Research Paper

Assessment of Soil Erosion and Deposition Using Fallout Radionuclide Technique under Different Land Uses and its Relationship with Soil Chemical Properties in the Low Country Dry and Intermediate Zones of Sri Lanka.

A.G. Chandrapala[1*], K.M.A. Kendaragama[1], S.K. Weththasinghe[1], C. Dissanayake[2]

[1] *Natural Resources Management Centre, Peradeniya, Sri Lanka*
[2] *Sri Lanka Atomic Energy Board, Wellampitiya, Sri Lanka*

**Corresponding author: ag.chandrapala@yahoo.com*

ARTICLE INFO

Article history:
Received: 17 April 2023
Revised version received: 12 May 2023
Accepted: 30 May 2023

Citation:
Chandrapala, A.G., Kendaragama, K.M.A., Weththasinghe, S.K., Dissanayake, C. (2023). Assessment of soil erosion and deposition using fallout radionuclide technique under different land uses and its relationship with soil chemical properties in the Low country Dry and Intermediate Zones of Sri Lanka. *Tropical Agriculturist, 171* (2), 1-12.

Abstract

Although there is a wealth of research findings on soil erosion in the central highlands, there has been meager attention given to soil erosion in the dry and intermediate zones. Therefore, an assessment of soil erosion/deposition under different land uses was conducted in Bathalagoda reservoir catchment in Kurunegala district and Payindikulama tank command area of Anuradhapura district in the year 2019, using Fallout Radionuclide (137Cs and 210Pb) Technique (FRN) and, its relationship with soil chemical properties was established. Results indicated that, the highest rate of soil erosion in the Bathalagoda reservoir catchment, was under coconut plantation (8.0 t ha^{-1} yr^{-1}). Paddy lands recorded 9.0 t ha^{-1} yr^{-1} of soil deposition. A high rate of sedimentation of 26.6 t ha^{-1} yr^{-1} was recorded in the Bathalagoda reservoir, measured using 137Cs method. The highest soil available phosphorus (52.5 mg kg^{-1}) and exchangeable potassium (320.7 mg kg^{-1}) was recorded under coconut cultivation. In the Payindikulama site, the highest soil erosion of 35.3 t ha^{-1} yr^{-1} was recorded under shifting cultivation. Paddy lands recorded 6.0 t ha^{-1} yr^{-1} of soil deposition measured using ^{137}Cs method. ^{210}Pb method also recorded approximately similar results in both sites. The highest soil available phosphorus was recorded under coconut cultivated lands (47.2 mg kg^{-1}) and the highest exchangeable potassium was in forest lands (338 mg kg^{-1}). A highly significant negative correlation exists between soil erosion rate and soil organic matter % in both sites. Moreover, a highly significant positive correlation exists between soil erosion and deposition rates, estimated using ^{137}Cs and ^{210}Pb methods in both sites. Based on the results, it was concluded that the highest rate of soil erosion occurs under the land use of shifting cultivation. The soil organic matter concentration can be used as an indicator of soil erosion status as evident by high negative correlation between the two parameters.

Keywords: Available Phosphorus, Exchangeable Potassium, Organic matter ^{137}Cs and ^{210}Pb

Introduction

Soil erosion and associated sedimentation are natural processes caused mainly by water and wind. Human induced activities such as deforestation, overgrazing, change in land use and non-sustainable farming practices tend to accelerate soil erosion and thereby sedimentation (Hewawasam, 2010). Soil erosion and sedimentation cause on site (Decline of soil fertility, soil depth) and off-site impacts (downstream sedimentation in reservoirs, streams and flood plains). Identifying the gravity of the problem, the government of Sri Lanka enacted soil conservation act No. 25 in year 1951 for minimizing soil erosion ensuring sustainable land use for future generations of Sri Lanka. Recent focus on sustainability issues has also resulted in increased attention on soil degradation, in particular soil erosion and sedimentation (Adhikari & Hartemink, 2016).

The lack of quantitative information on soil erosion status in different agro-ecological regions under different land uses is one of the major drawbacks in successful implementation of soil conservation programs. Specification used in establishment of soil conservation measures in Sri Lanka is quite old (Poesen, 2018) and with the changing climate, these specifications need to be revised for successful mitigation of land degradation of the country.

