Leaflet No. 13/2018

The Republic of the Union of Myanmar

Ministry of Natural Resources and Environmental Conservation

Forest Department

Investigation on Erosion and Sedimentation Rate using Isotopic Technique in Kalaw Watershed, Inle Lake

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December, 2018

Contents

အင်းလေးကန်ဒေသ၊ ကလောရေဝေရေလဲဇရိယာ၌ မြေတိုက်စားမှုနှင့် နုန်းအနည်ကျမှုကို အိုင်ဆိုတုပ်များအသုံးပြု၍ လေ့လာခြင်း

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စာတမ်းအကျဉ်း

အင်းလေးကန်ဒေသ၊ ကလောရေဝေရေလဲဇရိယာအတွင်း၌ မြေဆီလွှာတိုက်စားမှုနှင့် နုန်းအနည်ကျမှုကို နျူကလီးယားနည်းပညာများဖြစ်သည့် Fallout Radio Nuclei (FRN) အသုံးပြု၍ လည်းကောင်း၊ တည်မြဲသော အိုင်ဆိုတုပ်ဒြပ်ပေါင်း Compound Specific Stable Isotopes (CSSI) အသုံးပြု၍လည်းကောင်း ဆောင်ရွက်ခဲ့ပါသည်။ ဆီစီယမ်အိုင် ဆိုတုပ် Caesium-137 (^{137}Cs) စမ်းသပ်ခြင်းအတွက် မြေနမူနာပေါင်း (၁၃၅) ခုကို Gamma Spectrometry စက်ကိုအသုံးပြု၍စမ်းသပ်ခဲ့ပြီး၊ တည်မြဲသော အိုင်ဆို တုပ် ဒြပ်ပေါင်း (CSSI) စမ်းသပ်ခြင်းအတွက် မြေနမူနာပေါင်း (၄၅) ခုကို Isotope Ratio Mass Spectrometry စက်ကိုအသုံးပြု၍ စမ်းသပ်ခဲ့ပါသည်။ ဆီစီယမ်အိုင်ဆိုတုပ်ကိုအသုံးပြု၍ မြေဆီလွှာတိုက်စားမှုကိုရှာဖွေရာတွင် ကလောရေဝေရေလဲဇရိယာအတွင်းနှစ်စဉ် တစ်ဧကတွင် ၂၆တန် နုန်းဖြင့် တိုက်စားမှုရှိခဲ့ပြီး၊ တည်မြဲသောအိုင်ဆိုတုပ်ဒြပ်ပေါင်း စမ်းသပ်ချက်အရ နုန်းအနည်ကျမှုများ၏၄၅%ခန့်သည် သစ်တောများပျက်စီးခြင်းကြောင့်ဖြစ်ကြောင်းတွေ့ရပါသည်။ Caesium-137 (^{137}Cs) ပါဝင်မှုစမ်းသပ်ခြင်းသည် မြေဆီလွှာတိုက်စားမှု မည်မျှရှိသည်ကို ဖော်ပြနိုင်ပြီး (CSSI) စမ်းသပ်ခြင်းသည် ၎င်းမြေဆီလွှာတိုက်စားမှုဖြစ်ရခြင်း အကြောင်းရင်းကို သိနိုင်ပါသည်။

Investigation on Erosion and Sedimentation Rate using Isotopic Technique in Kalaw Watershed, Inle Lake

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Abstract

Unsustainable agricultural practices and deforestation around the Inle watershed in Myanmar have accelerated not only the soil erosion and land degradation, but also the sediments delivery into the lake, leading to the deterioration of water quality. There is an urgent need to understand how land use and management changes affect on water quality and quantity, sedimentation rate and sediment transport processes, for sustainable integrated watershed management of Inle Lake. The Kalaw watershed, one of the major streams flowing into the Inle Lake was selected for this study because of the serious erosion and the major contribution of sediments to Inle Lake. Here, we used the fallout radionuclides (FRN) i.e. Caesium-137 (^{137}Cs) to assess soil erosion and sedimentation processes, and compound specific stable isotope (CSSI) technique to identify the origins of erosion by land use type. CSSI is based on the measurement of carbon-13 isotopes ($\delta^{13}C$) of specific organic compounds of plants in the soil. By linking carbon-13 fingerprints of land use to the sediment in deposition zones, this technique is useful in determining the sources of eroded soil and in identifying areas prone to soil degradation. Forty-five CSSI samples across the entire Kalaw watershed of 480 km^2 and 135 ^{137}Cs samples from the sloping land with different cultivation years (5, 15, 20, 30 and 40-50 years) were collected. The FRN samples were measured using Gamma Spectrometry, while the CSSI analysis was based on Isotope Ratio Mass Spectrometry. The results showed that soil loss rates increased with cultivation time converted from forests, at an increasing rate of 26 t $ha^{-1}yr^{-1}$. After 40-year cultivation, soil erosion rates reach 120 t $ha^{-1}yr^{-1}$. The results also showed significant soil losses occurred in the upper slopes and soil accumulation at lower locations. Preliminary CSSI results determining contribution of different land use types to sediment sources in Inle Lake showed that almost 45% of the total sediment contribution from Kalaw watershed came from degraded or bare land as a result of deforestation. Our results suggested that a combinative use of ^{137}Cs and CSSI techniques has great potential in quantitative assessment of the watershed management practices on budgets of sedimentation.

