Spatial distribution of ^{137}Cs in surface soil under different land uses in Chao Phraya watershed: Potential used as sediment source tracing

**K Srisuksawad[1,3], B porntepkasemsan[1], N Noipow[1], A Omanee[1],
W Wiriyakitnateekul[2], R Chouybudha[2], P Srimawong[2]**
[1] Thailand Institute of Nuclear Technology, Nakhon Nayok, Thailand 26120
[2] Land Development Department, Bangkok, Thailand 10900

E-mail: kanitha.srisuksawat@gmail.com

Abstract. Sediment fingerprinting techniques involves the discrimination of sediment sources based on differences in source material properties and quantification of the relative contributions from these sources to sediment delivered downstream to the river catchments. Results of the previous study indicated that fallout radionuclides (FRNs); ^{137}Cs and excess ^{210}Pb (^{210}Pb$_{ex}$) are the most suitable radionuclides to be used as sediments sources tracers. This study investigated the spatial distribution of ^{137}Cs in soil under different land uses in Chao Phraya watershed; the most significant watershed in Thailand. Emphasis was placed on discriminating among potential sediment sources including the cultivated (upland crops), pasture field, uncultivated (swamp, forest, and grass field), and channel erosion (stream and river bank). One hundred and twenty four soil samples were collected from all sources and determining for ^{137}Cs. The ^{137}Cs mass activities in pasture areas varied from the limit of detection (LLD) to 1.22±0.05 with the average of 0.64±0.14 Bq kg^{-1}. In cultivated areas the ^{137}Cs mass activities varied from LLD to 1.41±0.04 with the average of 0.38±0.04 Bq kg^{-1}.The ^{137}Cs mass activities were higher in uncultivated areas varied from 0.12±0.03 to 1.73±0.05 with the average of 0.76±0.15 Bq kg^{-1}. The ^{137}Cs mass activities in channel bank varied from LLD to 1.16±0.04 with the average of 0.39±0.05 Bq kg^{-1}.GIS and geospatial interpolations revealed pattern in the spatial concentrations of ^{137}Cs and indicated important differences in its distributions showing the differences behaviour of ^{137}Cs in different land uses.

1. Introduction

Information on sediment source or provenance is difficult to obtain using conventional monitoring techniques, but in most environments it can be provided by sediment source fingerprinting techniques. The sediment source fingerprinting techniques involve the discrimination of sediment sources based on differences in source material properties and quantification of the relative contributions from these sources to sediment delivered downstream to the river catchments [1]. The fingerprinting procedures either employs statistical testing of a range of source material tracer properties to select a subset that discriminate sources [2] or the other approaches based exclusively on selected properties such as fallout radionuclides [3,4] or mineral magnetic measurements [5,6]. The key difference between these early approaches was the priori selection of specific tracers properties based on well established source

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[3]   To whom any correspondence should be addressed.

differences, in contrast to multi-parameter source fingerprinting which relies on statistical selection of subset of properties to discriminate sources. Currently, there are many reports on the successful use of environmental radionuclides in tracing sediment sources for many different environment and locations around the world [4, 7-18].The potential for using environmental radionuclides for sediment source tracing has been recognized particularly a group of environmental radionuclides that reach the land surface from the atmosphere, namely, fallout radionuclides (FRNs) . The FRNs most widely used are ^{137}Cs and excess [210]Pb (^{210}Pb$_{ex}$) [4, 7, 8, 10-19].

Caesium-137 (half-life 30.17 yr) is produced during nuclear fission. It worldwide presents in the environment during the period from 1952 to the mid 1980s. During the nuclear weapon tests, ^{137}Cs was injected into the stratosphere where it circulated globally [20, 21]. Caesium-137 moved back to the troposphere with deposition on earth thus being strongly related to local precipitation patterns and rates [22]. Caesium-137 down to earth was strongly and rapidly adsorbed to cation exchange sites on clay and organic soil particles, subsequently showing limited mobility by chemical processes and being essentially non-exchangeable [23]. These are making the ^{137}Cs the valuable fingerprints for distinguishing surface and subsurface sediment sources and surface sources influenced by mixing and disturbance.