There are different soil erosion assessment methods such as standard erosion plots, mathematical prediction models, expert judgments based on field observations and other conventional methods used in different countries (El-Swaify *et al*., 1982). However, there are own limitations exists in each of these methods (Boix-Fayos *et al*., 2009). In standard erosion plots, soil erosion is measured using 22.1 m length erosion plots. However, there are criticisms that whether the size of the erosion plot is sufficient to represent a watershed. Erosion plot method used to measure soil erosion are time consuming and the results obtained for an experimental plot are usually incomparable with one another. On the other hand, the suitability of mathematical models such as Universal Soil Loss Equation is questionable in tropical countries such as Sri Lanka. Land use, cover, conservation practices are quite complex in Sri Lanka due to existence of small land units. Slope of the land also varies within short distances in most part of the country due to differences in terrain. characteristics. Therefore, it is extremely difficult to compute soil erosion using causative factors (Slope length, slope steepness, conservation practices, land cover etc.) in catchment scale. In order to fill the existing gaps in catchment scale soil erosion data, International Atomic Energy Agency developed a technique of assessment of catchment scale soil erosion and deposition using radio isotopes of ^{137}Cs and ^{210}Pb. ^{137}Cs and ^{210}Pb are free falling radio isotopes from atmosphere in trace quantities, strongly binds with soil particles when it reaches to the soil surface. Therefore, it can be effectively utilized as a tracer for estimation of soil erosion. The use of Fallout Radionuclides (FRN) such as ^{137}Cs and ^{210}Pb to measure soil erosion, overcomes many of the limitations of the conventional methods. Thus, this method is a valuable alternative compared to the conventional methods. Furthermore, Fallout Radionuclides measurements can be used as the basis for studying both the spatial variability of soil loss and its magnitude. The technique is based on comparison of the ^{137}Cs inventory (Bq m^{-2}) at a given location with that of a nearby 'reference' location (Walling and Quine, 1990). A loss or gains of the ^{137}Cs inventory at that location in comparison with the inventory at the reference location represent erosion or deposition. These comparisons of measured inventories with the local reference values provide useful qualitative information on the spatial distribution of erosion and deposition in the landscape. Therefore, the study was conducted to (i). Assess soil erosion and deposition rates under major land uses in Bathalagoda tank catchment and Payindikulama tank cascade command area in the Low Country Intermediate and Low Country Dry Zones of Sri Lanka using fallout radionuclide technique. (ii). Find out the relationship among soil chemical properties (Available phosphorus, Exchangeable potassium, Organic matter concentration, Soil pH, Electrical conductivity) and rate of soil erosion/ deposition under different land uses. The assessment of soil erosion and deposition rates in different land uses will benefit the farmers, agricultural entrepreneurs, and decision makers to allocate lands for agriculture in a sustainable manner. The identification of the relationship between soil erosion and soil chemical parameters enables farmers to identify impacts of soil erosion on crop productivity.

Principle - Fallout Radionuclide Technique

Fallout radionuclides are radio-isotopes, which emit ionizing radiation due to radioactive decay. Therefore, the presence of a trace quantity of radio-isotopes can be detected using the property of emitting ionizing radiation. International Atomic Energy Agency has introduced two naturally occurring (^{210}Pb and ^{7}Be) and one man-made (^{137}Cs, which was emitted in nuclear weapon testing) radionuclides as tracers for determining soil erosion/deposition (Soil redistribution). The chemistry of ^{137}Cs and ^{210}Pb is well understood (Wallbrink and Murray, 1993). When ^{137}Cs and ^{210}Pb reach the soil surface, they are quickly and strongly adsorbed by exchange sites and are essentially non-exchangeable in most environments (Cremers *et al*., 1988). Therefore, these radio-isotopes can be effectively utilized as tracers in soil erosion assessment. As the half-life of ^{210}Pb is 22 years, it is possible to estimate soil erosion and deposition in past 100 years using ^{210}Pb radio-isotope. Whereas, as the half-life of ^{137}Cs is 30 years, it is possible to estimate soil erosion using ^{137}Cs from year 1954 which is the year of its first occurrence. In determining soil erosion/deposition, soil samples need to be collected from the "reference site" located at a flat terrain on a hill top. The assumption in the reference site is that the fallout radionuclides receiving from atmosphere deposited as it is, in the reference site, without removing or receiving radionuclides from other land uses. The presence of radionuclides in the soil sample from anywhere in the catchment can be compared with the reference site. If the radionuclides present in the other land uses are higher than that of the reference site (+ value), it denotes the sediment deposition and if lower than that (- value), denotes the soil erosion. The absolute value of soil erosion or deposition (t ha^{-1} yr^{-1}) can be computed by subtracting the radioactivity amount (measured in Becquerel) in the soil samples taken from the reference site from those collected at other locations within the catchment. This computation is performed using the "mass balance model ii" conversion method intended to measure soil erosion and deposition.

