.9% of power generation in Sri Lanka (Sri Lanka Energy Balance, 2018) are also located in Central Highlands. However, the siltation of hydropower reservoirs resulting 10% deduction of the capacity amounting 15 Million Rupees worth electricity generation loss per year.

To mitigate the adverse impacts of land degradation especially soil erosion and decline of soil fertility, Government of Sri Lanka enacted soil conservation act in year 1951 based on findings of scientific studies. However, one of the major limitations for successful implementation of soil conservation act is the unavailability of sufficient soil erosion/sedimentation data under different slope classes and land uses in catchment scale which is vital for the planning and establishment of soil conservation measures and rehabilitation of degraded lands.

Soil erosion can cause harmful effects to aquatic environments by reduce light penetration (Nakamura, et al., 2002) by siltation of waterbodies (Rabalais N N, et al., 1998), by eutrophication of lakes and other waterbodies (Rabalais, et al., 1998) etc.

1.9 billion hectares of agricultural land in the world was effected by soil erosion and it is increasing rapidly at a rate of 5-7 million hectares each year. This is mainly caused by poor land management practices in agriculture activities. Approximately 84% of affected areas by soil acidification, salinization, mining and soil erosion located in the developing countries like Sri Lanka. Studies of impact of soil erosion on crop productivity, soil conservation measures etc. have concerned an urgent need to have reliable quantitative data base on the actual rates of soil erosion (IAEA-TECDOC-1741, 2014).

Decreased productivity due to soil loss and degradation effect the stability of the Greek and Roman civilization. Historical evidences shows that the collapsing civilization due to depletion of soil resources (Matisoff, et al., 2011). Soil erosion can be measured by erosion pins, sediments in reservoirs, concentration of sediments in streamflow, photographic techniques and soil tracers (Matisoff, et al., 2011). ^{137}Cs is the most important and widely used tracer for soil erosion (Ritchie, et al., 1990).

Soil erosion can be widely measured by conservative tracer of the soil particles. The best known tracers for estimating soil erosion are natural and artificial radionuclides (Matisoff, et al., 2011). Naturally occurring radionuclides are originated by Thorium and Uranium decay chains and various nuclear reactions (Porcelli, et al., 2011).This includes ^{7}Be, ^{210}Pb etc. Anthropogenic radionuclide such as ^{137}Cs ^{134}Cs, 238,239,240Pu, and ^{241}Am are extensively produced by nuclear bomb testing and the fallout radionuclides distributed globally. ^{210}Pb, ^{137} Cs, ^{7}Be are more suitable radionuclides as particle tracers due to their global distribution, efficient adsorption to soil particles and can be measured easily (Matisoff, et al., 2011).

There are large number of papers following the Chernobyl accident. 2700 references are mentioned references to the use of ^{210}Pb as a tracer for soil erosion studies. The use of ^{7} Be as a tracer is relatively new technique for measuring soil erosion (Matisoff, et al., 2011).

Use of universal soil loss equation for predicting soil erosion is less accurate in tropical countries like Sri Lanka. To fulfil the long felt need of assessment of catchment scale soil erosion, sedimentation and identification of sources of sediments, measurement of fallout radionuclide technique is very important. This technique was introduced to Sri Lanka by International Atomic Energy Agency technical cooperation project in 2013.

The aim of these study was to assess soil erosion status of major agricultural land uses in sub catchments of Dolosbage in the Mid Country Wet Zone, Sri Lanka.

This study was conduct with the objectives of determining the soil erosion and deposition rates of major agricultural land uses (marginal tea, grass land, newly planted tea, well grown tea and home garden) in central highlands of Sri Lanka.

This experiment was conducted at the Merivilla tank micro catchment, Craighead estate, Udahentnna, Dolosbage in Kandy district. Dolosbage lies between Latitude - 7.08°, Longitude - 80.47° and elevation is around 790 m-890 m above sea level. It belongs to up country wet zone (WU1) agro ecological region of Sri Lanka and the average annual rainfall is about 4585.0mm. The Soil series belongs to Maskeliya series (USDA – Typic Dystropets/ Local – Red Yellow Podzolic Soils).

