World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:15, No:5, 2021

Radioactivity Assessment of Sediments in Negombo Lagoon Sri Lanka

H. M. N. L. Handagiripathira

***Abstract*—**The distributions of naturally occurring and anthropogenic radioactive materials were determined in surface sediments taken at 27 different locations along the bank of Negombo Lagoon in Sri Lanka. Hydrographic parameters of lagoon water and the grain size analyses of the sediment samples were also carried out for this study. The conductivity of the adjacent water was varied from 13.6 mS/cm to 55.4 mS/cm near to the southern end and the northern end of the lagoon, respectively, and equally salinity levels varied from 7.2 psu to 32.1 psu. The average pH in the water was 7.6 and average water temperature was 28.7 °C. The grain size analysis emphasized the mass fractions of the samples as sand (60.9%), fine sand (30.6%) and fine silt+clay (1.3%) in the sampling locations. The surface sediment samples of wet weight, 1 kg each from upper 5-10 cm layer, were oven dried at 105 °C for 24 hours to get a constant weight, homogenized and sieved through a 2 mm sieve (IAEA technical series no. 295). The radioactivity concentrations were determined using gamma spectrometry technique. Ultra Low Background Broad Energy High Purity Ge Detector, BEGe (Model BE5030, Canberra) was used for radioactivity measurement with Canberra Industries' Laboratory Source-less Calibration Software (LabSOCS) mathematical efficiency calibration approach and Geometry composer software. The mean activity concentration was found to be 24 ± 4, 67 ± 9, 181 ± 10, 59 ± 8, 3.5 ± 0.4 and 0.47 ± 0.08 Bq/kg for 238U, 232Th, 40K, 210Pb, 235U and 137Cs respectively. The mean absorbed dose rate in air, radium equivalent activity, external hazard index, annual gonadal dose equivalent and annual effective dose equivalent were 60.8 nGy/h, 137.3 Bq/kg, 0.4, 425.3 mSv/year and 74.6 mSv/year, respectively. The results of this study will provide baseline information on the natural and artificial radioactive isotopes and environmental pollution associated with information on radiological risk.

***Keywords*—**Gamma spectrometry, lagoon, radioactivity, sediments.

I. Introduction

THE naturally occurring radio nuclides such as pottasium-40, uranium and thorium series elements are abundant in every environment in the earth. The radiation associated with these radionuclides behaves as an important factor of the earth since its formation. According to UNSCEAR (1993), about 87% of the radiation exposure is due to the sources of the natural radiation and the anthropogenic radiation sources create the remains [1], [2]. The global environment was contaminated with anthropogenic radionuclides such as 137Cs due to the atmospheric testing of thermonuclear weapons, which took place primarily from the mid-1950s to the mid-1970s [3] and spread all over the world as a fallout radionuclide. Long-term exposure to uranium and radium through inhalation and irradiation has several health effects such as chronic lung diseases, acute leucopoenia, anemia, and necrosis of the mouth. Radium causes bone, cranial, and nasal tumors. Thorium exposure can cause lung, pancreas, hepatic, bone, and kidney cancers and leukemia [4]. Knowledge about the distribution of radioactivity enables one to assess any possible radiological hazard to humankind by the living in such environments [5]. In general, the activity concentrations of radio nuclide increase inversely with the grain size [6] and density of the sediments [7], [8]. The uranium and thorium radionuclides are associated with heavy minerals and 40K is concentrated with clay minerals [9]. Additionally other parameters such as mineralogy, organic content and geo chemical composition play an important role in the absorption of radioactive elements in the sediments.

