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The Investigation of ^{137}Cs Contamination in Soils of Aceh after the Tsunami

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ABSTRACT

Cs-137 is one of the most common radionuclides used for analysing man-made radioactive contamination in the environment beside Sr-90. Nangro Aceh Darussalam Province suffered the greatest mortality, with widespread destruction extending along more than 1000 km of coastline on 26 December 2004 due to tsunami. The disaster were affected areas about 220 km long and around 5 km wide along the coastlines of Aceh and North Sumatra. The purpose of this study is to investigate the artificial radioactivity ^{137}Cs in soil samples which have been collected from various locations along the areas affected by tsunami in Aceh. The surface soil samples were collected from 20 sites in this region. The soil samples from the middle area of Aceh which was not exposed to the tsunami have also been investigated for comparison. The activity concentration of ^{137}Cs in the samples was measured using a ORTEC P-type coaxial high purity Germanium (HPGe) detector system. The artificial radioactivity level of ^{137}Cs measured from these samples was found in the range of not detected to 2.09 Bq.kg^{-1} for the affected soil samples and 0.56 to 1.44 Bq.kg^{-1} for unaffected soil respectively. The radioactivity concentrations of ^{137}Cs within the coastline areas are comparable to that of the middle area, which was not exposed to the tsunami. The results indicate that there are no new inputs of man-made radionuclides into the area at that time and the data obtained could serve as baseline levels of ^{137}Cs in Aceh Region.

INTRODUCTION

Man-made radionuclides in the environment are an important source of radiation exposure for humans. ^{137}Cs is a man-made radionuclide released into the environmental ecosystems originating from nuclear weapon tests, nuclear facility accidents, radioactive waste dumping, and nuclear power plant leakage. The atmospheric nuclear test explosions in the Northern and Southern Hemisphere, with a distinct peak in 1962-1965, are the main source of global contamination by man-made radionuclides. Radioactive fallout from these test explosions contaminated globally on the surface of the Earth. ^{137}Cs is a radioactive isotope with a half-life of 30.2 years. Due to its long half-life, ^{137}Cs diffuses and is transported over the whole world by atmospheric circulation and falls to the ground in the form of dry depositions and wet depositiosn. Consequently, the concentration of ^{137}Cs fallout in environment has become an indicator for analyzing man-made radioactive contamination in the environment and been widely used as a tracer of soil redistribution and has been proven useful in soil erosion studies performed around the world [1-4].

In the terrestrial environment, soil is the principal reservoir of artificial radionuclides and acts as a media of migration systems for these radionuclides, because soil accumulates artificial radionuclides originating from the nuclear weapons and nuclear accident [5-7]. In the marine environment, artificial radionuclides introduced to surface waters by wet and dry depositions does not stay in steady-stay conditions, because the ocean is a dynamic system due to currents and processes in

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the water column. The artificial radionuclides are transported to different regions, as well as to bottom waters and sediments [8,9].

After the Great western coast of north Sumatra Earthquake and the resulting tsunami on 26 December 2004, serious damages occurred in Indonesia's Province of Aceh with widespread destruction extending along more than 1000 km of coastline [10]. The earthquake generated a large tsunami that traveled rapidly throughout the Indian Ocean, striking beachfront areas in many countries with catastrophic results in Indonesia, Thailand, Sri Lanka, India and Bangladesh, as well as other Asian and East African countries. As a result of the earthquake and tsunami, approximately 110,000 people died, and many buildings and infrastructure collapsed. The ensuing tsunami swept debris and sea water into homes and buildings up to 5 kilometers inland, crushing them and further damaging roads, bridges, telecommunications systems, water and electricity systems, crops, irrigation, fishery infrastructure, and food and fuel outlets [11]. The resulting movement of sea water and sand may have redistributed radioactivity along the Aceh coast of the Sumatra Island. Therefore, it is urgent to carry out an investigation on ^{137}Cs radionuclide in surface soil and its spatial distribution in this region to evaluate the influences of the Aceh tsunami disaster on Sunday morning, 26 December 2004.

Most previous studies on soil in tsunami-affected areas are limited to the physical and chemical properties of soils in Aceh [12-14] and did not attempt to study ^{137}Cs contamination. Several studies focus on the impacts of tsunami on agriculture, including soil salinity, soil profiles, changes in soil properties over time, and crop response [15-17]. Measurements of naturally-occurring radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in the soil from tsunami affected area were carried out to evaluate the changes of the naturally-occurring radionuclide contents in surface soils associated with soil erosion and sedimentation [18].

