Current ability of $^{137}\text{Cs}$ radionuclear fallout method for erosion assessment in Indonesia

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Abstract. Soil erosion is one of the most important natural resource management problems in watershed zone that affects soil quality, reduce soil nutrient content and further may harms food resilience. Erosion produced sediment is the biggest pollutant of surface water, contributes further to eutrophication and affecting water quality. Radionuclide Fallout (RNF) have been developed by Unesco to measure erosion qualitatively using isotope trace found in soils surface originated nuclear bomb test. This method has been applied in the Region of Sembalun at Lombok island and Kertasari at Greater Bandung in 2017. Grasslands of Mt Rinjani and Mt. Papandayan have been chosen as the reference sites. Kertasari area possess steeper slopes and receive more rainfall than Sembalun Area. The soil profiles at the expected reference on Mt. Papandayan contain less $^{137}\text{Cs}$ radioactivity than those of Mt. Rinjani. Both study area represents locations where the activity of $^{137}\text{Cs}$ was undetected due to the topsoil removal by high rate of erosion process. Undetected $^{137}\text{Cs}$ radiation is more widespread in Kertasari than in Sembalun area. $^{137}\text{Cs}$ RNF methods for quantitative assessments of erosion seems possess the limitation for the utilization in the steeply sloping region with high soil erodibility due to the presence of undetected radiation area. The method will still useful to be applied in a more flat area for both erosion and sedimentation study.

1. Introduction
Uncontrolled accelerated erosion is a human derived soil degradation process that may cause several further damages such as soil fertility loss, water body deterioration by transported eroded materials provoking turbidity in streams and water bodies as well as finally and channel sand reservoirs siltation. The consequences of prolonging continuous erosion process deal with food resiliency, environmental degradation and infrastructure damages. In the last several decades in Indonesia, soil erosion take place severely due to the extent of drastic land use and land cover change (LULC)and draw out due to inappropriate land use and unsuitable agricultural practices. The severe erosion take place normally at the volcanic area, which is extent in Indonesia, since it provide generally a good fertility soils in one hand and in the other hand situated at the sloping area.

Erosion assessment is important in order to measure the severity of ongoing processes as well as for rehabilitation design planning and evaluation. Erosion quantity is normally assessed by calculation model and USLE (Universal Soil Loss Equation Method) based methods (RUSLE, MUSLE) are the most used prediction models. The validation of the calculation results involves a laborious and costly works, particularly if it implies an extent area.

An alternative rapid and cost-effective techniques for assessing soil erosion, as the complementary to classical method is the use of radionuclides fallout (RNF) isotope. Particularly cesium-137 ($^{137}\text{Cs}$)
with a half-life of approximately 30 years, have been successfully used as tracers to obtain quantitative estimates of soil erosion and deposition on agricultural landscapes [1, 2, 3, 4, 5].

$^{137}$Cs was globally distributed by the deposition and infiltrated in the soil mostly by rainfall from atmospheric nuclear weapons tests in the mid-1954 through the mid-1963 [6]. When $^{137}$Cs fallout reached the soil, it adsorbed onto the exchange sites of the soil particles and nonexchangeable [5]. Soil clay will adsorb immediately this radioactive elements so as accumulates it at the soil surface. The amount of radioactive will drastically decrease with soil depth in an exponential manner until about 30 cm below surface. Soil particle transport by erosion involves radioactive elements. Consequently, eroded soil contains less radioactive, whereas deposition zone surface soil contains more comparing to the intact soil. Based on the above phenomenon, International Atomic Energy Agency (IAEA) and Food and Agricultural Organization (FAO) of UNESCO have been developed the method of erosion rate measurement using isotope trace found in soils. The principle of this methods is simple, but require radioactive measurement instruments which is relatively expensive and a control location of an intact soil surface during at least within the last 50 years. The other inconvenience of this method is, because Cesium is a decaying isotope, the radioactivity decreases by time and will attain the amount which is not sensitive anymore for measurement purpose.

Global distribution of $^{137}$Cs is not uniform. In the northern latitude, low latitude regions have significant higher $^{137}$Cs value than middle and high latitude, which are also higher than the entire southern hemisphere [2]. Most of Indonesia is included in the area of the third lowest recipient of $^{137}$Cs precipitation, except Java and lesser Sunda islands that belong to the second lowest (figure 1). Based on measurements carried out at 2013 that shows the amount of soil $^{137}$Cs about $< 200 – 300$ Bq/m$^2$ [7] utilisable amount of $^{134}$Cs predicted will still remain until the middle of this century.