Materials and methods

Study area

The study was carried out in Batalagoda, Ibbagamuwa divisional secretariat in the Kurunegala district (Low Country Intermediate Zone (IL1a)) and Paindikulama tank cascade system, Kekirawa in the Anuradhapura district (Low Country Dry Zone (DL1)) of Sri Lanka in 2019.

Batalagoda study area, receives 1400 mm of rainfall per year. Soil of the area is Red Yellow Podzolic with strongly mottled sub soil. Land slope of the area is around 10 - 20% in an undulating landscape, except the terraced paddy lands. Four land uses were identified in 7 km^2 of Batalagoda tank catchment where, natural forest was located in the hill tops of the catchment and coconut plantations and home gardens were located in the mid slope of the catena. Paddy lands were located in the low lying areas.

Payindikulama is a tank cascade system, in Kekirawa divisional secretariat area, located in Low Country Dry Zone agro-ecological region. The extent of the catchment is 4 km^2 and land slope of the area is around 0 -10 % except the terraced paddy lands. Land use sequence of the catena (in transect) is natural forest in hill crest - Chena cultivation - coconut plantations - home gardens - Agro-well farming in the middle and lowermost area is under paddy cultivation. Under agro well farming, other field crops and lowland vegetables are grown.

Compilation of background information and field reconnaissance of study area

The compilation of background information (land use history, current agricultural practices etc.) was done using the available government reports of the divisional secretariats and Agrarian service centers of respective areas. A thorough reconnaissance of the study area was done to determine whether suitable reference sites exist, to make an inventory of land forms, soils, and cultural practices present in the area. The specific land use/management practices used in the area was assessed through discussions with land owners. According to the land owners and village leaders of the area, it was revealed that the land use of the area remained the same for more than 50 years. Therefore, the comparison of soil erosion/deposition under different land uses was possible, although the deposition of ^{137}CS has occurred in late 1950's and early 1960's.

Selection of Reference site

For the comparison of a fallout radionuclide inventory, reference areas were chosen from the flat sites of the hill top of the area which had not been subjected to erosion and deposition, nor cultivated. Reference sites were selected from each study site having a size of approximately 100 m^2. In each reference site, 3 soil bulk samples were taken from each corner of the square in a triangle position with a core sampler with the core diameter of 6.9 cm. Soil samples were collected up to 50 cm depth of the soil profile. A total of 12 bulk soil samples were collected for estimating FRN activity inventories for each reference site. Additionally, one soil section sample from each site was also collected with 2 cm depth increments to determine the FRN depth profile.

Selection of sampling site

Two representative closed micro watersheds were selected in *Batalagoda wewa catchment* and *Payindikulama wewa* command area for assessment of soil redistribution using FRN. The selection was based on background information and field reconnaissance of the study area. Grid lines were marked on base maps to identify sampling locations.

Soil sample collection and analysis

Six georeferenced soil samples per each land use were collected up to 40 cm soil depth using a core sampler and placed in clean polythene bags and analyzed each sample separately. Soil sampling depth was decided based on the radionuclide distribution depth measured in reference site. The sampling locations were geo-referenced using a GPS. All the samples were sent to research laboratory of the Natural Resources Management Center at Peradeniya, for determination of chemical properties. Measurements of ^{137}Cs concentration were done at research laboratory of the Atomic Energy Board in Colombo on a sub sample of 1000 g from each bulked core sample using a hyper pure coaxial Germanium detector coupled to a multichannel analyzer (Honeywell Analytics, United Kingdom). The results of FRN activity were originally calculated on a unit mass basis (Bq kg^{-1}) and converted to an inventory value (Bq m^{-2}) using the total weight of bulked core soil sample and the sampling area (30 cm^2). Soil bulk density (Mg m^{-3}) calculation was based on volume of bulked soil cores and oven dried mass determinations (Pennock *et al*., 1994). Soil pH of 1:5 soil: water suspension was determined by a bench type pH meter (JENWAY 3520), electrical conductivity in a 1:5 soil: water suspension by a bench type conductivity bridge (JENWAY 4510). Available P (mg kg^{-1}) was determined using the method described by Olsen *et al.* (1954). Exchangeable potassium water determined by using flame using flame photometry photometer (Jackson, 1979). Soil organic matter percentage was analyzed by modified Walkley and Black method (Nelson and Sommer, 1996).

