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VALIDATION OF ^{137}Cs TECHNIQUE IN SOIL EROSION AND SEDIMENTATION STUDIES

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Soil is the basic constituent required for the production of plants and livestock and this necessary component is mostly affected by erosion worldwide. This factor neglected by most of the developing countries because of the longer time and larger manpower needed to estimates the actual rates of erosion by conventional methods. An alternate, economic and less time-consuming method being applied in many developed countries is the use of fallout radionuclides (FRN) in estimating not only erosion but also re-distribution within the catchment. For this purpose, the reference site was established at Lokot area 33^{o}52’37”N, 73^{o}23’74”E at altitude 1477 m above the mean sea level near the newly constructed Murree Motorway having the total ^{137}Cs inventory 4910 Bq/m^2 with very smooth and well distributed profile along the depth. Mass Balance 1 and the Profile Distribution Model were applied to calculate the soil redistribution. The soil redistribution at fields in Pind Begwal, Islamabad area range from 116 to12.7 t/h/yr and at Savor village ranging from 127 to 24 t/h/yr. The permanently grassy patches in the same area have very low erosion (~ 2 t/h/yr). Five samples collected from the area along road construction site on main Murree Motorway have shown severe erosion of topsoil ranging from 176 to 0.7 t/h/yr. The samples collected from the deforested hill in the same area indicate the severe erosion of around 176 t/h/yr. In comparison to this location, the samples in the same area with forest/ permanent plant cover, value range from (erosion) 14 t/h/yr to deposition of 5.4 t/h/yr at different points. In general, the human induced activities are found to be the major source of erosion in this area.

Keywords: Soil erosion, ^{137}Cs, Gamma spectrometry

1. Introduction

Soil is the basic component required for the growth of crop and livestock. About 200 years are required to develop only 10 cm thin soil layer but this thin layer is mostly affected by soil erosion. Both natural and unnatural processes are involved in soil erosion. Natural processes involved the erosion by water and wind while the unnatural are due to process the human induced activities like deforestation, overgrazing, urbanization, industriali-zation, low organic matter, inappropriate tillage practices. Soil erosion include both onside and offside impact. Onside impact is reduction in agricultural efficiency because of creation of gully that leads to decrease of area, which is cultivable. Secondly continual removal of the surface soil by sheet and rill erosion leads to decrease of soil fertility and break down of the soil structure. The off side impact increase sediment loads in rivers, sedimentation of transportation system and reservoir, increase costs of water handling, impairment of industrial use, and sealing of irrigated soils [1]. Causes and factors of soil-erosion in the Potwar Area are due to tillage practices, horizontal expansion of agriculture, overgrazing / loss of vegetative cover, rainfall, soil type, land slope, soil wetness, etc. [2].

One of the major constraints in soil erosion estimation in tropical countries is that long term studies are required. High rainfall changeability in these areas makes difficult to quantify erosion. Also, as a result of economical and technical constraints, most erosion studies in the tropics are conducted at small scales (i.e., runoff plots) with results that are difficult to extrapolate to larger areas [3]. An approach that is sustainable, suitable to local environment, flexible, obvious, environmentally sound, economically feasible and inter-institutional and inter-ministerially incorporated is required for land and water board.

The investigation of ^{137}Cs redistribution within the landscape has been used as an alternate for assessing long-term soil erosion and net

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deposition at various spatial scales. The basis of the ^{137}Cs technique is defined as:

- Caesium-137 was deposited as fallout during the late 1950s and the 1960s from the nuclear weapons tests.
- It was rapidly and strongly adsorbed by soil particles at the ground surface after deposition through the precipitation from the environment.
- Subsequent redistribution of the radiocaesium reflects the movement of soil particles since ^{137}Cs remains adsorbed and moves in association with the soil particles.
- If it is assumed that the initial distribution of the ^{137}Cs fallout input was uniform, then deviations in the measured distribution of ^{137}Cs from the local fallout Inventory represents the net impact of soil redistribution during the period since ^{137}Cs deposition.
- If a relationship between ^{137}Cs loss and gain and soil loss and gain can be established, it will be possible to estimate rates of soil erosion and aggradations from ^{137}Cs measurements.