![Figure 1. Global distribution of Cesium-137 fallout (After Welling, 2002)](image)

In Southeast Asian regions, distribution of $^{137}$Cs getting lower because it’s getting away from the location of the nuclear explosion. Besides geographical position, the variation of $^{37}$Cs inventory in soil depend also on (a) rainfall distribution [8]; (b) vegetation; (c) localized human disturbance [9]; and (d) micro topography [10]; (e) the amount of samples used and method of measurement [7]. The $^{137}$Cs measurement results in Southeast Asian region show the accordance distribution. The $^{137}$Cs deposition at 2012 measured in Shan State, Myanmar founded 612 ± 35 Bq/m$^2$ [7], 527 Bq/m$^2$ in Northern Laos, 739 ± 71 Bq/m$^2$ in Northern Thailand [11], 627 ± 279 to 852 ± 116 Bq/m$^2$ in Northern Vietnam and 342 ± 244 Bq/m$^2$ in Southern Vietnam [12], 125 ± 36 Bq/m$^2$ in Peninsular Malaysia [13], 189 ± 26 Bq/m$^2$ in Belaga, Malaysia [7], 195 ± 15 Bq/m$^2$ in Kuching, Malaysia [14], 212 ± 30 Bq/m$^2$ in Bogor, Indonesia [15].

The used of $^{137}$Cs isotopic erosion tracer have been successfully validated with conventional method for calculating soil erosion rates. Many researchers has investigated two different method $^{137}$Cs isotopic
tracer and RUSLE for conventional method in Marroco [16] and for conventional sediment measurement in Italy [17] and China [18].

The purpose of this descriptive study is to evaluate the actual possibility an in using use RNF method for erosion study in Indonesia with the particular regards to the progress decreasing method sensitivity and increasing erosion severity. Particular emphasis have been given to volcanic area for the above mentioned problems, especially to the upper Bandung basin as one of the most exploited watershed in Indonesia.

2. Materials and Methods

2.1. Soil Sampling

Sampling was Carried out at 2017 in Lombok Island and Bandung District West Java. Two type of Soil sampling for $^{137}$Cs study have been taken: for the reference of intact soils and for the estimation of soil loss.

Since both Java and Lombok islands is the islands where agriculture is the main traditional occupation of the inhabitants, outside of protected area, it is almost impossible to find the location that fulfil the requirements as RNF reference site where the soils were undisturbed or uncultivated for at least since 1950’s. Reference sites location were choose in the area of Mt. Rinjani National Park for Lombok island and in the preserve area of Mt. Papandayan in Greater Bandung. Savana type vegetation cover was chosen, simply for the reason of the ease field orientation. Sample have been taken using "soil scraper" [20] of 25*40 cm$^2$ width, for every 2 cm depth. Vegetation cover of both locations is savanna. Sampling for the reference of intact soil was carried out 2016. In Mt. Rinjani sampling was made in three positions located at the crest, slope, and deposition/depression, named respectively as SL1, SL2 and SL3. Whereas at Mt. Papandayan, two samples taken at Tegal Panjang: a grassland found at the middle slope of the volcanoes, at the crest and slope positions named TP1 and TP2.

Samples for soil loss estimation sample have been taken from the area around expected reference sites on various existing land use at different slope gradient. In Lombok island, sampling have been done at the Sembalun area at the eastern foot slope of Mt. Rinjani, whereas in Bandung District Java island, sampling was conducted in the south and eastern part of the uppermost sub watershed of Citarum River which cover the entire district. Sampling have been realized using cone sampler of 15 cm diameter for every 15 cm depth for the sample at the area of Sembalun and every 8 cm depth for the area Bandung district. (figure 2). Samples was taken in 8 location with different land cover type.

![Figure 2. $^{137}$Cs Sampling locations. ♦: reference sample ★: erosion sample](image)

2.2. Analyses

Radioactivity measurement for $^{137}$Cs have been carried out in the BATAN Bandung Laboratory, using HPGe detector. Measurement of every sample had been passed for 24 hours. Calculation of
measurement results was proceed involving sampler size and the results of soil Bulk density dosage for presenting the amount of $^{137}$Cs soil radiation in Bq/m$^2$.