Until now, the ^{137}Cs measurement data in soil of the environment in Aceh are not available. The fission product ^{137}Cs has similar chemical characteristics to K, which causes it to move easily through the environment. Data and knowledge of the distribution pattern of ^{137}Cs radionuclide in this region is essential in maintaining some sense of control of prevailing radiation levels to assess the radioactive environmental quality and to develop strategies for soil management and protection.

The measurement of radioactive contents of soil in this region is of interest not only for additional information to represent baseline data for the nation but also for worldwide database and further studies in the region. The objective of this research was to determine the present activity concentrations of ^{137}Cs in soil from along the coastal beaches of Aceh Region, and to provide the detailed baseline data and spatial distribution patterns in surface soil.

EXPERIMENTAL METHODS

Description of the study area

The study area is located in the northern part of the island of Sumatra, Indonesia. Aceh is one of a province in Indonesia officially named Nanggroe Aceh Darussalam. It is the western most province of the Indonesia with the Indian Ocean to the west, the strait of Malacca to the east, located between 2^0-6^0 North latitudes and 95^0-98^0 East longitudes with the area of approximately 57,365 km^2, or 12.26% of size of Sumatra Island. The Province of Nanggroe Aceh Darussalam is the most affected area by the tsunami of 26 December 2004. The Fig. 1, shows the areas affected by tsunami in Nanggroe Aceh Darussalam (NAD) province [11].

Fig. 1. The areas affected by tsunami in the Nanggroe Aceh Aceh Darussalam (NAD) province [11].

Sampling and sample preparation

Two types of soils were selected for the study those tsunami affected soil and unaffected soils. The tsunami affected soil samples were collected from various locations along the west, north and the east coast of Aceh by random selection [19]. The unaffected soil samples (normal soil) were used as the reference to compare with affected soil collected from various areas far away from the coast. Figure 2, shows the map of Nanggroe Aceh Darussalam (NAD) province and the location of the soil sampling sites. After collection, each soil sample was wrapped in black plastic bag and labelled according to the name of the location where

it is located. The geographical coordinates of the sampling point were recorded by using Global Positioning System, GPS Map 60CHx manufactured by Garmin.

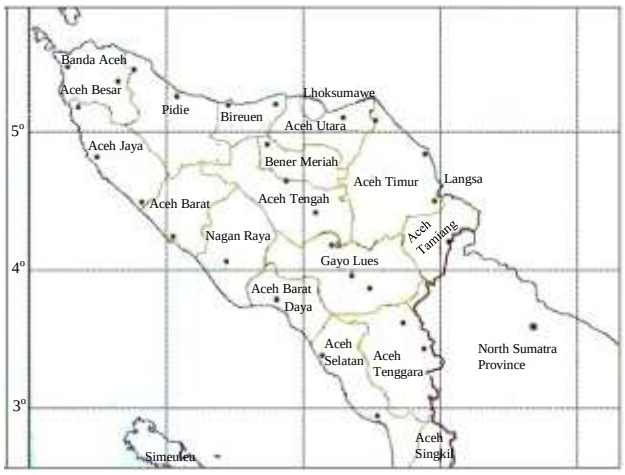

Fig. 2. The map of the Province of Aceh and the location of the soil sampling sites.

In the laboratory, the soil samples were dried in an oven at a temperature of 105°C to a constant weight to remove any available moisture. After drying, the samples were ground with a grinder to pass through a 250 µm sieve. Afterwards, the homogenized samples were packed to fill one-liter marinelli beakers.

Activity determination

The ^{137}Cs activity concentrations of the soil samples were determined with the help of an ORTEC P-type coaxial high-purity germanium (HPGe) detector with a relative efficiency of 60% and a resolution of 1.95 keV (full width at half maximum) for the peak of 1,33 keV. The detector was coupled to a computer-based multichannel analyzer. The gamma ray spectrum was recorded using a personal computer-based 4096-channel analyzer and processed using ORTEC GammaVision-32 gamma spectrum analysis computer software. To reduce the external gamma-ray background in the measured spectrum, the detector was put inside a cylindrical lead shield of 10.1 cm thickness with an internal diameter of 28 cm and a height of 40 cm. The lead shield is lined with several layers of tin and copper, each 0.5 and 1.6 mm thick respectively. The measurements were carried out in the counting room located in the basement of the laboratory building.

The energy and efficiency calibration of the system for the determination of radionuclides in the prepared samples was carried out using a certified standard source (mixed gamma) and International Atomic Energy Agency (IAEA) reference materials prepared in geometrical shape and composition to simulate the samples' matrix. The measurement time for samples and background was 17 hours. The background count was used to correct the net peak area of gamma rays of the measured isotopes. Since the absolute efficiency was employed in the same Marinelli beaker geometry and the same approximate density as the samples, the difference in the self-attenuation for gamma rays in the sources and samples was assumed to be negligible. Quality assurance was additionally guaranteed by regular participations in national and international intercomparison exercises [20].