Methodology

The extent of the sub catchment is 50ha and it is a closed system. There were five main land uses (marginal tea, well grown tea, newly planted tea, home gardens and grassland) in this catchment (Figure 1). Systematic soil conservation measures are practiced only for tea lands. They are lock and spills, grass hedge rows etc. Specific soil conservation measures were not practiced for other land uses. The hill crest is covered with grassland and sparse forest patches. Since the area is a closed system and there is no record of de-silting of the tank, it is possible to study the soil erosion and sediment redistribution history using both ^{137}Cs and ^{210}Pb. The Merivilla tank is located adjacent to the Gampola – Dolosbage road which is constructed about 100 years ago

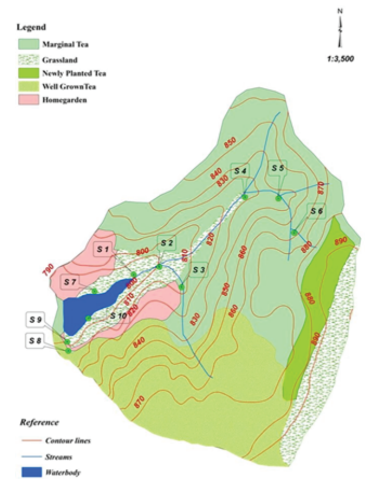

Figure 1: Land use map of the study area

Figure 2: Catchment area of Dolosbage

THE LOCATION MAP OF STUDY AREA - MIRIWILA ESTATE- DOLOSBAGE

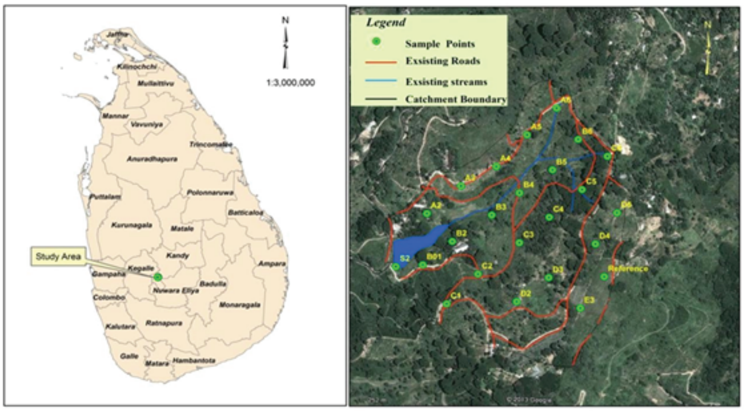

Figure 3: Location map of the catchment area of Dolosbage and sampling points

during colonial era

Combine use of ^{137}Cs and $^{210}Pb_{ex}$ to assess long term soil redistribution in a small agricultural field in Dolosbage , Sri Lanka allow to compare the soil erosion and deposition before and after year 1950 with the change of land uses and to identify most vulnerable land uses for soil erosion which will be useful to implement soil conservation programme (Figures 2 and 3).

Selection of reference site

For the comparison of fallout radionuclide inventory, reference area has been chosen from the uncultivated flat site of the hill top which had not been subjected to erosion and deposition. The vegetation type of the reference site is grassland.

Sampling strategy for determining fallout radionuclide (FRN) inventory

The samples were taken by sectional cores in 5cm intervals up to 40 cm to determine the appropriate depth of penetration of ^{137}Cs and $^{210}Pb_{ex}$. In order to define the spatial variability of soil ^{137}Cs inventory, bulk soil cores were collected from four parallel transects. Twelve cores were collected to a constant depth of 40 cm. Each transect consisted of 03 sampling points with the spacing of 10 m. At each sampling point three cores were collected within an area of 1 m^2. The three replicated samples were mixed and one composite sample was made from each sampling point. The diameter of the core is 8 cm.

Sampling strategy in cultivated sites

Core samples were collected up to 40cm depth and 03 composite samples were collected in 1 m^2 area from each sampling point in a grid pattern (Figure 4). Size of the one grid was 100 m ×100 m. 24 samples were collected in the grid patter including two sediment samples.