Caesium-137 present in the environment has two potential sources: first is due to atmospheric testing of thermonuclear weapons, during the period from the late 1950s to the 1970s, second source is released from the Chernobyl nuclear power plant because of the accident on; 26 April 1986 [1]. The basis of the ^{137}Cs technique is illustrated in Fig. 1.

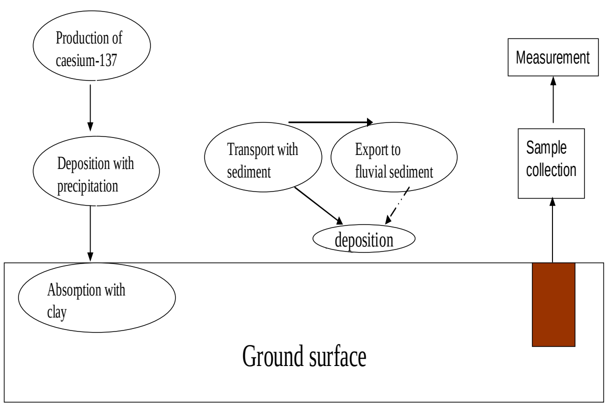

Figure 1. A schematic representation of the basis of ^{137}Cs technique.

2. Experimental Methods

2.1. Designing of fallout radionuclide (FRN) programme

The designing of fallout radionuclide sampling program have the following stages:

- To undertake a field reconnaissance survey.
- To establish reference inventory.
- To collect of soil samples from study area.
- To obtain additional information.

The main goal of the field reconnaissance is to select specific sites that can be used in the main sampling program. Reconnaissance survey was performed at eight different places to specify the reference inventory. Cesium-137 concentration is noted from each site. After comparing, the reference site were selected based on highest Caesium-137 inventory.

The selection of a suitable reference site is vital for the successful use of the FRN technique. It is essential because it is used to establish the ^{137}Cs inventory in the study region against which the changes inventory, both in disturbed sites and in depositional environments, can be evaluated. Therefore, the reference site should be located in or nearby to the study area, has not been disturbed or has experienced any erosion or deposition since 1953 and has maintained good vegetation cover.

2.2 Field study and sample collection

Twenty-seven samples of soil were collected from a site adjacent to the Murree Motorway Rawalpindi, Pakistan with the help of corer and scraper plate. Samples were collected at different locations including the cultivated, non-cultivated, sloppy and grassy land. Starting from the agricultural field, samples were taken from the Pind Beghwal area 33^{o} 39'12" N, 73^{o}12'11" E. It is an agricultural field having the well-defined boundaries. Second sampling was done at Savor Alipur, which is an agricultural field with no proper boundaries located near to the road. Third sampling was performed at the same location but opposite to the road in the cultivated land with no proper boundaries. Few samples were taken from the slope on grassy path located in Savour Alipur. At the slope, the samples were taken from top to the bottom. More grassy fields were sampled from

Village Khajot adjacent to the new Murree Motorway (33°39'12"N, 73°15'49"E). These samples were taken near the graveyard about 50m above the road. For bare land, samples were taken about 150m away from Village Khajut down to Murree Motorway. It is an area adjacent to the road. These three points make a curve grid. Along the slope, samples were taken at the site Lokot and first sample was taken near the graveyard at Jan Terrace. Second, was about 1½ km from the pervious one and have the flat area. Third point along the slope was 50 km down the previous.

2.3. Sample preparation and analysis

Each sample was taken in clean polyethylene bags and brought to the mineral processing laboratory of Pakistan Institute of Nuclear Science and Technology (PINSTECH). All samples were air and oven (100° C) dried, weighed, crushed and passed through 2 mm mesh sieve. The individual samples, in which each had a mass of about 500 g, were transferred into airtight plastic pots called "Marinelli beaker". Caesium-137 activity in the soil samples were undertaken using a high resolution, low background, low energy, hyper-pure n-type germanium coaxial gamma ray detector. The samples were counted for 10000s. Soil-6 was used as standard for the calibration of detector. The concentrations of ^{137}Cs were measured at 662 keV.