Keywords: Sedimentation, Erosion, FRN, CSSI, ^{137}Cs

Investigation on Erosion and Sedimentation Rate of Kalaw Watershed using Isotopic Technique

1. Introduction

Inle Lake, situated in Naung Shwe Township, Southern Shan State, is the second largest and the most important lake in Myanmar. The lake is a major tourist attraction, a provider of agricultural products, and a habitat for rich biodiversity and traditional culture. On account of floating garden practice, cottage industries, hotels and tourism industry, unsustainable fishing practices and increasing population pressure in and around the Inle Lake, the water quality of Inle Lake becomes worse than before. Unsustainable agriculture practices and deforestation in Inle watershed area accelerated not only the deterioration of water quality but also the sedimentation rate into Inle Lake, with a consequent shrinking of the open water surface. There is an urgent need to understand how land use and management changes affect sedimentation rate and sediment transport processes, for sustainable integrated watershed management of Inle Lake.

Although many watershed management, soil erosion and sedimentation research have done within Inle lake watershed area, nuclear technology has never been used for this case. Analysis of erosion and sedimentation processes can be done more precisely, effectively and timely by using nuclear technology, especially isotope based techniques. In this paper, isotope based technique and relevant nuclear technologies were used to assess the current erosion and sedimentation status of Inle Lake by the help of International Atomic Energy Agency (IAEA). This paper is an outcome of the project collaboration of IAEA and Forest Department, entitled "Monitoring and Assessment of Watershed Management Practices on Water Quality and Sedimentation Rate of Inle Lake".

The objectives of the study are to study the isotope based monitoring and assessment techniques on erosion and sedimentation rate, Human Resource Development on Isotopic techniques, to know the guidelines for improved watershed management and water quality monitoring, reporting and verification process, to understand the assessment of model validation.

2. Literature Review

2.1. Soil Erosion Studies

Soil erosion and associated sedimentation are natural processes caused by water, wind, and ice. Several men's activities such as deforestation, overgrazing, changes in land use and non-sustainable farming practices tend to accelerate soil erosion. Soil erosion and sedimentation cause not only on-site degradation of a non-renewable natural resources but also off-site problems such as downstream sediment deposition in fields, floodplains and streams. These problems and concern over the degradation of the landscape by erosion and their impacts on soil fertility and crop productivity in agricultural land, water pollution and sedimentation in lakes, reservoirs and flood plains are well documented (F. Zapata et. al. 2002).

Many empirical and theoretical mathematical equations/models have been developed to estimate soil erosion. The most widely used is the Universal Soil Loss Equation (USLE), which is powerful and practical tool for estimating sheet and rill erosion on the landscape for management planning. Conventional methods for measuring soil erosion are labour intensive and time consuming and data need to cover several decades to get a good representation of mean erosion rates. Furthermore, most conventional methods (except for geodetic method) do not provide information on the spatial distribution of erosion. Isotope tracers can help meet these deficiencies as some radionuclides and stable isotopes occurring in the environment can serve as environmental tracers and hence facilitate the investigation of these landscape processes.

2.2. Fallout Radionuclides (FRN) in Soil Erosion and Sedimentation Studies

In the investigation of erosion and sedimentation, the use of the particular group of environmental radionucliedes, namely fallout radio nuclides (FRNs), which include artificial radionuclides such as **^{137} Cs** originated from thermo-nuclide weapon tests in the 1950s-1960s, and geogenic radioisotopes such as **^{210} Pb** and also more recently cosmogenic radioisotopes such as **^{7} Be**. They have been used worldwide to obtained rates and patterns of soil erosion and deposition at several temporal and spatial scales.

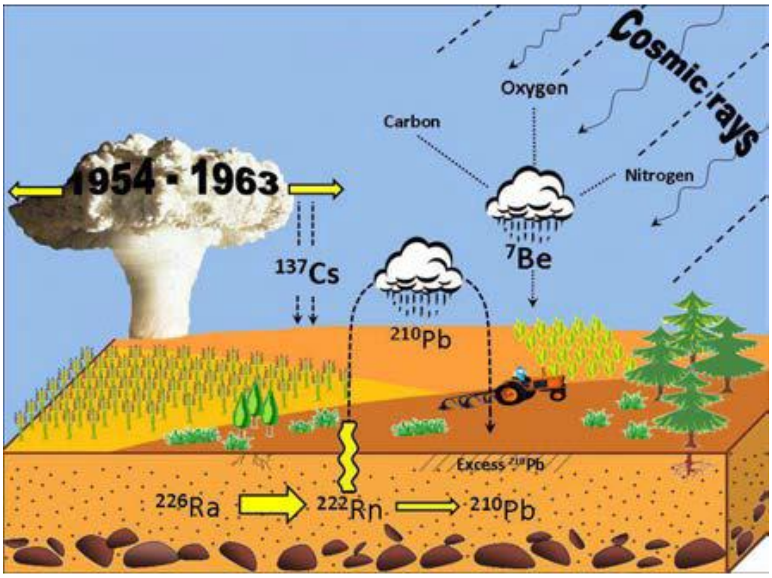

Figure 2.1. The origin of Fallout radionuclides (FRN)
source:IAEA-TOCDOC-1741

The main assumption for the use of these radiotracers in soil erosion and sedimentation investigations is similar. When deposited on the soil surface, they are strongly bound to soil colloid particles (clay and organic matter) and move in the environment by mechanical processes such as soil erosion (water, wind, or tillage erosion). To use FRN methods, it is necessary to establish the content of FRNs at a reference location (i.e., an undisturbed site where neither significant erosion nor deposition is occurring) located near the study area. Investigated areas are identified as erosion sites or deposition sites by comparing their FRN inventories with those of the reference site.