In this study we investigated the spatial distribution of ^{137}Cs in soil under different land uses in Chao Phraya watershed. The objective was to study the differences in the ^{137}Cs activity concentrations among potential sediment sources in order to use it as sediment sources tracing in the catchment. Emphasis was placed on discriminating among potential sediment sources included the cultivated (upland crops), pasture field, uncultivated (swamp, forest, and grass field), and channel erosion (stream and river bank). Geostatistics and Geographical Information Systems (GIS) techniques were applied together for mapping of the ^{137}Cs spatial distribution in surface soil.

2. Study area

Chao Phraya watershed occupies the area of 20,523 km^2 and covers 16 provinces in Central Thailand. It is the most important watershed in Thailand. Seventy percent of its catchment is the agricultural land comprising of 55% rice, 18% upland crops (maize, cassava and sugarcane), and 23% fruit trees and vegetables. Chao Phraya watershed encounters flooding in rainy season every year. In 2011 the watershed experienced the severe flooding which affected millions of farmland and area wide. Runoff from upland agricultural catchments to lowland flood plain has damaged 2.01 M ha of farmland including 1.5 M ha rice fields, 0.3 M ha upland crops and 0.12 M ha fruit trees. Soil under flooding has lost their water holding capacity and aggregate stability made them sensitive to soil erosion. Determination of the extent and severity of soil erosion in agricultural landscape is required to provide information on erosion, sedimentation and associated loss of nutrients resulting from flood events. In addition identification and apportion hot spots of land degradation are crucial information to be used in land inventory data highlighting main land management factors that may contribute to soil instability and erosion during an heavy rainfall events.This information is valuable in targeting appropriate soil and water conservation practices or strategies where they are the best deployed to the flood preparedness. With the well flooded preparedness, the severity of the flood impacts should be reduced.

Two small sub catchment with differences in their geologic origin and one flat plain were selected for this study : Khlong Dong sub catchment (15º35$'$3.23$''$-16º5$'$10.57$''$N , 99º35$'$3.19$''$-100º5$'$6.65$''$E; 80% younger terrace deposit, 15% alluvial deposit, 5% erosion surface and foot slope of culluvium of metamorphic rock) with 5-15% mean slope and located in Nakhon Sawan and Kamphaeng Phet province; Huai Lumpayan- Huai Phu Kirio sub catchment (15º8$'$12.37$''$-15º22$'$1.78$''$N, 100º 29$'$24.61$''$-100º52$'$40.3$''$N; 50% younger terrace deposit, 20% alluvial deposit, 5% erosion surface and foot slope, and 25% residuum and colluvium of sedimentary rock) with 5-35% mean slope and located in Lopburi

province; and lower Chao Phraya flat plain (14º22′15.08″-15º32′51.27″N, 100º6′26.36″-100º32′39.82″E; 100% alluvial flood plain) and located Chai-Nat province.

Within each catchment, three potential sediment sources were defined: pasture (paddy field), cultivated (mixed cultivated) and channel bank.
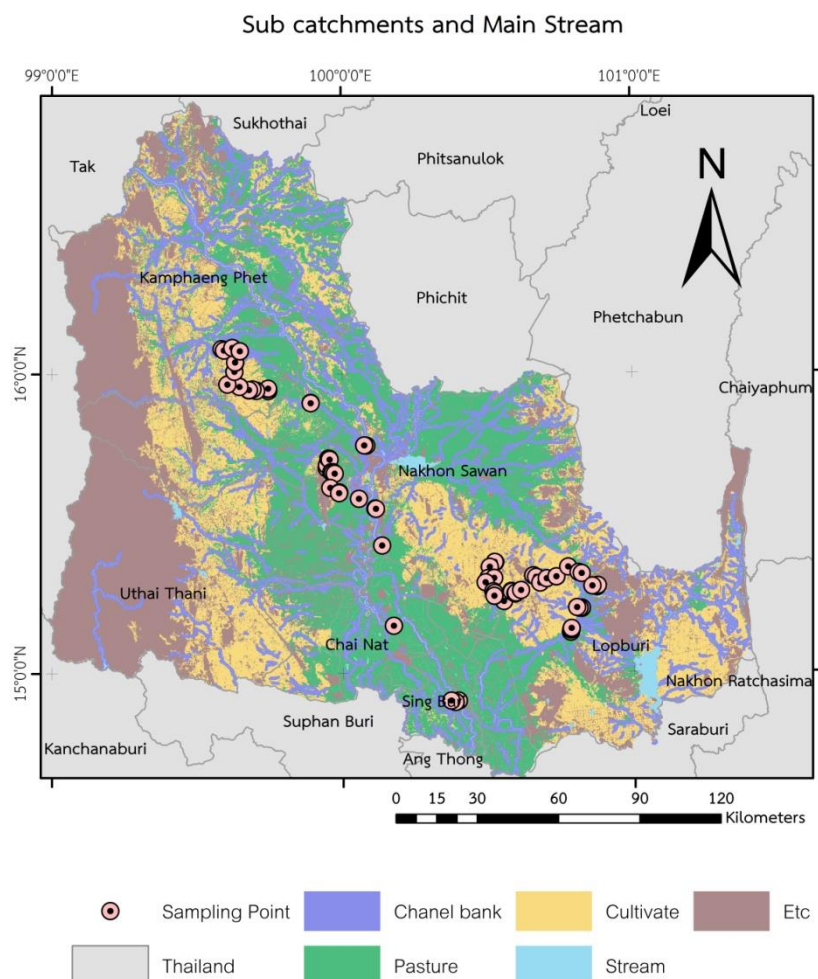
Figure 1. Land use scheme and soil sampling position