In particular, elevated concentrations of several natural radionuclides in water and soils collected from different rivers, beaches, oceans and other landscapes throughout the world [10]-[12] were published and accessible to the scientific community. However scientific data of the natural and anthropogenic radio nuclides in the Sri Lankan marine and coastal environments are limited at the moment. Sri Lanka has numerous productive lagoon ecosystems along its coastline, which is over 1340 km long. Regrettably, some coastal lagoon ecosystems are being threatened by human-induced activities, as a result of growing urban recreational and industrial development of the coastal areas of Sri Lanka. The Negombo lagoon in the Western province, situated very close to the capital city, Colombo, is a major lagoon ecosystem which has recently experienced severe environmental degradation, both in and around the lagoon.

The aim of this study is to determine natural (238U, 232Th, 40K, 210Pb, 235U) and anthropogenic radioactivity levels (137Cs) in surface sediments of different locations in Negombo lagoon. Also, the associated radiological risk parameters and indexes such as average radium equivalent activity, the total absorbed dose rate, the external hazard index, the annual gonadal dose equivalent and the annual effective dose equivalent will be calculated and compared with the global levels published in the literature. These data will serve as the baseline level for naturally occurring and anthropogenic radionuclides in the study area.

II. Materials and Methods

A. The Study Area

Negombo lagoon (70 12’ 0 N and 790 50’ 0 E to 70 6’ 0 N and 790 55’ 0 E) is a large, shallow basin, estuarine lagoon situated in the Western Province of Sri Lanka. The surface

H. M. N. L. Handagiripathira is with the Sri Lanka Atomic Energy Board, Sri Lanka (e-mail: lhandagiripathira@gmail.com).

area of the lagoon is 35 km^2 [13] and maximum depth is about 2-3 m while most of very shallow areas are less than 50 cm. The lagoon is fed by fresh water from a number of small rivers and canals. It is linked to the sea at its northern end by a single narrow channel near to the city of Negombo.

B. Sampling and Sample Preparation

The surface sediment samples from the upper 5-10 cm layer were collected at 1 km intervals along the lagoon bank using a plastic scoop. The 27 sampling locations (Fig. 1) were selected and the sample size was around 1 kg in wet weight. The samples were placed into contamination-free plastic bags, labeled and then transported to the laboratory. The samples were air dried at room temperature divided into two halves (250 g dry weighted each), packed in air-tight bags and stored for radioactivity analysis and grain size analysis.

C. Hydrographic Parameters of Water

The hydrographic parameters of water lead the association, transport and biological activity of radionuclides in the adjacent environment. In this study, water temperature, pH, Rugged Dissolved Oxygen (RDO), Total Dissolved Solids (TDS), conductivity and salinity were determined by a portable meter (ORION STAR A329, Thermo Scientific) at 5-10 cm depth water layer. The variation of hydrographic parameters of water was presented in Fig. 2. The depth of the water column at the sample sites was ranged from 0.5 s–1.0 m.

Conductivity is one of the water quality parameters which are most useful and commonly measured. The conductivity of the water varied from 13.6 mS/cm to 55.4 mS/cm in the sampling locations close to the fresh water inputs at the southern end and near to the lagoon mouth at the northern end, respectively.