Calculation of soil erosion/deposition

Soil redistribution rates induced by water erosion were calculated by Mass Balance Model II developed by Walling and He (2001).

Y = (10 B×d / P) × [1-(1-(x / 100)) 1 / (t-1963)]

Where,

Y = the mean annual soil redistribution (t $ha^{-1}yr^{-1}$);

x = the percent loss of ^{137}Cs at the sampling site compared to the reference site;

B = the bulk density of soil (kg m^{-3});

d = the depth of the plowed layer (m);

t = the year of sample collection; and

P = a correction factor for particle surface area.

Results and discussion

Batalagoda wewa catchment consists of mixed land uses such as homesteads and agricultural lands. On the other hand, command area of *Payindikulama wewa* also act as a catchment to the reservoir located in lowlying area, since the system is a tank cascade system.

Batalagoda

Sedimentation rate of Batalagoda irrigation tank was around 26.7 to 27 t ha^{-1} yr^{-1} according to the assessment methods of ^{137}Cs and ^{210}Pb respectively (Table 1). Although, the rate of soil erosion under different agricultural land uses occurring within Batalagoda tank catchment was not alarming, higher rate of tank sedimentation need to be considered seriously. Although, not studied, there may be higher rate of soil erosion in non-agricultural lands such as roadsides, stream banks and construction sites. The highest soil erosion rate of Batalagoda reservoir catchment was observed under coconut was 8.1 and 7.2 t ha^{-1} yr^{-1} according to the ^{137}Cs and ^{210}Pb methods, respectively followed by home gardens (Table 1). Natural forests recorded the lowest soil erosion rate. Three distinct canopy layers (Emergent, canopy and understory) could be observed in the home gardens in the studied area. Interception of rain drops by tree canopies might have reduced the erosive power of rain drops. In addition, the thick litter layer and understory vegetation also might have minimized the direct impact of rain drops with soil and might have facilitated the water infiltration, minimizing the surface runoff.

Table 1. Soil chemical properties and soil erosion in different land uses in Batalagoda site

Land use	pH	EC (dS m^{-1})	Available P (t $ha^{-1}yr^{-1}$)	Exchangeable K (t $ha^{-1}yr^{-1}$)	Soil erosion ^{137}Cs method (t $ha^{-1}yr^{-1}$)	Soil erosion ^{210}Pb method (t $ha^{-1}yr^{-1}$)
Paddy	5.6^{b}	0.04^{b}	32.6^{b}	285.1^{b}	$+9.2^{b}$	$+9.0^{b}$
Coconut	6.4^{a}	0.09^{a}	52.5^{a}	320.7^{a}	-8.1^{c}	-7.6^{c}
Forest	5.4^{b}	0.04^{b}	10.3^{c}	143.0^{c}	-1.0^{d}	-0.8^{d}
Home Garden	5.2^{b}	0.03^{b}	14.4^{c}	187.8^{c}	-2.8cd	-2.5^{cd}
Reservoir sediment	3.9^{c}	0.04^{b}	13.8^{c}	252.6^{b}	$+26.7^{a}$	$+27.0^{a}$
CD	0.5	0.02	18.4	38.6	5.7	5.5
SE	0.2	0.01	8.7	18.6	2.7	2.6
CV%	8	12	11	19	29	21

Means followed by the same letter are not significantly different at 5% probability level. – Sign denotes net soil erosion and + sign denotes net soil deposition. SE.± = standard error, CD = critical difference CV %= Coefficient of variance

However, the home gardens in the catchment are less diverse than natural forests. It was observed that, all these erosion rates were within the upper natural tolerable limit of 12.92 mg kg^{-1} (Mandal *et al.*, 2021). Land use of paddy recorded the soil deposition at the rate of around 7 to 8 t $ha^{-1}yr^{-1}$.