3. Materials and methods

One hundred and twenty four samples of soil and sediment samples were collected at sites of different land uses (Fig. 1). Soil and sediment were collected at the surface (0-2 cm depth) of sources material from areas with good connectivity to the stream. For the channel bank, the individual samples comprised composite samples of material from the full vertical extent of the bank profile. The source material samples retrieved from each sampling point were typically 0.5-1 kg in order to provide sufficient mass for subsequent laboratory analyses.

The target sediment and source material collected from the catchments were air-drying, disaggregation and sieving through a 2 mm sieve. The < 2 mm fraction of the potential sources materials and target sediments were used for subsequent radionuclide analyses.

An aliquot of about 500 g of each sample was placed in a Marinelli beaker in preparation for gamma spectrometer analysis. The mass activity concentration of ^{137}Cs were simultaneously determined by

gamma –ray spectrometry, using an ORTEC high resolution Ge detector of 60% relative efficiency, coupled to a PC based digital analyzer system employing ORTEC Gamma Vision software. Count time was in excess of 80,000 sec per sample, providing results with analytical precision of around 1 % at the 95% level of confidence. The efficiency of the detector system was established using mixed radionuclides standard provided by AMALE INTERNATIONAL type EG-ML 1443-67-5.

4. Results and discussion

Within the study area the ^{137}Cs mass activity concentrations according to land uses have been calculated and the range and mean value ± SE (1σ) are shown in Table 1. The detailed information of the data is as the followings:

Table 1. Mean and range values for ^{137}Cs of different land uses. Means are reported with standard error (SE).The units are Bqkg^{-1}.

| Radionuclide	Pasture	Cultivated	Uncultivated	Channel erosion
^{137}Cs				
Mean ± SE	0.64 ± 0.14	0.38 ± 0.04	0.76 ± 0.15	0.39 ± 0.05
Range	LLD-1.22	LLD-1.41	0.12-1.73	LLD-1.16
No. of sample	12	63	16	33

The mean value of ^{137}Cs activity concentrations in hill slope forest topsoil, hill slope cropland topsoil, and river sediments in Shan State, Myanmar were reported of 3.80±3.20 (n=11), 1.33±0.64 (n=11) and 0.67±0.40 (n=48) Bqkg^{-1}, respectively. At Belaga in Sarawak, Malaysia, an unseived (bulk) topsoil sample from the forest ridge had the ^{137}Cs activity concentration of 1.57±0.69 Bqkg^{-1}, and in addition six samples out of twelve of river sediment had the mean value of 0.60±0.10 Bqkg^{-1}.The ^{137}Cs activity concentrations in hill slope and river sediments (Cimanuk River catchment) of 0.88±0.19 Bqkg^{-1} (n=3) and 0.69±0.23 Bqkg^{-1} (n=4), were found in West Java, Indonesia. In East Java the ^{137}Cs activity was not found in bulk samples from hill slope cropland soils in Brantus River catchment. In Timor Leste, the weighted average of ^{137}Cs activity for hill slope topsoils was 2.11± 0.26 Bqkg^{-1}(n=20), however, the ^{137}Cs were not detected in river sediments [24].The ^{137}Cs activity concentrations in this study are therefore in the range of ^{137}Cs activity concentrations found at the same altitude in neighbouring countries.