The activity of ^{137}Cs was determined from its gamma energy peak of 661 keV. The activity concentrations (A) of ^{137}Cs in Bq kg^{-1} for the samples were determined using the following expression:

$$A = \frac{N_e}{\varepsilon_f P_\gamma t_C M} \quad (1)$$

where N_e = net counts of a peak at energy E, ε_f = the counting efficiency of the detector system at energy E, P_γ = the gamma ray emission probability (gamma yield) at energy E, t_c = sample counting time, and M = mass of sample (kg).

RESULTS AND DISCUSSION

The analysis results of soil sample collected from tsunami affected area are presented in Table 1. Results indicate that the ^{137}Cs activity concentration in the surface soil of tsunami affected area ranged from the ND (not detected) to 2.09 ± 0.32 Bq.kg^{-1}. As appears from Table 1, activity concentrations of ^{137}Cs in surface soil collected from tsunami affected area remarkably vary from location to location and are not uniform. ^{137}Cs in some soil samples was found to be lower than the minimum detectable activity of the gamma counting systems (<MDA). This could be explained by the fact that the tsunami had destroyed the land along of coastline. Several changes in land and soil texture due to tsunami flow and the subsequent backflow could be attributable to transfer and redistribution of ^{137}Cs from one location to another. Removal of topsoil through accelerated sea water erosion could be attributable to vary distribution. These suggest that there are runoffs and soil redistribution effect on ^{137}Cs in soil so that ^{137}Cs was transferred.

Unlike the analysis results of soil samples from tsunami-affected areas, all soil samples collected from unaffected areas showed that the ^{137}Cs activity concentrations varied within a relatively narrow range. As can be seen in Table 2,

the activity concentrations of ^{137}Cs in the surface soil ranged from the 0.56 ± 0.19 Bq kg^{-1} to 1.44 ± 0.25 Bq kg^{-1}. This results indicate that ^{137}Cs in soil of areas unaffected by the tsunami was nearly uniformly distributed because this areas were not affected by the tsunami disaster. The ^{137}Cs in the soil unaffected by the tsunami was believed to have originated from the global fallout of atmospheric nuclear weapons tests and accident. The atmospheric nuclear weapons tests were carried out worldwide mostly by the USA and the Soviet Union with the most intense periods in 1961–1962. After the Limited Test Ban Treaty came into effect in 1963, the debris from low-yield detonations performed by China and France dominated until 1980.

Table 1. Specific activities (Bqkg^{-1}) of ^{137}Cs in surface soil samples affected by tsunami.

Sample Code	Site	GPS Coordinates		^{137}Cs Activity Concentration (Bg/kg)
		N	E	
TS01	Banda Aceh	5.47161	95.24448	0.93 ± 0.14
TS02	Aceh Jaya	5.18233	95.29869	ND
TS03	Aceh Jaya	4.81709	95.43815	2.09 ± 0.32
TS04	Aceh Jaya	4.49125	95.77591	ND
TS05	Aceh Barat	4.23783	96.04992	1.0 ± 0.16
TS06	Nagan Raya	4.06144	96.43505	ND
TS07	Aceh Barat Daya	3.7837	96.80564	ND
TS08	Aceh Selatan	3.37766	97.1019	ND
TS09	Aceh Selatan	2.92003	97.49597	0.47 ± 0.12
TS10	Aceh Singkil	2.62498	98.02823	0.88 ± 0.19
TS11	Aceh Besar	5.36396	95.64641	ND
TS12	Pidie	5.44914	95.76147	1.44 ± 0.27
TS13	Pidie	5.25523	96.07725	ND
TS14	Pidie	5.18892	96.44817	ND
TS15	Bireuen	5.20065	96.79985	0.73 ± 0.15
TS16	Aceh Utara	5.10299	97.29214	ND
TS17	Aceh Timur	5.07926	97.5258	ND
TS18	Aceh Timur	4.83416	97.88653	0.44 ± 0.18
TS19	Langsa	4.49937	97.95509	ND
TS20	Aceh Tamiang	4.19614	98.06158	0.72 ± 0.16

Table 2. The activity concentration of ^{137}Cs in surface soil samples of normal area.