Soil pH of the catchment ranges from 3.9 – 6.4. According to soil pH classification, soil in the area is acidic. The catchment experiences higher rainfall (1750 mm – 2500 mm) (Panabokke, 1996). Higher rainfall may leach down soil basic cations. Higher soil pH was observed in coconut cultivation lands. Soil EC of the catchment ranges from 0.03 – 0.09 dS m^{-1}. The highest EC value was recorded in coconut plantations (0.09 dS m^{-1}) possibly due to the addition of soil amendments such as dolomite and chemical fertilizer containing potassium salt. while the lowest was recorded in home gardens (0.03 dS m^{-1}). Among the land uses studied, Coconut cultivation recorded the highest available soil phosphorus (52.5 mg kg^{-1}) and Forest lands recorded the lowest soil available phosphorus (10.3 mg kg^{-1}) Among the land uses studied, Coconut cultivation recorded the highest soil available potassium (320.7 mg kg^{-1}) and Forest lands recorded the lowest soil available potassium (143.0 mg kg^{-1}).

Reservoir sediment recorded the lowest pH (3.9), possibly due to the anaerobic decomposition accumulated in tank bed. Land use of coconut recorded the highest soil pH (6.4), EC (0.09 dS m^{-1}) and available phosphorus (52.5 mg kg^{-1})

Payindikulama

Significantly highest soil erosion was recorded under shifting (Chena) cultivation, estimated using both ^{137}Cs method (35.3 t ha^{-1} yr^{-1}) and ^{210}Pb method (34.1 t ha^{-1} yr^{-1}); (Table 2).

Table 2. Soil erosion/Deposition and soil chemical properties in different land uses in Paindikulama site

Land use	pH	EC	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	OM (%)	Soil erosion ^{137}Cs method (t $ha^{-1}yr^{-1}$)	Soil erosion ^{210}Pb method (t $ha^{-1}yr^{-1}$)
Paddy	6.8^{a}	0.06^{ab}	6.9^{c}	106^{c}	2.5^{a}	6.0^{a}	7.2^{a}
Coconut	6.8^{a}	0.08^{a}	47.2^{a}	295^{ab}	0.9^{cd}	-13.8^{d}	-13.3^{c}
Forest	6.4^{ab}	0.08^{a}	23.5^{b}	338^{a}	1.5^{b}	-0.6^{b}	-0.5^{b}
Chena cultivation	5.8^{c}	0.03b	17.7^{bc}	215^{bc}	0.7^{d}	-35.3^{e}	-34.1^{d}
Agro well farming	6.6^{ab}	0.09a	11.7^{bc}	113^{c}	1.3b^{c}	-13.4^{d}	-13.3^{c}
Home Garden	6.3^{b}	0.05^{ab}	12.8^{bc}	166^{c}	1.3b^{c}	-5.6^{c}	-3.3^{b}
CD	0.4	0.04	13.6	106	0.4	4.6	3.4
SE	0.2	0.02	6.3	52	0.2	2.1	2.1
CV%	6	10	14	18	9	27	26

Means followed by the same letter are not significantly different at 5% probability level. S E.± = standard error, CD = critical difference, CV % Coefficient of variance

Generally, farmers clear the lands before the onset of seasonal rainfall. During the high-intensity short rainy season, land preparation exposes the disturbed soil resulting in increased erosion. When farmers cultivate vegetables and other field crops, without appropriate soil conservation measures, the rate of soil erosion increases. Use of conventional tillage practices, especially those used to produce fine seed beds produce an abundant source of small, lighter, particles that are vulnerable to erosive forces. Re-deposition of these fine particles on the soil surface can result in surface sealing and capping, which can reduce the infiltration capacity of a soil and increase the risk of surface runoff. Bandarathilake, (1997) also reported that most of vegetable cultivated lands in upper Mahaweli watershed have annual erosion rates over 75 t $ha^{-1}yr^{-1}$ thus significantly increasing the sediment yield in runoff and stream water. The lowest soil erosion was observed under natural forest (0.6 t ha^{-1} yr^{-1}, ^{137}Cs method, 0.5 t ha^{-1} yr^{-1}, ^{210}Pb method). Dissanayake *et al*. (2010) assessed soil erosion rates in Uma oya catchment using radio-nuclide of ^{137}Cs and reported that 52 t ha^{-1} yr^{-1} of soil erosion in shifting cultivation lands, 22 t ha^{-1} yr^{-1} of soil erosion in homestead and 10 t ha^{-1} yr^{-1} of soil erosion in plantation forests in Uma oya catchment which was much higher than the rate of soil erosion in the Payindikulama tank command area. Compared to Uma oya catchment, Payindikulama tank command area is having lands with very gentle slope resulting lower rate of soil erosion. There was a soil deposition under the land use of paddy 6.0 t ha^{-1} yr^{-1} (^{137}Cs method), 7.2 t ha^{-1} yr^{-1}, and (^{210}Pb method). Rate of soil erosion in home gardens and natural forest were less than the natural tolerable limit of 10 t $ha^{-1}yr^{-1}$ for tropical countries (Bennett,1939). However, soil erosion under the land uses of shifting (chena) cultivation, coconut lands and agro-well farming was higher than the critical limit of natural rate of soil erosion. Soil erosion under agro-well farming was mainly due to the practices of irrigation. The use of irrigation hose caused soil erosion considerably even though cultivation was practiced in flat lands. Frequent soil disturbance in shifting cultivation caused most of the soil erosion.