Sample preparation and analysis

Soil samples were air dried, disaggregated and passed through 2 mm mesh to separate the gravel from soil. A sub sample from the weighed fine fraction were filled

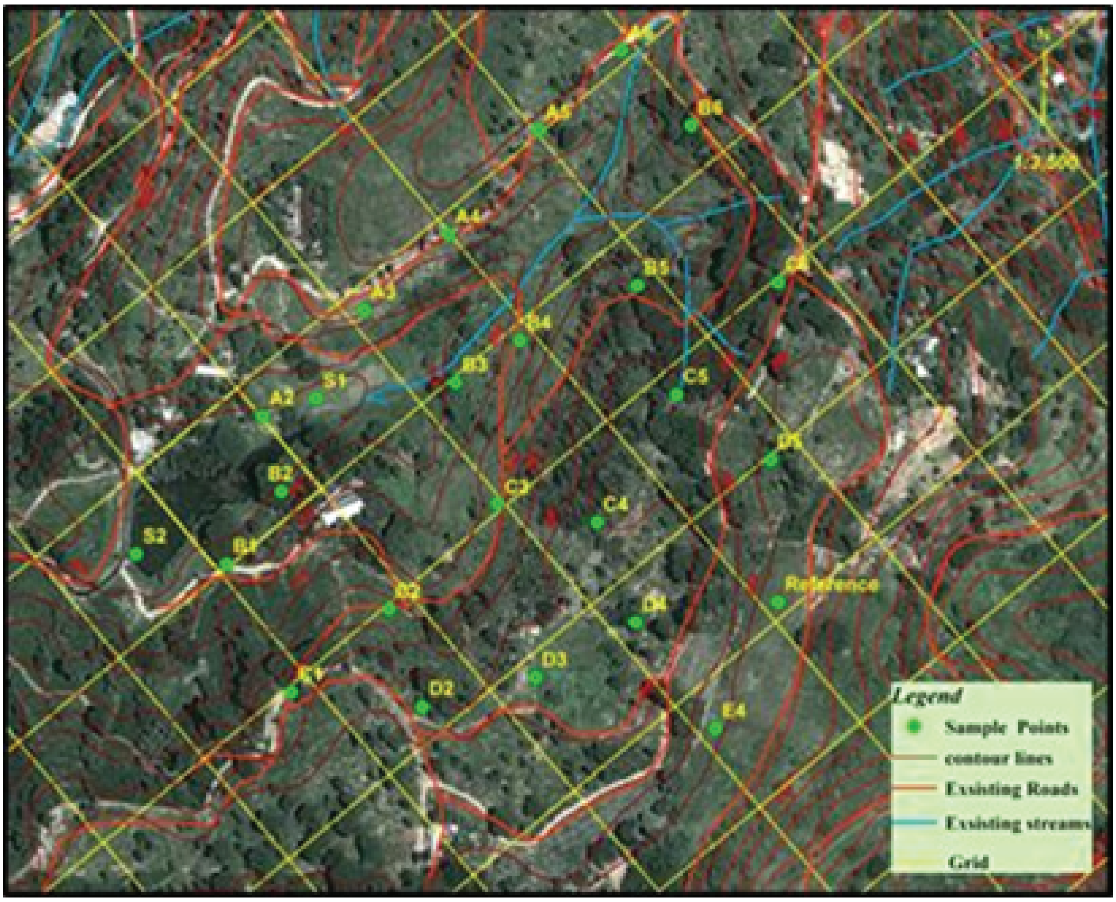

Figure 4: Sampling points in a grid pattern

Figure 5: HPGe detector and containers used for analysis

into a specific container designed for the detector and kept for 21 days to allow complete ^{222}Rn decay in order to achieve secular equilibrium (seven half-lives of Rn^{222}, half-life of Rn^{222}=3.82 days) for the measurement of ^{210}Pb and ^{226}Ra using it's daughters of ^{214}Pb or ^{214}Bi. (IAEA,1989). The specific containers are called G1 geometry (8.4cm x2.9cm radon impermeable plastic containers). The activity of ^{137}Cs and^{210}Pb were measured using a Hyper Pure Germanium (HPGe) detector installed at the Gamma spectrometry laboratory of the Sri Lanka Atomic Energy Board , (Figure 5) with the relative efficiency of 30% and the resolution of 2.20 KeV at the gamma energy of 1332.5 KeV of ^{60}Co. The detector is surrounded by a 10 cm thick Lead shield, to reduce the background radioactivity. Each sample was counted for 20 hrs. The background of the system was measured using an empty container (Figure 5).