Among the soil erosion studies, the ^{137}Cs method for soil erosion assessment effectively provides long-term mean soil redistribution rates, representing the period since its release (mid-1950s) until the time of the 137Cs sampling. The basic principle of the ^{137}Cs method for soil erosion assessment is based on the chemical characteristics of Caesium-137. The ^{137}Cs is a human-induced environmental radionuclide, When ^{137}Cs gets into contact with soil material, it binds firmly to soil colloids and is often not transferred by processes such as leaching or plant uptake. It can move only together with soil particles and this means that any change in ^{137}Cs inventories indicate the occurrence of processes of soil redistribution by physical agents (soil erosion). As ^{137}Cs is non-exchangeable, it is not released into soil solution and cannot significantly migrate or take part in the chemical processes running in soil. (FAO/IAEA. 2017).

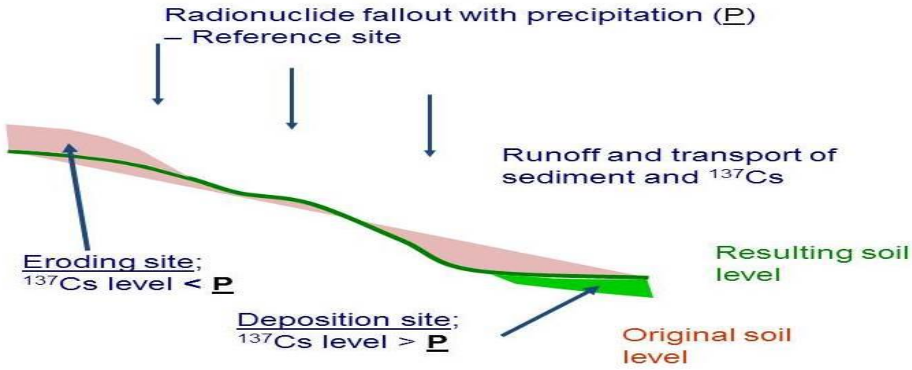

Fig.2.2. The concept of the use of fallout radionuclides ^{137}Cs

The ^{137}Cs inventories at study sites where soil redistribution is expected are compared to that of the stable reference sites. The landscape positions where the ^{137}Cs inventories are smaller than at the reference site are interpreted as eroded and those positions where they are greater are interpreted as deposition sinks. Those with similar ^{137}Cs contents are either stable or with a long-term balanced equilibrium of erosion and deposition.

To obtain such information a concept of **reference site** was introduced. According to D.J. Pennock (2002), a reference site is a stable undisturbed area where neither erosion, nor accumulation took place so it represents the initial ^{137}Cs fallout input (only reduced by radioactive decay). These stable locations are selected at flat surfaces where water runoff and associated soil erosion cannot originate. Most suitable are somewhat elevated landscape positions such as terraces or denudation plateaus. The lowest landscape positions such as alluvial plains are not suitable because they may be affected by deposition. At some alluvial plains the recent evidences of inundation may be lacking but it is not sure if and when it might occur in the past. Therefore if there is no other choice than to select the reference site at alluvial plain the reliable information on the history of flood is of highest importance.

^{137}Cs can be easily measured by gamma spectroscopy (at 662 keV energy). After determination of ^{137}Cs inventories, data processing and the interpretation must be carry out to calculate soil erosion rates using erosion modeling. The obtained data can be used for various purposes, such as characterizing the erosion over a range of environments or land uses; estimating the impact of land management and crop rotation on the soil erosion; and assessing the efficiency of particular soil conservation measures.

2.3. Compound Specific Stable Isotopes (CSSI) Techniques

CSSI is based on the measurement of Bulk stable isotope ($\delta^{13}C$) in soil was measured using Isotope Ratio Mass Spectrometry (IRMS). CSSI is based on the measurement of carbon 13 isotopes of specific organic compounds of plant in the soils. Carbon 13 is unique for each for each compound, fingerprints of land use to sediment in deposition zones. This techniques is useful in determining the sources of eroded soil and in identifying areas prone to soil degradation.

Flora and fauna (including microbiological) in a particular habitat produce substantial amounts of organic compounds that can be stabilized to some extend in soil. Consequently, some of these organic compounds can be used as biomarkers to check for the presence of particular flora and fauna in a habitat (e.g., Liang et al. 2008). One group of organic compounds often used as biomarkers are the straight-chain fatty acids (FA), especially those with a carbon chain-length from 14 to 24. Fatty acid methyl ester (FAME) analysis of a soil can provide a "fingerprint" characteristic of that soil based on a concentration profile of the FA present. Depending on the plant species, these biomarkers have a different stable isotopic signature, making them suitable for discriminating and apportioning the sources of soil contribution that originate from different land uses (Gibbs, 2008; Reiffarth, Petticrew, Owens, & Lobb, 2016; Upadhayay et al., 2017).