Two different models were applied on the ^{137}Cs inventory level and the soil redistribution rate calculation. Mass balance 1 and Profile distribution model were used in order to calculate the soil redistribution in this area. Mass balance model was used on the agricultural field while the profile distribution model was used on the non-cultivated land.

2.3.1. A simplified mass balance model (mass balance model 1)

A site with a total ^{137}Cs inventory *A* (Bq m^{-2}) less than the local reference inventory A_{ref} (Bq m^{-2}) is assumed to be an eroding site, while sites with inventories higher than the reference inventory are assumed to be depositional sites. In its original form, this simplified mass balance model did not take into account of particle size effects but a correction factor *P* has been included. *P* is a function of the ratio of the ^{137}Cs concentration of mobilised sediment to that of the original soil [4]. Because the grain size composition of mobilised sediment is usually enriched in fines compared with the original soil. For an eroding site (A (t) <A_{ref}), assuming a constant erosion rate R (mm^{-2} y^{-1}), the total ^{137}Cs inventory at year *t* (y) can be expressed as :

$$A(t) = A_{ref}\,(1 - P\frac{R}{d})^{t-1963} \quad (1)$$

The above equation can be rearranged to derive the erosion rates as follows :

$$Y = \frac{10\,dB}{P}\left[1 - \left(1 - \frac{X}{100}\right)^{1/(t-1963)}\right] \quad (2)$$

Where :

Y = mean annual soil loss (t ha^{-1} y^{-1}),

d = depth of plough or cultivation layer (m),

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

X= percentage reduction in total ^{137}Cs inventory (defined as $(A_{ref}-A)/A_{ref} \times 100$,

P = particle size correction factor.

2.3.2. Profile distribution model

For uncultivated soils, the depth distribution of ^{137}Cs in the soil profile is significantly different from that in cultivated soils where ^{137}Cs is mixed within the plough or cultivation layer. In many situations, the depth distribution of ^{137}Cs in an undisturbed stable soil exhibits an exponential decline with depth that may be described by the following function [5, 6]:

$$A'(x) = A_{ref}\,(1 - e^{-x/h_0}) \quad (3)$$

Where:

$A'(x)$ = amount of ^{137}Cs above the depth *x* (Bq m^{-2})

A_{ref} = ^{137}Cs reference inventory (Bq m^{-2}),

x = depth from soil surface (kg m^{-2}),

h_0 = coefficient describing profile shape (kg m^{-2}).

The larger the value of the shape factor h_0, the deeper the ^{137}Cs penetrates into the soil profile. If it is assumed that the total ^{137}Cs fallout occurred in 1963 and that the depth distribution of the ^{137}Cs in the soil profile is independent of time, the erosion rate Y for an eroding point (with total ^{137}Cs inventory A_u (Bq m^{-2}) less than the local reference inventory A_{ref} (Bq m^{-2})) can be expressed as:

$$Y = \frac{10}{(t-1963)P} \ln\left(1 - \frac{X}{100}\right) h_0 \quad (4)$$

Where:

Y = annual soil loss (t ha^{-1} r^{-1}),

t = year of sample collection (y),

X = percentage ^{137}Cs loss in total inventory in respect to the local ^{137}Cs reference value [defined as $(A_{ref}- A_u)/A_{ref}\times100$],

A_u = measured total ^{137}Cs inventory at the sampling point (Bq m^{-2}).

3. Results and Discussion

The Potwar region consists of hilly areas in North and North East with gentle slope agricultural and barren fields in the South West region of Pakistan. The upper Potwar region consists of small to medium hills that receive the annual rainfall of around 2000 mm. The area is rich with forest on hill slopes and large grassy patches. However, the current land use changes have resulted in deforestation and construction of civil structures in the area. This current trend of land use has accelerated the erosion of soil and organic matter from landscape and ultimately the increase of sediment load in channels, rivers and reservoirs.

The application of ^{137}Cs requires the establishment of a smooth and uniform distribution profile at an undisturbed soil within the study area. The reference inventory established at study site is located at Lokot area that lies at 33^0 52.37′ N and 73^0 23.74′ E with an altitude of 1477 m above sea level. Two other sites sampled for reference inventory were located in the same area but the results were not so significant. The total reference inventory established for the area is shown in Fig. 2 4910 Bq/m^2 from Lokot (Murree Motorway) by scraper and plate method.