The ISOCS/LabSOCS software calibration method (Geometry Composer Method) was used for efficiency calibration. The reference materials, IAEA Soil - 6 and MBSS 2 of known ^{137}Cs content were used for method validation. The net area under peak at 661.5 KeV was used to determine the ^{137}Cs concentration of soil and for total ^{210}Pb is 46.5 KeV in Bq kg^{-1}. The $^{210}Pb_{ex}$ activity was determined by subtracting $^{210}Pb_{supp}$ (average of ^{214}Pb and ^{214}Bi activities) from total ^{210}Pb for each depth interval and core samples.

High voltage supply is required to supply high voltage to the detector (1500-5000V). DSA1000 (Digital Spectrum Analyzer 1000) is responsible for spectra accumulation. The spectra were analysed using the software packages Genie 2000. The MDA (minimum detectable activity) of ^{137}Cs is 1.0 Bq kg-1 for the counting time and the geometry used. Activity concentration of each of the radionuclides was calculated by using below equation (Miah, et al., 2012).

$A = (N_C X1000)/ (\varepsilon \times I\gamma \times W)$

A= Activity concentration of the sample in Bq/kg

Nc= Net Count Rate= Gross counts per seconds from the sample – background counts per second

Ɛ = Efficiency of the detector for the specific energy Iγ = Intensity of the gamma ray

W= sample weight in gram.

Quality control procedures were applied using control charts (efficiency, resolution and background), certified reference materials and regular participation in inter-comparison exercises and proficiency tests organised by IAEA. The laboratory was accredited under ISO17025:2005 from year 2006.

The areal activity of ^{137}Cs and ^{210}P bex were calculated using the equation 1 $S = cmA^{-1}$ (1)

Where c is the ^{137}Cs concentration in the sample < 2mm (Bq kg^{-1}), m is total sample dry mass of the fine fraction (kg) and A is the cross section area of the sampling device (m^2)

Soil redistribution rates induced by water erosion were calculated by Mass Balance Model II for ^{137}Cs measurements and Mass Balance Model I for $^{210}Pbex$ developed by Walling and He (WALLING, et al., 2001).

Determination of other soil parameters

Soil physical parameter such as soil bulk density, SOC, soil nutrients (available phosphorus, exchangeable potassium.) were determined at the Department of Agriculture.

Results and Discussion

The depth distributions of ^{137}Cs and $^{210}Pbex$ concentrations associated with the reference site are shown in Figure 6. Most of the ^{137}Cs and $^{210}Pbex$ were contained in the top 10 cm. For the reference site, the vertical distributions associated with both radionuclides were similar with exponential decrease with depth.

Sampling points A4, A5, C2 and C3 have not presented detectable level of ^{137}Cs. It is revealed that those samples points are highly erodible and it may be higher than 56.95 t ha^{-1} yr^{-1} which is the highest value of the site (Table 1) (Figure 7).

According to the ^{137}Cs inventories, highest soil erosion was recorded in marginal tea lands (37.36$tha^{-1}yr^{-1}$) followed by grassland (6.4 $tha^{-1}yr^{-1}$) and home gardens (5.31 tha-1yr^{-1}). Well grown tea recorded the lowest soil erosion rate (Table 3). Complete ground cover was observed in land uses of grassland, home gardens and well grown tea. However, considerable vacant areas were observed in marginal tea lands. It may be the reason for highest erosion rate in marginal tea lands.

According to the 210 Pbex inventories all the land uses studied in the catchment recorded the net soil deposition. Highest deposition rate was observed in grassland (16. 90 tha-1yr-1) followed by well grown tea (3.61 $tha^{-1}yr^{-1}$). Marginal tea recorded the lowest deposition rate (2.17 $tha^{-1}yr^{-1}$). According to the land use history of the catchment, the area was under forest cover before the year 1930. The forest was cleared in 1930 to establish tea plantations. It can be assumed that during the land clearing eroded soils may get deposited the low land areas and depressions of the catchment. Therefore, it may be the reason for net soil deposition observed during past 100 years. This assumption seems to be correct because the grassland located lowermost position recorded highest soil deposition rate (Table 2-3).

Soil organic matter content, available P and exchangeable K content was also analysed in order to find relationship among soil erosion, soil organic matter content and soil nutrient availability. Total organic carbon content and available phosphorus content showed a positive correlation with ^{137}Cs and ^{210}Pb inventories (Table 4)(Figures 8 and 9).