The key factors making this possible were: 1) the CSSI values were stable when bound to soil particles and could survive hundreds of years unchanged; 2) the CSSI values were characteristic of specific flora and fauna growing on the soil; and 3) land-use is typically defined by the flora and fauna on the land. Conceptually, the CSSI values from the eroded soil represent the isotopic signatures of the soils contributing to the eroded soil mixture. By having a set of reference soils or "library" of CSSI values from known land-use soils from the same watershed, the proportion of each source soil contributing to the eroded soil mixture could be estimated using a mixing model.

Stable isotopes are not radioactive and therefore do not decay over time. A stable isotope is an element with one or more additional neutrons in the core of each atom giving it additional mass. Both the element and the heavier isotope of the element are stable isotopes. In order to distinguish between the stable isotopes of an element, the mass number is included as a super-script before the element symbol. For example, the element carbon (C) has 2 stable isotopes, the most common or abundant isotope (98.89% of all C) has a mass of 12, is written as ^{12}C, and is referred to as the light isotope. The heavier isotope of carbon (1.11% of all C) has one extra neutron giving it a mass of 13, is written as ^{13}C, and is referred to as the heavy isotope. These proportional concentrations are the "natural abundance" of the carbon isotopes.

The heavy isotope, ^{13}C has the same chemical properties as the light isotope, ^{12}C. Because of the extra neutron, the 13C atoms are larger than the 12C atoms causing the rate of reaction to be slower than ^{12}C. This difference allows ^{12}C to pass through a cell wall faster than ^{13}C. This results in slightly more ^{13}C remaining on the starting side and slightly more 12C reaching the other. This discrimination process is called **isotopic fractionation**.

The difference in ^{12}C and ^{13}C concentrations due to fractionation through one cell wall is small at around 1 part per 1000 (‰), commonly called 1 per mil, which is written 1 ‰. In biological processes, the 1 ‰ step per transfer through a cell wall is essentially constant and is referred to as a trophic step. The difference is expressed in delta notation (δ) and the δ value is calculated using the equation:

$$\delta^{13}C = [\ (R_{sample} / R_{standard}) - 1\ ] \times 1000 ‰ \text{ (per mil)}$$

where R is the molar ratio of the heavy to light isotope i.e., $^{13}C/^{12}C$. The international reference standard for carbon was a limestone, Pee Dee Belemnite (PDB), which had a δ13C value of 0 ‰. Instruments commonly used to measure these $^{13}C/^{12}C$ ratios are Isotope Ratio Mass Spectrometers (IRMS) which produce the results in delta notation (δ).

.CSSI-based techniques provide information on sources and can provide quantitative information as well as an additional dimension to generic source information that is more relevant to land use management decision making. However, this technique is still in its infancy with only a few published applied studies using specifically $\delta^{13}C$ of FAs to explore sediment transfer and origin within agro-ecosystems. Several aspects are still under investigation such as the best proxy or parameter to be used to convert isotopic signature into soil proportion. The CSSI technique is ideal for identification of “Hot Spot” of the land degradation. It is a qualitative tool indentifying the source of eroded soil but not how much erosion. FRN techniques can provide the erosion rate data. In combination the CSSI and FRN techniques provide valuable tools for land conservation management.

3. Materials and Method

3.1. Study area

The Kalaw watershed, one of the major streams flowing into the Inle Lake was selected for this study because of the serious erosion and the major contribution of sediments to Inle Lake. The selection was done after discussion with Staff Officer of Shwe Nyaung Township, Forest Department about the condition of erosion around the Inle Lake, observing in the Inle Lake which is the most happen area of the erosion and sedimentation, observing the gully erosion along the road side and *Thayet-Pu* Village.

Site selection for erosion and sedimentation were selected along the Kalaw Stream. Soil Samples for sedimentation study were collected from *Mwe-daw* Village, *Mye-gya* Village, *Ngo*t Village and Ngot Stream which is situated in the along the *Kalaw* Stream, *Nat-daw* Village, *In-wun* Village, *Nan-on* Village and along the Kalaw- Taunggyi Road side. The study areas were in the same slope position (14%).

3.2. Sample Collection

Soil sample collection for erosion study was conducted near *Thayet-pu* village and *Kan-dan* Village in the Kalaw- Taunggyi Road side. There are 5 Erosion sites such as 5 year, 15 year, 20 year, 30 year and 40-50 years old Potato Field and Pine Forest (slope) and Pine Forest (flat) for Reference site. Soil samples from nine sources were collected from Mix forest, Pine Forest, Shrub Land, Bank, Cart Lane, Potato Field, Groundnut Field, Mix Agricultural Field, Maze Field for CSSI study.

All soil samples were collected at different land use types with different slope portions (upper, middle and lower) and three different soil depths such as at 0- 10 cm, 10 - 20 cm and 20 - 30 cm depths of in each plot of the study area. An augur (steel core) was used for digging soil samples. Totally, Forty-five CSSI samples across the entire Kalaw watershed of 480 km^2 and 135 FRN samples from the sloping land with different cultivation years (5, 15, 20, 30 and 40-50 years) were collected.