Among the different land uses, paddy and coconut recorded the highest soil pH (6.8) on par with soil pH under the land uses forest and agro well farming (Table 2). Agro well farming recorded the highest EC possibly due to the high saline water in agro-wells (Kendaragama *et al*., 1998). Highest available P content was observed under the land use of coconut, however, highest exchangeable K content was observed under the land use of natural forest. Even though, it is reported the application of higher dose of chemical fertilizer to the vegetables (Rajakaruna *et al*., 2005), reconnaissance survey carried out under this study revealed that most of farmers doing shifting cultivation apply a little dose of chemical fertilizer to their lands which also might have washed off due to heavy rainfall on uncovered lands without proper soil conservation measures. However, the result of nutrient status in different land uses in present study is contradictory to the results of the study of Amarasekara *et al*. (2008) where, it was found that higher soil available phosphorus and exchangeable potassium content in vegetable cultivated fields than natural forests and home gardens. This disparity may be due to the management practices of individual farmers. It was observed that farmers who are doing shifting cultivation and famers practicing agro well farming apply little amount of fertilizer in Payindikulama tank command area. Highest soil organic matter content was observed under lowland paddy. Net soil deposition might have enriched the soil organic matter percentage in paddy lands. Lowest soil organic matter percentage was observed under shifting (chena) cultivations possibly due to the frequent soil disturbances.

There was a highly significant negative correlation exist between the rate of soil erosion measured using ^{137}Cs method (-0.943**) / ^{210}Pb method (-0.977**) and soil organic matter percentage. (Table 3). Therefore, it seems to be possible to use soil organic matter percentage as an indicator of the rate of soil erosion. There was also highly significant positive correlation exist between rate of soil erosion/deposition measured using ^{137}Cs method and ^{210}Pb method. Therefore, either radionuclide can be effectively utilized for estimation of soil erosion.

Similar to the Batalagoda tank catchment, there was a highly significant negative correlation exist between soil organic matter percentage and rate of soil erosion measured using either ^{137}Cs method or ^{210}Pb method (Table 4.). In addition, highly significant positive correlation exists between the rates of soil erosion measured using ^{137}Cs method and ^{210}Pb method. There was a significant positive correlation exist between soil pH and soil available phosphorus concentrations. Significant negative correlation also exists between soil pH values and soil organic natter percentage. Increasing soil pH up to certain level increase the microbial activity and decomposition of organic matter in the soil making it more available to the plants.

Table 3. Correlation matrix in pooled land uses in Batalagoda tank catchment area

Soil property	pH	EC	Ava, P (mg kg^{-1})	Exch. K (mg kg^{-1})	OM %	Soil erosion/ Deposition ^{137}Cs method	Soil erosion/ Deposition ^{210}Pb method
pH							
EC	-0.185^{NS}						
Ava. P (mg kg^{-1})	0.380^{NS}	-0.333^{NS}					
Exc. K (mg kg^{-1})	0.536^{NS}	-0.224^{NS}	-0.002^{NS}				
OM (%)	0.171^{NS}	-0.158^{NS}	-0.567^{NS}	-0.074^{NS}			
Soil erosion/Deposition ^{137}Cs method	-0.262^{NS}	0.153^{NS}	0.393^{NS}	0.256^{NS}	-0.943**		
Soil erosion/Deposition ^{210}Pb method	-0.293^{NS}	0.106^{NS}	0.459^{NS}	0.137^{NS}	-0.977**	0.984**	