Highest soil available phosphorus and organic matter percentage was recorded in the well grown tea. It was observed that thick litter layer covering the ground in well grown tea. It may be the reason for higher organic matter content in well grown tea. The thick litter layer also might have minimized the soil erosion. Home gardens also recorded the higher soil nutrient content even though farmers normally applied any chemical fertilizer to the home gardens. Multi-storied vegetation in the home gardens might have minimized the soil erosion conserving the much of the available soil nutrient (Table 5).

Table 1: ^{137}Cs inventories and soil redistribution rates obtained for 24 bulk cores collected from the cultivated field at Dolosbagein Sri Lanka

Core No./ Sample No.	**^{137}Cs activity Bq kg^{-1}**	**^{137}Cs activity Bq m^{2}**	**Soil redistribution rates using MBM II t^{-1}ha^{-1} yr^{-1}**
DOL-A2	1.4	650.86	-1.43
DOL-A3	0.64	268.40	-23.61
DOL-A4	N/D	-	>50
DOL-A5	N/D	-	>50
DOL-A6	1.66	643.01	-1.73
DOL-B1	1.15	399.04	-13.43
DOL-B2	1.78	747.89	2.81
DOL-B3	1.99	684.97	-0.21
DOL-B4	1.62	680.99	-0.35
DOL-B5	0.29	81.19	-56.94
DOL-B6	0.55	216.00	-29.36
DOL-C1	0.79	350.15	-16.74
DOL-C2	N/D	-	>50
DOL-C3	N/D	-	>50
DOL-C4	2.2	1060.85	23.37
DOL-C5	1.44	400.02	-13.37
DOL-C6	1.84	626.75	-2.34
DOL-D2	1.07	479.15	-8.88
DOL-D3	3.23	1597.34	53.54
DOL-D4	2.77	1112.08	24.87
DOL-D5	1.78	689.84	-0.04
DOL-E4	0.48	130.19	-43.29
DOL-S1	6.88	8057.90	456.05
DOL-S2	4.9	1597.93	56.14

N/D –Not Detectable

Ref In	691 Bq/m2		^{137}Cs
	14290 Bq/m2		$^{210}Pb_{ex}$
Mass Balance Model II			
Proportion Factor			0.5
Relaxation depth			4 cm
Tillage depth			170cm
Year of tillage commence 1954			
Particle size factor			1
sampling year			2013
Gross erosion rate -10.6			
net erosion rate		20.3 t ha^{-1} yr^{-1}	
sediment delivery ratio -191%			

Table 2: ^{210}Pbex inventories and soil redistribution rates obtained for 24 bulk cores collected from the cultivated field at Dolosbagein Sri Lanka

Core No./ Sample No.	^{210}Pbex activity BqKg-1	^{210}Pbex activity Bqm2	Soil redistribution rates using MBM1 t-1ha-1yr-1
DOL-A2	13.71	6373	-11.28
DOL-A3	44.09	18489	25.93
DOL-A4	22.74	10336	1.03
DOL-A5	31.03	13716	11.35
DOL-A6	28.68	11109	3.39
DOL-B1	22.84	7925	-5.77
DOL-B2	32.6	13697	10.86
DOL-B3	55.55	19120	26.78
DOL-B4	45.02	18924	26.21
DOL-B5	30.26	8472	-4.1
DOL-B6	24.63	9672	-0.82
DOL-C1	15.93	7060	-8.68
DOL-C2	18.04	7823	-6.09
DOL-C3	32.93	12166	6.17
DOL-C4	36.6	17648	21.77
DOL-C5	30.97	8603	-3.72
DOL-C6	34	11581	4.46
DOL-D2	20.22	9054	-2.45
DOL-D3	34.74	17180	20.15
DOL-D4	38.17	15324	14.94
DOL-D5	29.15	11297	3.64
DOL-E4	23.63	6409	-11.14

Gross erosion rate: -14.4 Net erosion rate -12.3
Reference Inventory 14289Bq m-2 Relaxation depth 4.0
Particle size correction factor =1 Year of tillage commencement 1930 Tillage depth: 170 Kgm-2

Table 3: Average soil erosion/deposition under different land uses

Land Use	Soil erosion/deposition according to ^{137}Cs inventory (t ha^{-1}yr^{-1})	Soil erosion/deposition according to ^{210}Pbex inventory (t ha^{-1}yr^{-1})
Grassland	-6.40	+16.90
Marginal Tea	-37.60	+2.17
Home garden	-5.31	+2.54
Well grown tea	-3.59	+4.65