3.3. Sample Preparing in Laboratory

All collected samples were air-dried, ground and passed through 2 mm sieve to separate stones, roots, and large organic residues at Soil Laboratory of the Forest Research Institute. The air-dried soil samples were weighed, packed and sent to Institute of Environment and Sustainable Development in Agriculture (IESDA), Chinese Academy of Agricultural Sciences (CAAS), Beijing, China to analyse the ^{137}Cs content using Gamma Spectrometry. For CSSI technique, a sequence of processes: Planning, Sampling, Processing, and Analysis were carried according to Max Gibbs (2013) at IESDA-CAAS.

The ^{137}Cs samples were measured using Gamma Spectrometry and the ^{13}C/^{12}C ratios were measured Isotope Ratio Mass Spectrometers (IRMS) which produce the results in delta notation (δ).

3.4. Data Analysis

3.4.1. Convert from Specific activity to areal activity

The proportional model is probably the simplest of the conversion models used for ^{137}Cs measurements. It is based on the premise that ^{137}Cs fallout inputs are completely mixed within the plough or cultivation layer and the simple assumption that the depth of soil removed by erosion is directly proportional to the fraction of the original ^{137}Cs inventory removed from the soil profile by erosion since the beginning of ^{137}Cs fallout or the onset of cultivation, whichever is later.

Radionuclide measurement using HPGe Gama Spectrometry provides the specific activity of ^{137} Cs and the activity unit or rate of nuclear transformation of radionuclide expressed as Becquerel per kilogram (Bq kg^{-1}). Specific activity is transferred into area per activity for the sample according to the equation-

Areal activity (Bq m$^{-2)}$ = Specific activity (Bq kg^{-1}) x Total sample mass< 2mm (kg)

According to the proportional model, an erosion rate in units of mass per unit time (i.e. t ha^{-1} year^{-1},) was calculated using the following equation and analysis was done using AddIn software.

$$Y = 10\frac{B\,d\,X}{100\,T\,P}$$

where:

Y is the mean annual soil loss (t ha^{-1} a^{-1});
d is the depth of plough or cultivation layer (m);
B is the bulk density of soil (kg m^{-3});
X is the percentage reduction in total ^{137}Cs inventory (defined as (A_{ref}-A)/A_{ref}×100);
A_{ref} is the local ^{137}Cs reference inventory (Bq m^{-2});
A is the measured total ^{137}Cs inventory at the sampling point (Bq m^{-2});
T is the time elapsed since the initiation of ^{137}Cs accumulation or the commencement of cultivation whichever is later (a);
P is the particle size correction factor for erosion.

3.4.2. Convert isotopic proportions to soil proportions

The outputs from the mixing model are isotopic proportions not soil proportions (Gibbs 2008). As the isotopic biomarkers are a small fraction of the total organic carbon in the soil and the total organic carbon is typically less than 10% of the whole soil, the isotopic proportions must be converted to soil proportions. That is, if the source soils were mixed together in the corrected soil proportions, the resultant mixture would have the same isotopic signatures as found in the sediment mixture. This conversion uses a linear correction equation based on the carbon content of each source soil:

$$\%source_n = \frac{I_n / \%C_n}{\sum_n^1 (I_n / \%C_n)} x100$$

where *In* is the mean feasible proportion of source n in the mixture as estimated from isotopic values of carbon by the mixing model, and %Cn is the % carbon in the source n soil.

4. Results and Discussion

4.1. Caesium 137- (^{137}Cs) Determination

The fallout radionuclide, Caesium-137 (137Cs) was used to assess soil erosion and sedimentation processes. In table 4.1., ^{137}Cs inventories (Bq m^{-2}), Soil erosion rate (t/ha/yr), and Mean (t/ha/yr) were showed with cultivation time (year) and Slope position in specific location. ^{137}Cs inventories representing the total ^{137}Cs activity per area unit at the sampling points, and ^{137}Cs depth distribution along the vertical soil profiles (activity in Bq kg^{-1} per selected depth intervals in cm). The inventories are calculated from the ^{137}Cs mass activity.

Table 4.1. Changes in soil erosion rates due to deforestation/forest conversion to farmland within Kalaw Watershed, Inle Lake

Particular	Cultivation time (year)	Slope position	Cs-137 (Bq/m2)	Soil erosion rate (t/ha/yr)	Mean (t/ha/yr)
Thayet Pu Village	5	Upper	60.30	-21.76	-49.06
	5	Middle	1.00	-167.75	
	5	Lower	277.34	42.33	
Kandan Village	15	Upper	1.00	-167.75	-102.55
	15	Middle	1.00	-167.75	
	15	Lower	158.85	27.85	
	16	Upper	1.00	-167.75	-114.11
	16	Middle	1.00	-167.75	
	16	Lower	103.13	-6.83	
	20	Upper	1.00	-167.75	-124.80
	20	Middle	1.00	-167.75	
	20	Lower	33.94	-38.9	
	30	Upper	1.00	-167.75	-30.56
	30	Middle	48.82	-27.91	
	30	Lower	232.75	103.99	
	40	Upper	1.00	-167.75	-119.60
	40	Middle	1.00	-167.75	
	40	Lower	57.18	-23.29	
Natural Forest	-	Upper	1.00	-167.75	13.40
Natural Forest	-	Middle	169.97	38.7	
Natural Forest	-	Lower	293.36	169.24	
Reference site	-		133.40		

In this table, negative values indicate soil loss by water erosion while the positive value suggests soil accumulation due to water erosion in the landscapes.