The coefficients of variation (CV) of our study are also comparable with others. Mabit et al. [25] stated that the CV of reference samples in forested sites was large (0.19-0.47), but low in pasture and grassland (0.051-0.41). The CV of our results is within the range (0.13-0.22). It is found that the ^{137}Cs activity concentrations for all land uses in Huai Lampayan – Huai Phu Kirio sub catchment are higher than those in Khlong Dong sub catchment. The scattered plan of sampling, variation in slope gradient, the differences in parent rock and rate of soil mixing during planting has resulted in the variation of ^{137}Cs activity in samples. The variation of data between two sub catchments highlighted the important role of parent rocks and rate of soil disturbance in the study area.

Geostatistics together with geographic information system (GIS) was used for mapping of soil redistribution based on ^{137}Cs activity [26, 27]. This technique is applicable to small catchments with similar land use and topographic conditions [28]. In this present study, ^{137}Cs activity distribution was mapping based on land uses and similarities in each sub catchments. ^{137}Cs activity values determined for each land use within catchment was extended to other areas of the same land use within the same catchment. The ^{137}Cs distribution map is shown in Fig. 2. It revealed patterned in the spatial concentrations of ^{137}Cs and indicated important differences in its distributions showing the differences behaviour of ^{137}Cs in different land uses.
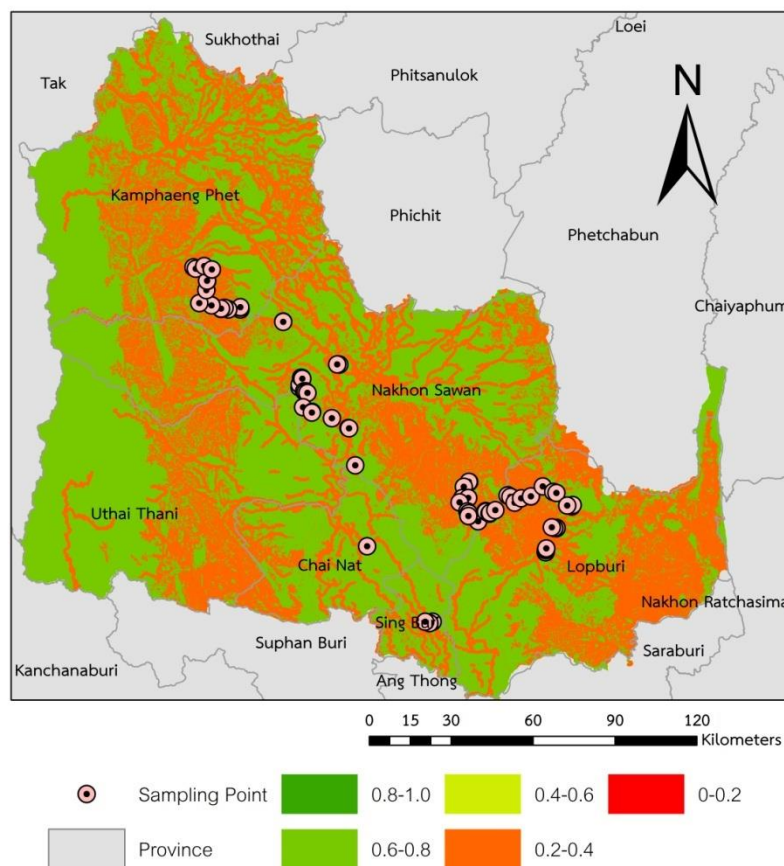
Figure 2. Caesium-137 distribution map of the Chao Phraya watershed.

5. Conclusion

Mass activity concentrations of ^{137}Cs in surface soil (0-2 cm depth) of the potential sediment sources in two sub catchments and one flood plain of the Chao Phraya watershed were determined. The activity concentrations were in the range of those in the neighbouring countries. The activity distribution reflected the important role of parent rock and rate of soil disturbance to the variation of the ^{137}Cs activity. The ^{137}Cs activity distribution map was carried out applying the Geostatistics together with geographic information system (GIS).

Acknowledgments

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