Table 4: Phosphorus, exchangeable Potassium and soil OM content

Sampling Point	Olsen's P ppm.	Exch.K ppm.	OM%	TOC%= OM%/1.724
Reference AVG.	4	49.2	3.6	2.09
DOL-A2	0.27	55	3.47	2.01
DOL-A3	1	97	2.21	1.28
DOL-A4	2	152	1.58	0.92
DOL-A5	1	166	2.71	1.57
DOL-A6	8	263	3.34	1.94
DOL-B1	2	55	3.97	2.3
DOL-B2	6	235	2.96	1.72
DOL-B3	11	124	3.97	2.3
DOL-B4	1	55	4.35	2.52
DOL-B5	3	28	3.21	1.86
DOL-B6	4	83	3.97	2.3
DOL-C1	3	124	2.58	1.5
DOL-C2	4	97	5.3	3.07
DOL-C3	2	111	2.46	1.43
DOL-C4	0.34	28	8.63	5.01
DOL-C5	4	83	3.47	2.01
DOL-C6	2	55	2.59	1.5
DOL-D2	2	55	2.96	1.72
DOL-D3	17	69	5.36	3.11
DOL-D4	2	41	4.09	2.37
DOL-D5	2	110	2.71	1.57
DOL-E4	1	55	3.21	1.86
DOL-S1	3	83	10.4	6.03
DOL-S2	4	193	11.91	6.91

Table 5: Average Soil nutrient content and organic matter percentage under different land uses

Land Use	Olsen P ppm	Exch K ppm	OM%
Grassland	3.31	82.75	3.5
Marginal Tea	3.60	138.40	2.96
Home garden	4.00	145.00	3.46
Well grown tea	4.03	73.66	4.16

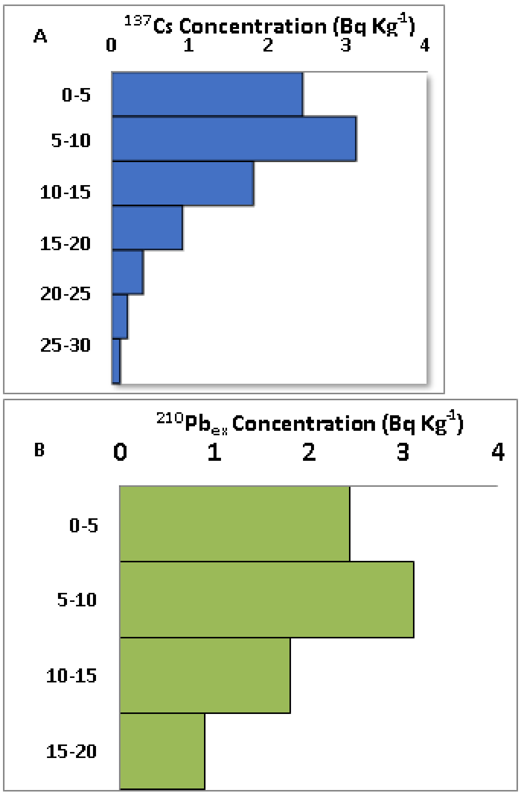

Figure 6: Vertical distribution of ^{137}Cs (A) and ^{210}Pbex (B) in the reference site