The results showed that soil loss rates increased with cultivation time converted from forests, at an increasing rate of 26 t $ha^{-1}yr^{-1}$. After 40-year cultivation, soil erosion rates reach 120 t $ha^{-1}yr^{-1}$. The results suggested that significant soil losses at the upper slope location but soil accumulation at the lower locations of the slopes. Deforestation has resulted in tremendous soil erosion within the Inle Lake Watershed over the last 40 years.

Table 4.2. Changes in soil erosion rates due to deforestation/forest conversion to farmland within the Kalaw Watershed derived from ^{137}Cs measurements

Cultivation time (yr)	Soil Erosion rate (t/ha/yr)
Reference	**13.00**
5	-49
15	-103
16	-114
20	-125
40	-120

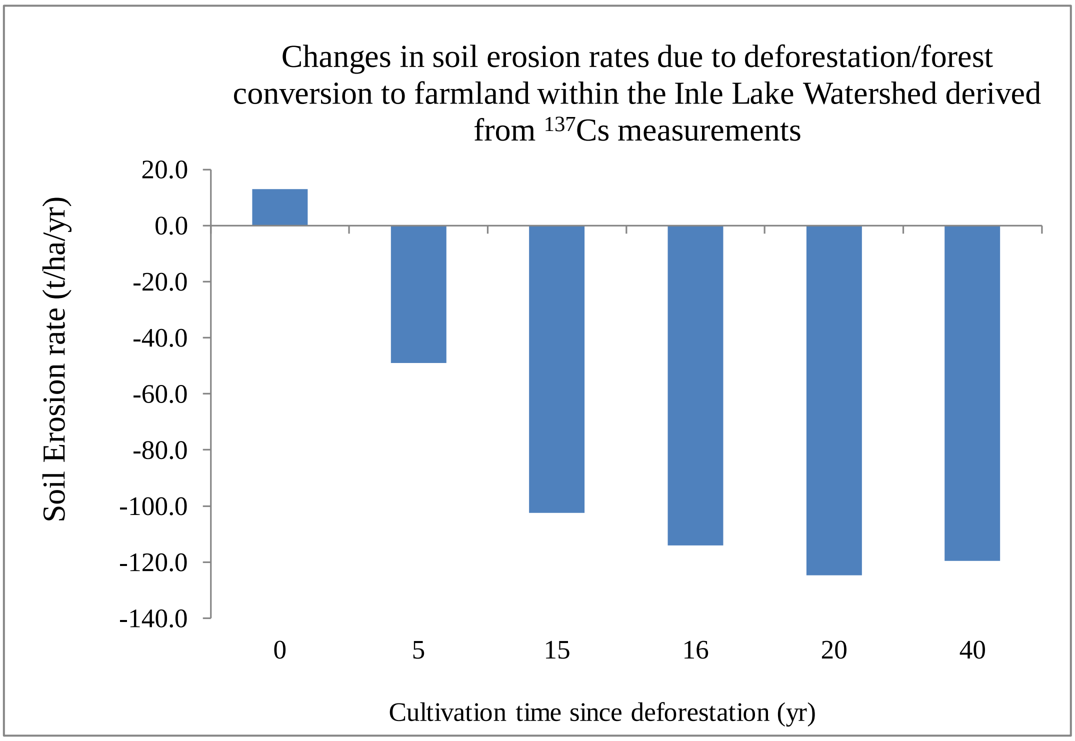

Fig.1. Changes in soil erosion rates due to deforestation/forest conversion to farmland within the Inle Lake Watershed derived from ^{137}Cs measurements

4.2. Compound Specific Stable Isotope (CSSI) Determination

CSSI technique to identify the origins of erosion by land use type. CSSI is based on the measurement of carbon-13 isotopes of specific organic compounds of plants in the soil. As the makeup of carbon-13 is unique for each compound, measuring its carbon-13 signature can reveal the origin of the eroded soil. By linking carbon-13 fingerprints of land use to the sediment in deposition zones, this technique is useful in determining the sources of eroded soil and in identifying areas prone to soil degradation.

According to the determination of carbon-13 measurement, it shown that the soil samples from degraded land and bare land found to be the same carbon-13 value ($\delta^{13}C$) and were grouped as degraded land. The soil samples from agricultural land, 3 years fellow land and plough land have the same $\delta^{13}C$ values and were noted as cultivated land. That of samples from village road, roadside were the same and grouped as road, and samples having the same δ13C values, from stream bank, hill bank, bank growing groundnut, gully wall were grouped as bank.. Similarly, the samples from farmland growing potato, maize, groundnut, bean, sunflower, has nearly the same $\delta^{13}C$ values and were noted as Vegetable land. The soil sample from 80% shrub cover land has different $\delta^{13}C$ values from all the tested land types. The $\delta^{13}C$ values from the samples of closed forest, pine forest was denoted as forest land.