3. Results

3.1. Reference Sites

The $^{137}$Cs radioactivity of the uppermost soil profiles at the three reference sites in the Mt. Rinjani Lombok (figure 3) show the total magnitude of $^{137}$Cs radioactivity for all depth varied from 188.5 Bq/m$^2$ at eroded slope (SL2) to 598.7 Bq/m$^2$ at the depression where eroded soil particles are supposed to be deposited (SL3). At the location SL1 where soils are expected to be undisturbed, the all depth radioactivity show 319 Bq/m$^2$ magnitude, slightly above average predicted magnitude for this region [7][20]. The depth of soil radioactivity is also varied from 17cm at SL1 to 27 cm at SL3. The vertical distribution of radioactivity at the expected reference site SL1 show a disguised tendency of reduction with depth. Even though the ideal distribution of reference site which is characterized by exponentially decrease of radioactivity with depth doesn’t appear. There are also the radioactivity-undetected samples, found at the layers of 6-8 cm depth of SL 1 and at 12-14 cm of SL 2.

![Figure 3. Vertical distribution of 137Cs radiation in soils of Reference site of Mt. Rinjani.](image3)

Comparing to those of Mt. Rinjani, the soil profiles at the expected reference in Mt. Papandayan contain less $^{137}$Cs radioactivity (figure 4). Total radioactivity magnitude for all depth obtained at the crest (TP1) is 207.9 Bq/m2 and 162.2Bq/m2 at eroding slope (TP2). The maximum depth of soil containing $^{137}$Cs radioactivity detected at 20 cm for both sites. As in the case of Mt. Rinjani, the pattern of downward radioactivity decrease is not very clear and doesn’t show the exponentially decreasing shape of the typical radiation profile of the uppermost undisturbed soils.

![Figure 4. Vertical distribution of 137Cs radiation in soils of Reference site of Mt. Papandayan.](image4)

3.2. Soil Loss Assessments

The location of soil sampling for soil loss assessment in both Sembalun (RS 1 to RS 8) and Bandung District (DL17T01 to DL17T06) was selected at the sloping area where soil erosion is supposed taking place. The magnitude of surface radioactivity obtained from samples taken from locations in Sembalun...
and Bandung District is listed at tables 1 and 2. The analyses results show the presence of the sampling locations where $^{137}$Cs soils radioactivity is undetected in both Sembalun and Bandung District area.

**Table 1.** Soil surface radioactivity from sampling sites of several land use type of different slope gradients in Sembalun area.

| NO | SAMPLE CODE | LANDUSE           | SLOPE (%) | DEPTH (cm) | As$^{1)}$ (Bq/m$^2$) |
|----|-------------|-------------------|-----------|------------|----------------------|
| 1  | RS 1-1      | Secondary Forest  | 15-30     | 0-8        | ud                   |
| 2  | RS 1-2      |                   |           | 8-16       | ud                   |
| 3  | RS 2-1      | Grassland         | 8-15      | 0-8        | 58.67                |
| 4  | RS 2-2      |                   | 8-16      |            | 20.17                |
| 5  | RS 3-1      | Secondary Forest  | 8-15      | 0-8        | 49.67                |
| 6  | RS 3-2      |                   | 8-16      |            | 63.67                |
| 7  | RS 4-1      | Grassland         | 15-30     | 0-8        | ud                   |
| 8  | RS 4-2      |                   |           | 8-16       | 53.67                |
| 9  | RS 5-1      | Upland Agriculture| 8-15      | 0-8        | 30.17                |
| 10 | RS 5-2      |                   | 8-16      |            | 171.67               |
| 11 | RS 6-1      | Upland Agriculture| 15-30     | 0-8        | 7.17                 |
| 12 | RS 6-2      |                   | 8-16      |            | 35.83                |
| 13 | RS 7-1      | Plantation        | 15-30     | 0-8        | ud                   |
| 14 | RS 7-2      |                   |           | 8-16       | ud                   |
| 15 | RS 8-1      | Plantation        | 8-15      | 0-8        | ud                   |
| 16 | RS 8-2      |                   |           | 8-16       | ud                   |

$^{1)}$ Surface radioactivity; ud = undetected.