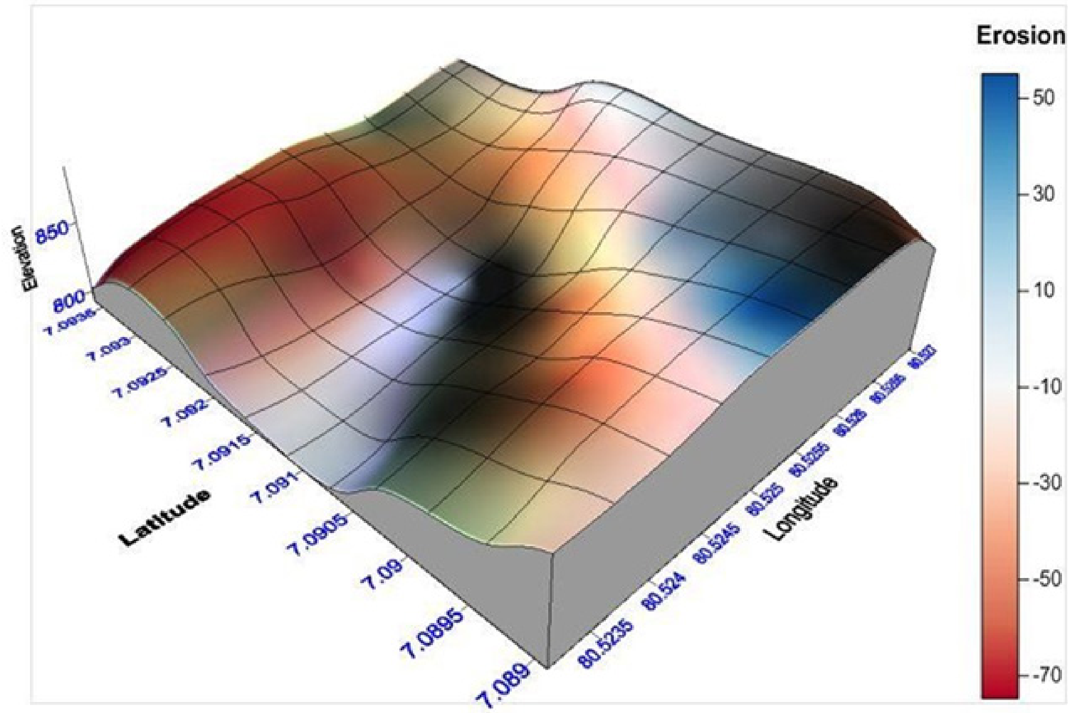

Figure 7: Spatial patterns of mean annual soil redistribution rates based on ^{137}Cs measurements in Dolosbage in Sri Lanka