The $\delta^{13}C$ values of the different land use type were shown in Table 4.3. In this table, $\delta^{13}C$ values and soil organic carbon (SOC) values were computed from the results of IRMS measurement. Then, Iso-source Model were used to know how much contribution to the sediment mixture of the watershed. According to Table 4.3, it can be found that the $\delta^{13}C$ value of natural forest was -24.47%, that of vegetable was -23.22%, Fellow land -21.25% $\delta^{13}C$, Degraded land has -18.04% $\delta^{13}C$, Shrub land has -16.76%, Bank has -16.35% $\delta^{13}C$ and Road has -10.12% $\delta^{13}C$ respectively.

It was also founded that, the sediment from degraded or bare land has the highest contribution to the Kalaw watershed about 43.8%. The fellow land has the least contribution to the watershed. The shrub land with 80% cover and natural forest contributed about 5.7% and 8.9% respectively. The composition of these land use type in Kalaw watershed has to be taken into account.

Table 4.3. Changes in soil erosion rates due to deforestation/forest conversion to farmland within the Kalaw Watershed derived from ^{137}Cs measurements

Land use or Vegetation type	Results from IRMS		Model out put	Calculation	
	$\delta^{13}C$ (%)	SOC (%)	Iso-Mix (%)	Iso-Mix/SOC	Contribution (%)
	-18.18	1.46			
Degraded/ bare land	-18.04	5.93	24	16.10	43.8
Fallow land	-21.25	3.06	5	0.86	2.3
Road	-10.12	2.52	14	4.42	12.0
Bank	-16.35	3.34	13	5.00	13.6
Vegetable land	-23.22	3.26	17	5.03	13.7
Shrub with 80% cover	-16.76	6.62	7	2.11	5.7
Natural Forest	-24.47	2.84	22	3.28	8.9

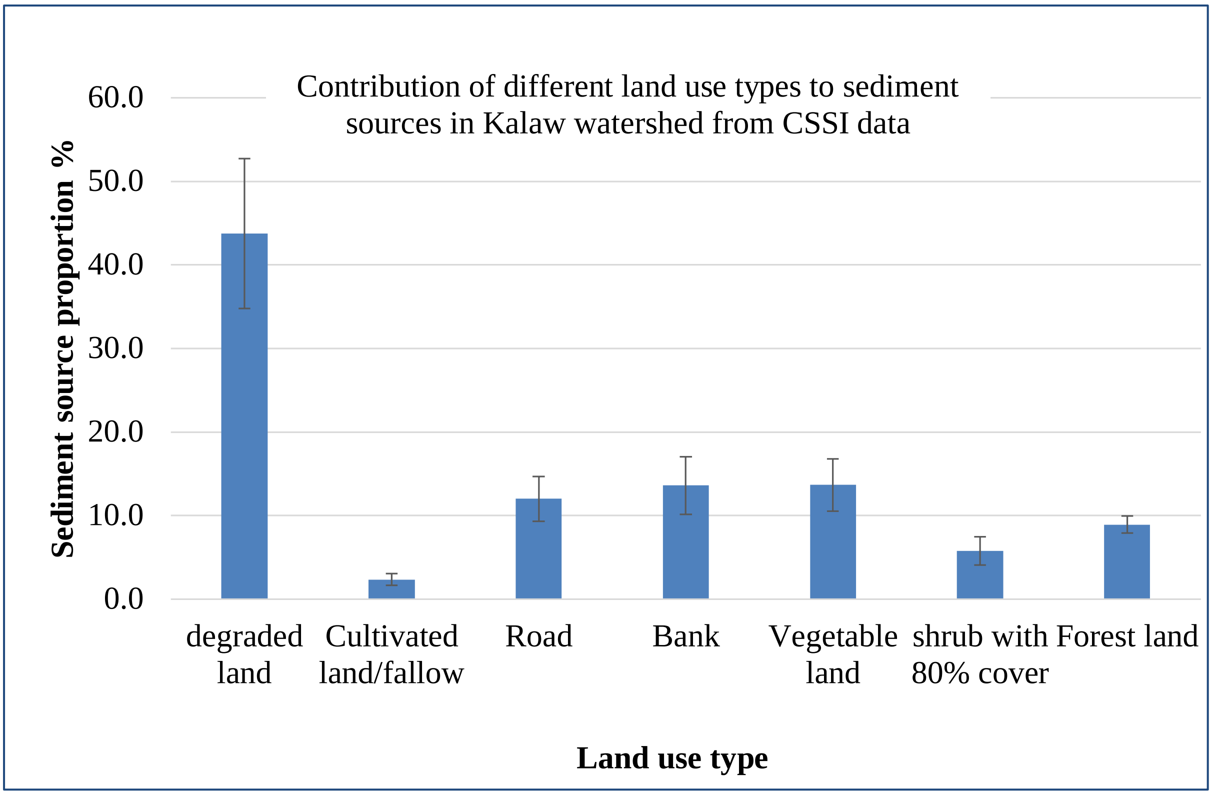

Fig.4.2. Contribution of different land use types to sediment sources in Kalaw watershed from CSSI data

4.3. General Discussion

Regarding the erosion and sedimentation of Inle lake, there are a lot of research works have been done. In 2005, Furuichi et. al studied for the whole Lake Inle catchment they reported that total inputs were approximately 277,000 t/yr, total storage in the sinks was about 263,000 t/yr, and output at the outlet was about 14,000 t/yr, indicating that 95% of sediment was stored in the sinks. Contributions from topsoil and subsoil were 69% and 31%, respectively. The deltas stored the largest amount of sediment among the sinks (about 62%), followed by marshes (about 20%). Although relative storage in river mouths accounted for only 12%, the highest specific storage was found in river mouths. Deposition in the lake was estimated to be about 1,500 t/yr (1%), and outflow from the lake was approximately 5%.