The reference site is further confirmed by making the grid around the reference point and measure the activity at all grid points. Calculation shows that mostly all the grid points have activity closer to each other that match with the reference inventory as shown in Fig. 3.

The results of two other sites for establishment of reference inventory were 4133 and 3574 Bq/m^2 as shown in Fig. 4. However, the distribution of ^{137}Cs was not uniform with the depth from these locations and therefore, the reference site 1 was selected for all calculations.

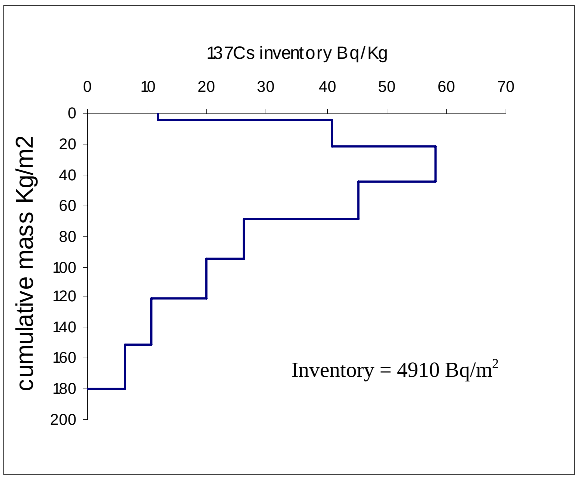

Figure 2 The ^{137}Cs depth distribution profile at reference site.

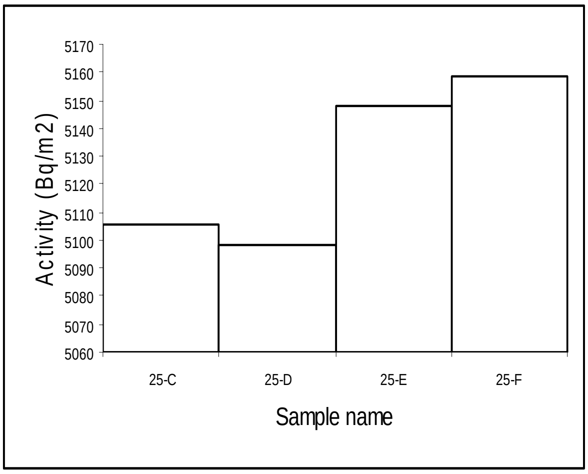

Figure 3. The ^{137}Cs inventory at grid points.

In order to estimate the soil redistribution in the study area, samples were collected from various slopes of hilly area, agricultural fields with different management practices, grasslands and areas under civil works. Two different models were applied depending on the land use. In case of a cultivated soil, the ^{137}Cs was well mixed within the plough depth, and uniformly distributed over the surface, while in undistributed soil, the ^{137}Cs is likely to be concentrated near the surface in response to its origin as atmospheric fallout. In this case, most of the ^{137}Cs is held within the top 10 cm layer. Loss of given amount of the ^{137}Cs inventory reflect a much higher erosion rate for a cultivated soil than for an undistributed soil, since in latter case, most of the ^{137}Cs will be concentrated near the surface. Equally the ^{137}Cs contents of eroded soil are likely to be much more variable in the case of undistributed soil, being dependent on the cumulative depth of erosion [7].