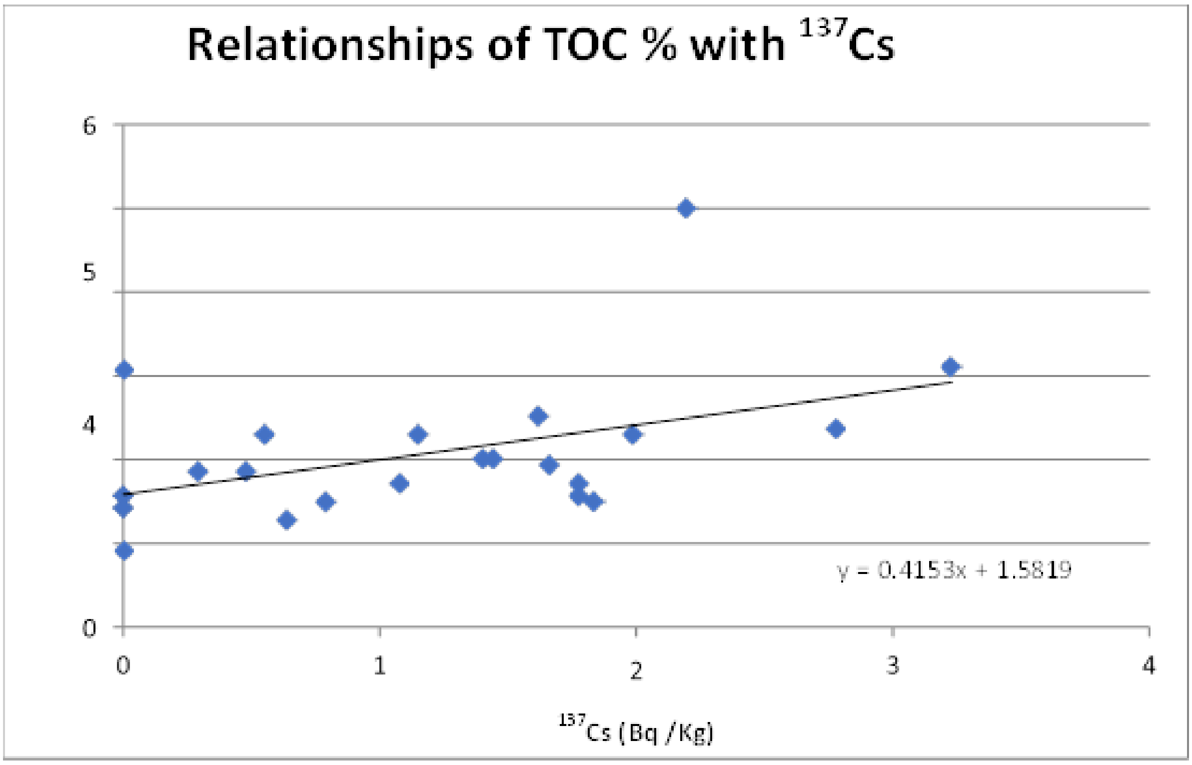

Figure 8: Relationship of %TOC with ^{137}Cs in Dolosbage site

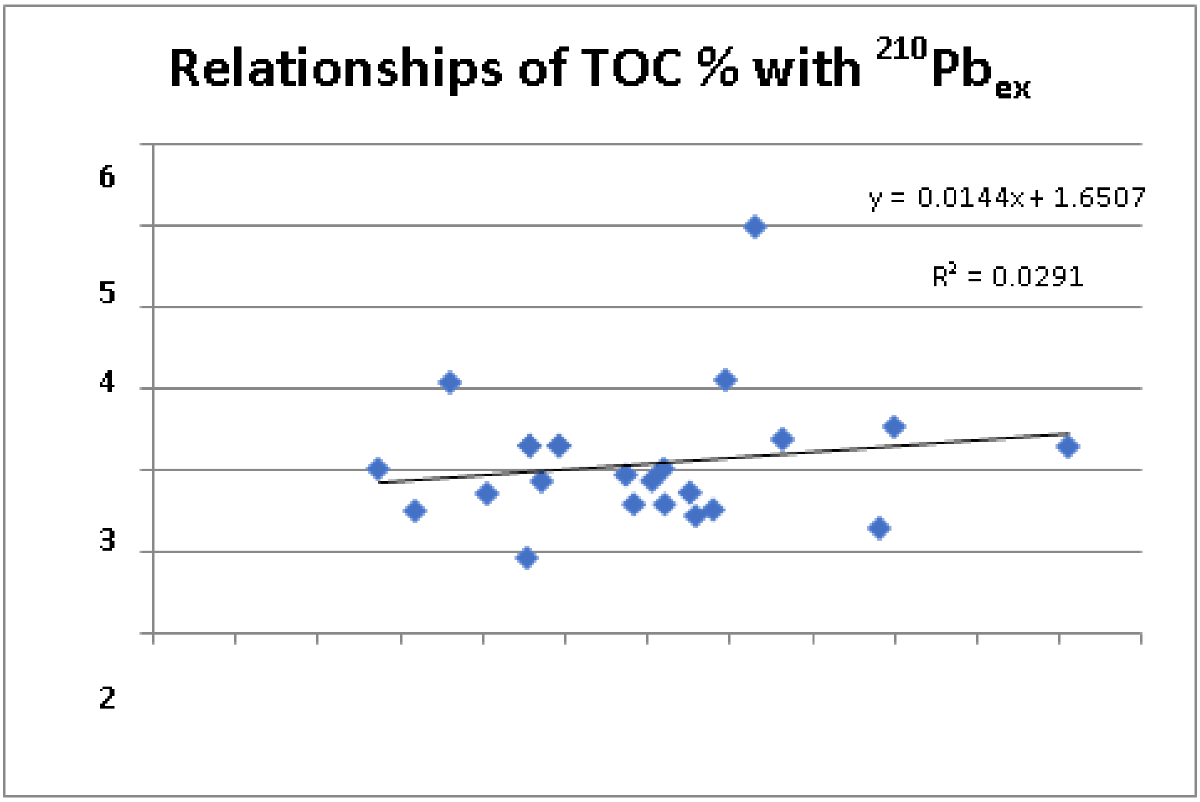

Figure 9: Relationship of %TOC with ^{210}Pbex in Dolosbage site

Conclusion

For the reference site, the vertical distributions associated with both radionuclides were similar with exponential decrease with depth. Marginal tea lands showed highest soil erosion rate. Considerable vacant areas in marginal tea lands may be the reason for highest erosion rate. ^{210}Pbex inventories revealed that the highest deposition rate was observed in grasslands. The forest was cleared in 1930 to establish tea plantations. It can be assumed that during the land clearing eroded soils may get deposited the low land areas and depressions of the catchment. Therefore, it may be the reason for net soil deposition observed during past 100 years. This assumption seems to be correct because the grassland located lowermost position recorded highest soil deposition rate. Highest soil available phosphorus and organic matter percentage was recorded in the well grown tea. Thick litter layer covering the ground in well grown tea. The thick litter layer minimized the soil erosion.

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