Spatial variability of sedimentation rates is evident, with the highest rates of mass accumulation in the river mouth and delta areas (4.3 to 21.9 kg/m^2/yr), reducing to about 0.01 kg/m^2/yr in the centre area of the lake. Temporal changes showed higher sedimentation rates over the last 50 years compared to those in the previous period. Based on projections of sedimentation rates Furuichi concludes that the marsh would be infilled in 120 years, and the lake would disappear in approximately 700 to 2200 years, depending on the mass accumulation rates used.

In 2011, Furuichi et. al (2011) studied the placing sediment budgets in the whole Inle Lake, Results of the sediment sourcing analysis using tracers showed topsoil was the dominant source of fine sediments in the rivers in the Nanlet sub-catchment, indicating surface erosion is the dominant mechanism of soil erosion in this sub-catchment. In the

Negya sub-catchment, the governing mechanism of soil erosion seems to vary spatially. This spatial contrast probably depends on geological difference in the areas; the Shan Dolomite Group occurs in the areas where gullies are most developed. Dominant source of fine sediments leaving this sub-catchment is consistently subsoil. In the Kalaw and Upper Balu sub-catchments, topsoil is generally the major source of river fine sediments in the upper as well as the middle reaches, whereas subsoil provides the majority of the fine sediments in the downstream reaches. However, nobody finds out the erosion hot spot, which comes from. This paper is the preliminary study for that purpose.

5. Conclusion

According to the results, soil loss rates increased with cultivation time converted from forests, at an increasing rate of 26 t $ha^{-1}yr^{-1}$. After 40-year cultivation, soil erosion rates reach 120 t $ha^{-1}yr^{-1}$. The results also showed significant soil losses occurred in the upper slopes and soil accumulation at lower locations. Preliminary CSSI results determining contribution of different land use types to sediment sources in Inle Lake showed that almost 45% of the total sediment contribution from Kalaw watershed came from degraded or bare land as a result of deforestation.

Preliminary CSSI results determining contribution of different land use types to sediment sources in Inle Lake showed that almost 45% of the total sediment contribution from Kalaw watershed came from degraded or bare land as a result of deforestation.

The results from the present research were suggested that a combinative use of ^{137}Cs and CSSI techniques has great potential in quantitative assessment of the watershed management practices on budgets of sedimentation.

FRN tells how much sediment yields produced and CSSI tell us where it comes from. Combining FRN and CSSI is an effective approach to link the upland soil erosion by land use changes and sedimentation in water bodies.

6. Acknowledgments

The authors acknowledge to the IAEA for giving funding for the TC Project MYA/5/025, "Monitoring and Assessment of Watershed Management Practices on Water Quality and Sedimentation Rate of Inle Lake". Under this project, we had many chance to study the isotopic techniques in the field of not only erosion and sedimentation study but also soil and water management and crop nutrition study. We deeply thank to Dr. Nyi Nyi Kyaw, Director General, Forest Department for permission to participate in this project. Our special thank to Assistant Director, U Htay Lwin (at that time Township officer of Nyaung Shwe Township) and Assistant Director, U Aung San (former Township officer of Kalaw Township) for their kind help in the site selection for this research. We would like to thank Sayar U Sein Thet (Chairman, FREDA) for giving valuable suggestion for this research. Finally, our special thank to Dr. Thaung Naing Oo, Director of Forest Research Institute for allowing us to submit this research to the congress.

Term of Reference

Soil	Loose upper layer of earth in which plants grow.
Land use	Classification of soil by the variety of plants and animals growing on it.
Landuse practice	How the land use is managed.
Landscape	Expanse of land visible from any viewing point.
Catchment	Expanse of land from which all surface water drains into the same waterway
Erosion	Loss of soil from its original location caused by water or wind.
Soil degradation	Loss of soil fertility through poor landuse practice or erosion.
Sediment	Soil suspended in or deposited from water at a location.
River delta	Deposition zone at the mouth of a river entering a larger water body.
Source	Reference soil from a well-defined land use.
Mixture	Sample of sediment from a downstream location in the catchment.
Aliquot	Small portion of the main sample.
Biomarker	Naturally occurring organic compound (e.g. fatty acid) found in the sample.
%C	Percentage of organic carbon in the sample after acidification.
Acidification	Removal of inorganic carbon (carbonate) by reaction with hydrochloric acid.
Stable isotope	Naturally occurring, non-radioactive isotope of carbon (13C).
Bulk δ13C	The isotopic value of the organic 13C content in the whole sample.
Derivatisation	The conversion of a fatty acid to its methyl ester by adding a methyl group in place of the acid group. Also called methylation.
FAME	Fatty Acid Methyl Ester produced by derivatisation.
Freeze dry	The sample is frozen at -20oC before being placed in a high vacuum, which causes the ice to sublime to water vapour. The water vapour is removed by the vacuum leaving the sample dry.

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