**Table 2.** Soil surface radioactivity from sampling sites of several land use type of different slope gradients in Bandung district area.

| NO  | CODE       | LANDUSE           | SLOPE (%) | DEPTH (cm) | As$^{1)}$ (Bq/m$^2$) |
|-----|------------|-------------------|-----------|------------|----------------------|
| 1   | DL 17 T.01-1 | Secondary Forest  | 30-40     | 0-15       | ud                   |
| 2   | DL 17 T.01-2 |                   |           | 15-30      | ud                   |
| 3   | DL 17 T.02-1 | Upland Agriculture| 15-30     | 0-15       | ud                   |
| 4   | DL 17 T.02-2 |                   |           | 15-30      | ud                   |
| 5   | DL 17 T.03-1 | Upland Agriculture| 0-8      | 0-15       | ud                   |
| 6   | DL 17 T.03-2 |                   |           | 15-30      | ud                   |
| 7   | DL 17 T.04-1 | Secondary Forest  | 30-40     | 0-15       | 22.83                |
| 8   | DL 17 T.04-2 |                   |           | 15-30      | ud                   |
| 9   | DL 17 T.05-1 | Grassland         | 0-8       | 0-15       | ud                   |
| 10  | DL 17 T.05-2 |                   |           | 15-30      | ud                   |
| 11  | DL 17 T.06-1 | Forest            | 0-8       | 0-15       | 37.17                |
| 12  | DL 17 T.06-2 |                   |           | 15-30      | ud                   |

$^{1)}$ Surface radioactivity; ud = undetected.

In Bandung District area only two of six sampling location where $^{137}$Cs radiation was detected, whereas from Sembalun five out of eight locations where radiation was detected. The location without $^{137}$Cs Radioactivity is related to steeper area: more than 15% slope for Sembalun area and more than
30% for Bandung District area. In the Sembalun area undetected $^{134}$Cs locations was found under secondary forest and plantations, whereas under upland agricultural lands $^{134}$Cs radiation was yet detected. In Bandung District area detected $^{134}$Cs radiation was found only under forest vegetation, whereas under agriculture and plantation covers, $^{134}$Cs radiation was undetected.

The magnitude of detected $^{137}$Cs soils surface radioactivity of soil loss sampling location always less than the magnitude of reference sites. In general, the detected radiations around Mt. Papandayan area is much less than that of Mt. Rinjani.

4. Discussion

According to the approximate map of bomb test derived global distribution of $^{137}$Cs fallout compiled at 1963, Both Java and Lombok Islands are situated at the same region where the activity of soil $^{137}$Cs was less than 300 Bq/m². Another measurement of $^{134}$Cs RNF in Java have been carried out at 2013 [7] on the sediments of river and slope in the Cimanuk watershed west Java where the measured activity found are $0.61 \pm 0.13$ and $0.48 \pm 0.16$ Bq/kg (to about one third to half radioactivity of Mt. Rinjani). At the same measurement moment and study area, the presence of $^{137}$Cs radioactivity on cropland topsoil was not detected.

About a decade earlier, some previous studies have done in Java island. In Bogor Botanical Garden [21], the $^{137}$Cs radioactivity was recorded at $380.83\pm16.46$, $379.02\pm2.25$, $405.32\pm30.88$ and $359.79\pm16.30$ Bq/m². [14] [22] found that under the tea plantation in Puncak, Bogor, most $^{137}$Cs activity was varied between 250 -700 Bq/m², indicating that soil particle redistribution took place. Whereas at the reference site located at reserve forest of Mt. Pangrango, the total depth soil $^{137}$Cs activity detected is 520 Bq/m². [23] in Nganjuk East Java. show the average estimates about 281 Bq/m² for the measurement at 2006. The above measurements results illustrates the variation of within the delimited RNF precipitation area in the function of distance from bomb testing location, derived from other causes more than radioactive decay.

Since radionuclide on earth surface is fixed particularly at fine size soil particles, the different magnitudes of erosion and sedimentation factors will determine the post fallout spatial distribution of radioactivity. Rainfall, slope and vegetation cover will influence the spatial distribution of $^{137}$Cs radioactivity. In the higher annual rainfall, spreading by fine soil particles transport proceed faster. In a long run, the $^{137}$Cs radioactivity variation among landform unit will be more varied in the higher annual rainfall climate. The higher remnants of $^{137}$Cs radioactivity in Mt. Rinjani than that in Mt. Papandayan seems due to the annual rainfall of the two area: Mt. Papandayan region receives about 3200 mm and Mt. Rinjani 1890 mm, beside the landforms of both regions are characterized by strong relief of dissected volcanic slopes.