*NS = non-significant, * = Significant at p<0.05. ** = Significant at p<0.01*

Table 4. Correlation matrix among soil parameters in pooled land uses in Payindikulama tank command area

Chemical property	pH	EC	Ava. P (mg kg^{-1})	Exch. K (mg kg^{-1})	OM (%)	Soil erosion/ Deposition ^{137}Cs method	Soil erosion/ Deposition ^{210}Pb method
pH							
EC	-0.036^{NS}						
Ava. P (mg kg^{-1})	0.829*	0.676^{NS}					
Exch. K (mg kg^{-1})	0.160^{NS}	0.103^{NS}	0.062^{NS}				
OM (%)	-0.899*	-0.239^{NS}	-0.395^{NS}	0.459^{NS}			
Soil erosion/Deposition ^{137}Cs method	-0.185^{NS}	-0.460^{NS}	-0.430^{NS}	-0.649^{NS}	-0.819**		
Soil erosion/Deposition ^{210}Pb method	-0.019^{NS}	-0.325^{NS}	-0.323^{NS}	-0.619^{NS}	-0.884**	0.985**	

*NS = Non-significant, * = Significant at p<0.05, ** = Significant at p<0.01*

If soils are too acidic, phosphorus reacts with iron and aluminum and makes it unavailable to the plants (Andrew *et al*., 2018). Organic matter decomposition is directly related to the soil microbial population and microbial activities (Morris, 2004). Up to a certain level, increasing pH favors the growth of microbial population (Bartz and Showalter, 1981). Therefore, increasing soil pH might have reduced the soil organic matter percentage, leading to a negative correlation. Significant correlations were not observed among other soil chemical properties and rate of soil erosion.

Conclusions

Land use of lowland paddy is acting as a sink for eroded soils from other land uses. Even in flat lands, cultivation practices, such as the method of irrigation, lead to a higher rate of soil erosion. Fallout Radionuclide technique was useful in identification of land uses having high, medium and low rate of soil erosion as well as areas where soil get deposited, important for land use planning. Fallout radionuclide technique enabled estimation of both soil erosion and deposition that cannot be done using conventional erosion estimation methods. Although, agricultural land uses in Bathalagoda tank catchment caused low rate of soil erosion, rate of sedimentation of Bathalagoda tank is alarming indicating the need of investigation of soil erosion in non-agricultural lands. Since there was a highly significant negative correlation exist between rate of soil erosion and soil organic matter percentage in both Bathalagoda tank catchment and Payindikulama tank command area, soil organic matter percentage can be effectively utilized as an indicator for the assessment of rate of soil erosion. Highly significant positive correlation exist between the rate of soil erosion/deposition measured using both ^{137}Cs method and ^{210}Pb method. Therefore, either ^{137}Cs method or ^{210}Pb method could be used to measure the rate of soil erosion.

References

Adhikari, K., & Hartemink, A. E. (2016). Linking soils to ecosystem services—A global review. *Geoderma*, 262, 101-111. https://doi.org/10.1016/j.geoderma.2015.08.009

Amarasekara, M. G. T. S., Dayawansa, N. D. K., & De Silva, W. P. R. P. (2008). Institutional aspects of implementation of land and water policies in the Upper Mahaweli Catchment, Sri Lanka. In *Proceedings of the International Conference on Water Resources Policy in South Asia. Colombo, Sri Lanka*.

Bartz, J. A., & Showalter, R. K. (1981). Infiltration of tomatoes by aqueous bacterial suspensions. *Phytopathology, 71*(5), 515-8.

Bandarathilake, H. M. (1999). Optimal land use in the hill country of Sri Lanka: Land degradation and forestry. Proceedings of the workshop on Economic policy reforms and the environment: Land degradation in Sri Lanka. Taj Samudra Hotel, Colombo, Sri Lanka. 19 December, 1997. Pp 202-267.

Bennett H. H. (1939). *Soil conservation* (1st ed.). McGraw-Hill Book.

Boix-Fayos, C., de Vente, J., Albaladejo, J., & Martínez-Mena, M. (2009). Soil carbon erosion and stock as affected by land use changes at the catchment scale in Mediterranean ecosystems. *Agriculture, Ecosystems & Environment, 133*(1-2), 75-85. https://doi.org/10.1016/j.agee.2009.05.013

Cremers, A., Elsen, A., Preter, P. *et al*. Quantitative analysis of radiocaesium retention in soils. *Nature* 335, 247–249 (1988). https://doi.org/10.1038/335247a0

Dissanayake, D. C. K. K., Mahawatte, P., Weerasekera, T. S. B. & Abeynayake. K. (2010). Spatial Variability of Ceasium-137 in soil at two reference sites in Uma Oya catchment – paper presented at the Tenth Anniversary International Symposium, Sabaragamuwa University of Sri Lanka, 4-8 July 2006.