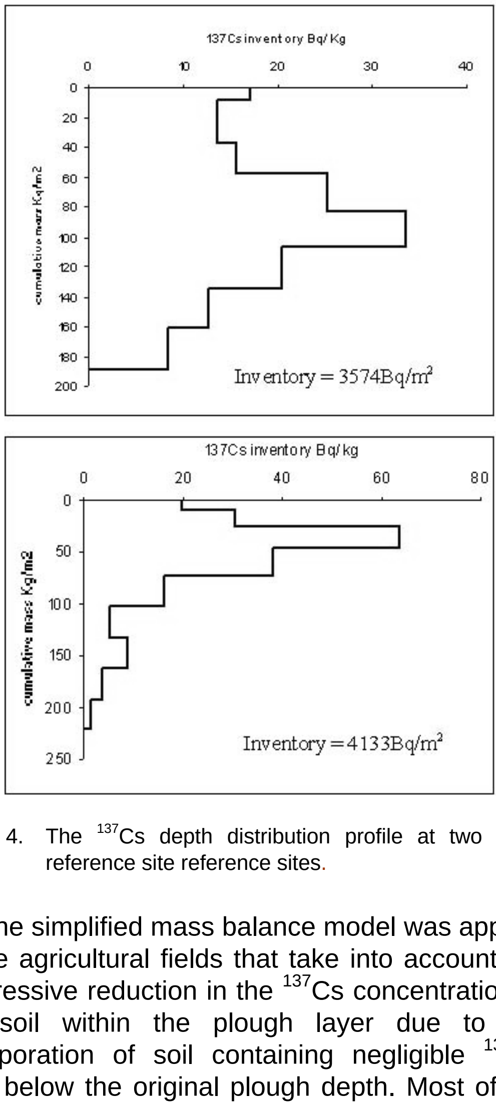

Figure 4. The ^{137}Cs depth distribution profile at two other reference site reference sites.

The simplified mass balance model was applied in the agricultural fields that take into account the progressive reduction in the ^{137}Cs concentration of the soil within the plough layer due to the incorporation of soil containing negligible ^{137}Cs from below the original plough depth. Most of the agricultural fields are located on the slopes and therefore show a significant loss of soil along the slope. However the fields with some proper field boundaries and gentle slope have shown a small loss of soil. The soil redistribution at fields in Pind Begwal area range from 116 to12.7 t/h/y with the most eroded point is in the middle of field with steep slope and lowest value at the bottom of field covered with the grass at the time of sampling. Lower values of ^{137}Cs are observed at top of the fields indicating gradual removal of top soil whereas highest ^{137}Cs inventories found at bottom shows that the greatest soil accumulation occurred at the bottom of the field [8]. The agricultural fields at Savor village are more eroded ranging from 127 to 24 t/h/y. These fields are located on large slopes with no proper boundaries. The permanently grassy patches in the same area have very low erosion (~ 2 t/h/y and deposition at some locations within the field. The results reveal that the current agricultural practices are not properly managed and the slopes along the fields are major sources of erosion of fertile soil as well as loss of organic matter from the top soil. The low erosion / some deposition values at the plain land or at the field boundaries in some fields indicate that proper management of the land can effectively decrease the soil loss from the fields.

The profile shape model is applied to the non agricultural fields / area. The samples were collected from various locations of the Murree hill area with different land use practices. Five samples collected from the area under road construction site have shown severe erosion of topsoil ranging from 176 to 0.7 t/h/y. The only point having very low erosion seems to be unaffected by this activity with grass on top.

The samples collected from the deforested hill in the same area indicate the severe erosion of around 176 t/h/y. Although the sampling points were looking very stable with some small grass, but due to forest cutting and no permanent plant cover, most of the topsoil has been vanished. In comparison to this location, the samples in the same area with forest/ permanent plant cover, value of redistribution range from (erosion) 14 t/h/y to deposition of 5.4 t/h/y at different points. These values indicate the effect of current land use changes in the area.

4. Conclusions

Caesium-137 measurement technique was applied to calculate the soil redistribution rates within a catchment of different land use practices.

The reference inventory established for the area reflects the total fallout of ^{137}Cs during the 1950's and 60's. Results from different agricultural fields reveal that there is no proper management of land and very high erosion is observed along the slopes. This affect is not only reduce the soil fertility but also a major source for the reservoirs and channels passing through the area. On the other hand, deforestation is the major source of soil loss from hill slopes in the upper Potwar. The civil activities like road construction, establishment of housing schemes and bulldozing of land for agricultural terraces in the area are the other major sources responsible for heavy load of sediment to the Rawal lake water reservoir. The rate of sedimentation can be reduced by taking proper management practices within the catchment. The ^{137}Cs reference inventory established from the area is very reasonable and smooth according to the literature. Since, no data is available for soil redistribution from the area by conventional methods, the results achieved are the baseline data for the future studies and can be used as a reference.

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