Soil physics such as soil texture, porosity and permeability will influence vertical distribution of radioactivity content within soil profile. As a product of fallout precipitation, $^{137}$Cs accumulates at soil surface. Some part of the isotope leached to the lower subsoil by water infiltration and distributed in the uppermost part of soil profile, trail a pattern of gradual exponentially downward diminution to the undetectable radioactive layer. This ideal vertical distribution generally found a in homogenous grain size distribution. In an undisturbed soil profile, coarser textured soils will have thicker radioactive layer than finer one. At the references sample of Mt. Rinjani and Mt. Papandayan, vertical distribution of radioactivity doesn’t show this ideal distribution. Without neglected the possibility of errors origin, the nature of soil parent materials that originated from young volcanic ash could cause this irregularity. Both Mt. Rinjani and Mt. Papandayan are the active volcanoes which occasionally ejects its activity products, generally volcanic ash. Earth surface surrounding the active volcanic crater is generally covered by thin (dimension of cm) stratified layers volcanic ash originated from recurring weak eruptions. Mineralogy of the layers is normally similar. The different among layers appears more clearly on the grainsize which is still conserved even long time after soils developments, marked by organic matter accumulation, have been take place [24]. This soil parent material stratification could alter the ideal shape of vertical radioactive redistribution.

In the sloping area, the lack of RNF trace from soil surface could be caused by completely removal of the uppermost part of the soils where the RNF product is normally accumulated. Whereas in the flat or in the depression area, burying by radioactive clean soil particles could disappear RNF trace. For the
case of Sembalun and Bandung District, the absence of detected $^{137}$Cs radioactivity at many soil samples taken for soil loss estimation indicates the erosion rate at the location is high, since the location was chosen in the sloping area. The soils of the study area consist of andosols which is known sensitive to erosion once vegetation cover have open. The presents of the undetected FNR remnants in both Bandung District and Sembalun area, specify the height of erosion rate in this two region. Beside the weak detected radiation magnitude, the greater number of the lack $^{137}$Cs radioactivity locations showing that erosion in the Bandung District area is more severe than in Sembalun area. Seemingly, the disappearance of $^{134}$Cs Radioactivity relates more related to slope gradient rather than to vegetation cover since in the Sembalun area undetected $^{134}$Cs locations was found under secondary forest and plantations, under upland agricultural lands $^{134}$Cs radiation was yet detected. Whereas in Bandung District the detected $^{134}$Cs radiation was found only under forest vegetation and other under vegetation cover such as agriculture and plantation covers, $^{134}$Cs radiation was undetected.

Mountainous volcanic provinces are widespread in Indonesia, attractive for agricultural developments and tourism since it provides fertile soils, good water quality, beautiful scenery and fresh air. One constraint for intensive developments in this region is sloping morphology that could cause severe soil erosions. In order to assess soil erosion and soil particles redistribution in strongly sloping volcanic region in Java and Lesser Sunda, $^{137}$Cs RNF methods utilization seems begin to meets limitation, particularly for quantitative assessments due to the extent disappearance of marker top soils. The use the $^{137}$Cs RNF methods will still useful if it is applied in a more flat area for both erosion and sedimentation study.

5. Conclusion

$^{137}$Cs RNF method for quantitative assessments of erosion has been applied in the Sembalun and Bandung District Area. Grasslands of Mt Rinjani and Mt. Papandayan have been chosen as the reference sites. The soil profiles at the expected reference on Mt. Papandayan contain less $^{137}$Cs radioactivity than those of Mt. Rinjani. Both study area represents locations where the activity of $^{137}$Cs was undetected due to the topsoil removal by high rate of erosion process.

This method seems begin to possess the limitation for the application in the steeply sloping region with high soil erodibility such as in volcanic product soils origin, particularly for quantitative assessment purpose, due to the presence of undetected radiation area. The method will still useful to be applied in a more flat area for both erosion and sedimentation study.

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