El-Swaify, S. A., Dangler, E. W. & Armstrong, C. L. (1982). *Soil erosion by water in the tropics. Research Extension Series 024*. College of Tropical Agriculture and Human Resources, University of Hawaii.

Hewawasam, T. (2010). Effect of land use in the upper Mahaweli catchment area on erosion, landslides and siltation in hydropower reservoirs of Sri Lanka. Journal of the National Science Foundation of Sri Lanka, 38(1), 3-14.DOI: https://doi.org/10.4038/jnsfsr.v38i1.1721

Jackson, M.L. (1979). *Soil Chemical Analysis-Advanced Course*. 2nd Edition. Author's Publication. Pp 76-87. University of Wisconsin, Maidison, USA.

Kendaragama, K. M. A., Samaraweera, G. S. & Thenabadu, M. W. (1998). Salinity status of water resources in village tank farming system. *Proc. of the 54th Annual Session of the Sri Lanka Association for the Advancement* *of Science*. Part 1. 119.

Mandal, D., Chandrakala, M., Alam, N. M., Roy, T., & Mandal, U. (2021). Assessment of soil quality and productivity in different phases of soil erosion with the focus on land degradation neutrality in tropical humid region of India. *Catena, 204*, 105440. https://doi.org/10.1016/j.catena.2021.105440

Margenot, A. J., Sommer, R., & Parikh, S. J. (2018). Soil phosphatase activities across a liming gradient under long-term managements in Kenya. *Soil Science Society of America Journal, 82*(4), 850-861. https://doi.org/10.2136/sssaj2017.12.0420

Morris, L.A. (2004). Soil organic matter forms and functions in soil biology and tree growth. In J. Burley (Ed), *Encyclopedia of Forest Science* (pp. 1201 - 1207). https://doi.org/10.1016/B0-12-145160-7/00245-3

Nelson, D. W. & Sommer, L. E.(1996). Total Carbon, Organic Carbon, and Organic Matter. In D.L. Sparks, A.L. Page, P.A. Helmke, R.H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston, M. E. Sumner (Eds.), *Methods of Soil Analysis. Part 3. Chemical Methods* (pp. 961-1010). Soil Science of America and American Society of Agronomy, SSSA Book Series No.5. Madison-USA. https://doi.org/10.2136/sssabookser5.3.c34

Olsen, S. R. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (No. 939). US Department of Agriculture.

Panabokke, C. R. (1996). Soils and agro-ecological environments of Sri Lanka. *Natural Resources*, 35-101.

Pennock, D.J., D.W. Anderson, E. de Jong. (1994). Landscape-scale changes indicators of soil quality due to cultivation in Saskatchewan, Canada. *Geoderma, 64*(1-2), 1-19. https://doi.org/10.1016/0016-7061(94)90086-8

Poesen, J. (2018). Soil erosion in the Anthropocene: Research needs. *Earth surface processes and landforms, 43*(1), 64-84. https://doi.org/10.1002/esp.4250

Rajakaruna, R. M. P., Nandasena, K. A., & Jayakody, A. N. (2005). Plant nutrient contamination of shallow- Ground water in intensive vegetable gardens of Nuwaraeliya. *Tropical Agricultural Research, 17*, 80-92.

Wallbrink, P. J., & Murray, A. S. (1993). Use of fallout radionuclides as indicators of erosion processes. *Hydrological processes, 7*(3), 297-304. https://doi.org/10.1002/hyp.3360070307

Walling, D. E. and He, Q. 2001. Models for converting 137Cs measurements to estimates of soils redistribution rates on cultivated and uncultivated soils and estimating Cs-137 reference inventories (including software for model implementation). A contribution to the I A E A Coordinated Research. Program on soil érosion. (DA. 50 05) and sedimentation. (F3 10 01).

Walling, D. E., & Quine, T. (1990). Calibration of caesium-137 measurements to provide quantitative erosion rate data. *Land Degradation & Development, 2*(3), 161-175.