Sample Code	Site	GPS Coordinates		^{137}Cs Activity Concentration (Bg/kg)
		N	E	
NTS01	Bener Meriah	4.90428	96.73234	1.18 ± 0.23
NTS02	Aceh Tengah	4.64109	96.87324	0.78 ± 0.20
NTS03	Aceh Tengah	4.41647	97.08724	1.02 ± 0.15
NTS04	Gayo lues	4.17936	97.20503	0.56 ± 0.19
NTS05	Gayo Lues	3.95845	97.3554	0.88 ± 0.16
NTS06	Gayo Lues	3.8682	97.48696	1.44 ± 0.25
NTS07	Aceh Tenggara	3.61532	97.72728	1.37 ± 0.30
NTS08	Aceh Tenggara	3.42684	97.87721	1.15 ± 0.25

To confirm the assumption, a measurement of ^{137}Cs concentration was carried out in different depths of undisturbed soil collected from the tsunami unaffected areas (Bener Meriah, Gayo lues and Aceh Tenggara). Soil samples were collected by a corer 12 cm × 12 cm and 20 cm depth, segmented in 0-5, 5-10, 10-15 and 15-20 cm layers. The vertical distribution profile of ^{137}Cs for the tsunami unaffected area is showed in Fig. 3. As can be seen in Fig. 3, the activity concentration for each layer of the locations were plotted against depth to show the depth distribution of ^{137}Cs in the soils. The activity concentrations of ^{137}Cs from this area showed that the highest values found in the surface and second layer and the activity concentrations decreased gradually with depth, showing a penetration depth of approximately 20 cm from the surface. The result of this study is close to that from some locations in neighboring regions such as in Pahang, Sarawak and Serpong reported in previous studies conducted by Hamzah, Z. *et al.* [21], Takahisa, F. *et al.* [22] and Lubis, E. [23]. The depth profiles of ^{137}Cs activity concentration in the overall distribution patterns were observed and it seems to have the similar pattern.

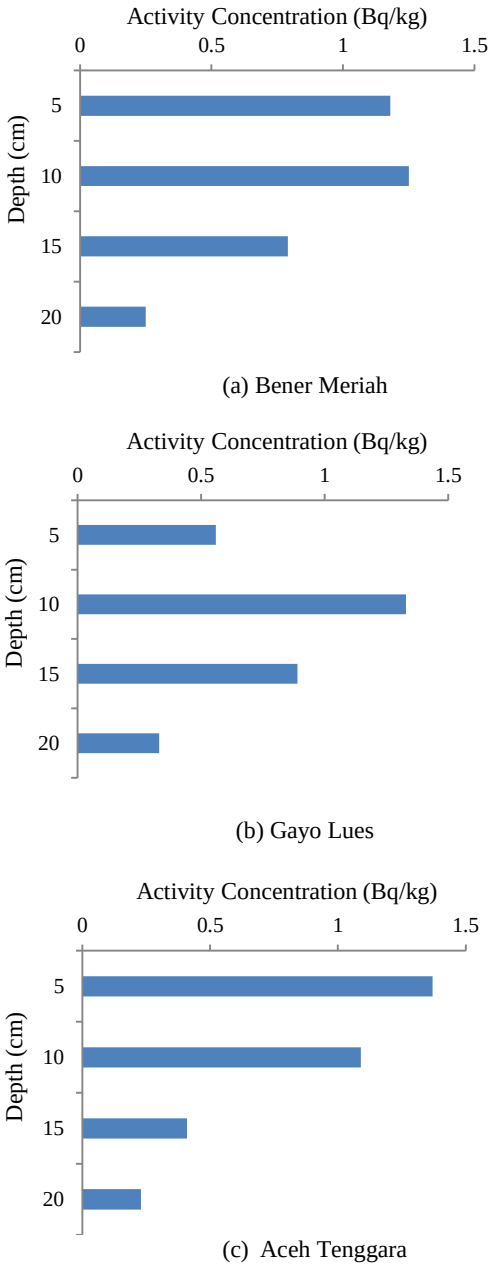

Fig. 3. Depth distribution of ^{137}Cs activity concentration in soils of areas unaffected by the tsunami (a) Bener Meriah, (b) Gayo Lues and (c) Aceh Tenggara.

CONCLUSION

The activity concentration of a man-made radionuclide (^{137}Cs) in surface soils collected from 20 locations in tsunami-affected areas of the Province of Aceh were analyzed to evaluate the influences of the 2004 tsunami disaster on surface soil and to understand the differences in their contamination. The evaluation results of the activity concentration of ^{137}Cs show that the activity concentrations of ^{137}Cs in the surface soils are remarkably dependent on the sampling location due to the tsunami disaster. In general, the range of the activity concentrations of ^{137}Cs in soil samples collected from tsunami-affected areas is comparable with normal area (areas unaffected by the tsunami), which suggests that the radioactive environments in these areas were affected mainly by the fallout from past atmospheric nuclear explosion tests.

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