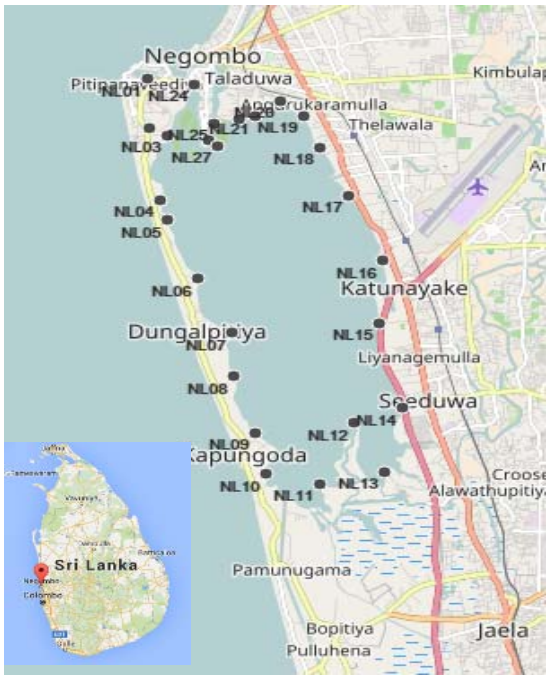


Fig. 1 The sampling stations in the Negombo lagoon

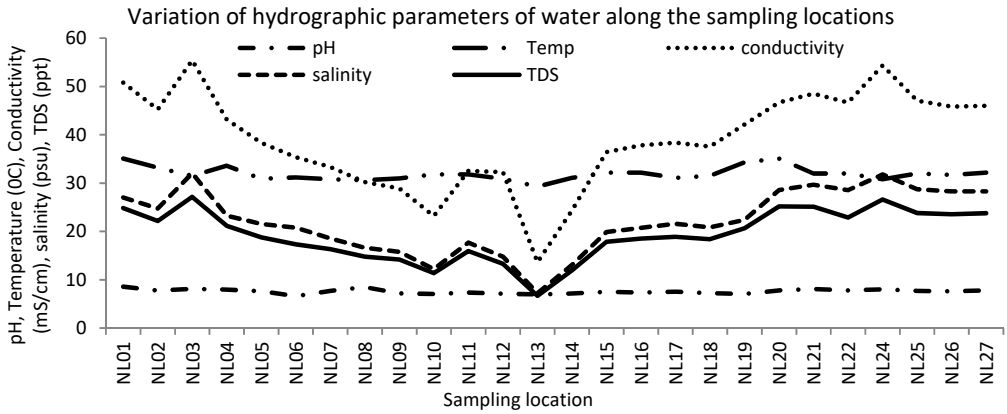


Fig. 2 The variation of hydrographic parameters of Negombo lagoon

The salinity is important in particular as it affects dissolved oxygen solubility, as such the higher the salinity level leads to lower the dissolved oxygen concentration. The measured salinity levels of the water varied from 7.2 psu to 32.1 psu which represented the southern end and northern end, respectively.

Obtained variations of the hydrographic parameters were related to the dilution of lagoon with fresh water inputs at the south end and the water discharge at the north end to the sea. The pH and water temperature showed less variation along the lagoon bank; those were pH from 6.6 to 8.6 and temperature from 29.3 °C to 35.1 °C.

D. Grain Size Analysis of the Sediment Samples

The samples were segregated in four particle size classes by dry sieving technique as > 2 mm, 2-0.25 mm, 0.25-0.063 mm and < 0.063 mm. Weight fraction of samples in the different particle sizes is shown in Fig. 3. The maximum mass fraction for the samples lies in the 2-0.25 mm particle size class (60.9%) and 0.25-0.063 mm particle size class (30.6%), that are sand and fine sand fractions, respectively. The mass fraction of < 0.063 mm particle size was 1.3% and it

represented the mix of fine slit and clay fraction in the sampling points.

E. Sample Preparation for Radioactivity Measurements

Samples were oven dried at 105 °C for 24 hours to get a constant weight, homogenized and sieved through a 2 mm sieve [14]. The sediment fraction of < 2 mm particle size was then filled into a plastic cylindrical container (8.3 cm diameter x 2.8 cm height). Each sample was sealed, weighed and stored for 30 days to achieve equilibrium for 238U and 232Th with their respective progeny.

F. Measurement Methodology

Sample preparation and all radioactivity measurements were made in the Sample Preparation Laboratory and Gammaspectrometry Laboratory of the Life Sciences Division, Sri Lanka Atomic Energy Board. Gamma spectrometry measurements were made with an Ultra-Low Background Broad Energy High Purity Ge Detector (BEGe) of 48% relative efficiency and resolution 2.0 keV at the 1332.5 keV of 60Co (Model BE5030, Canberra). The active area of the U-style cryostat detector was 5000 mm^2 and active diameter was 81 mm [15]. The detector was shielded in a 15 cm thick lead, internally lined with graded cupper and tin.

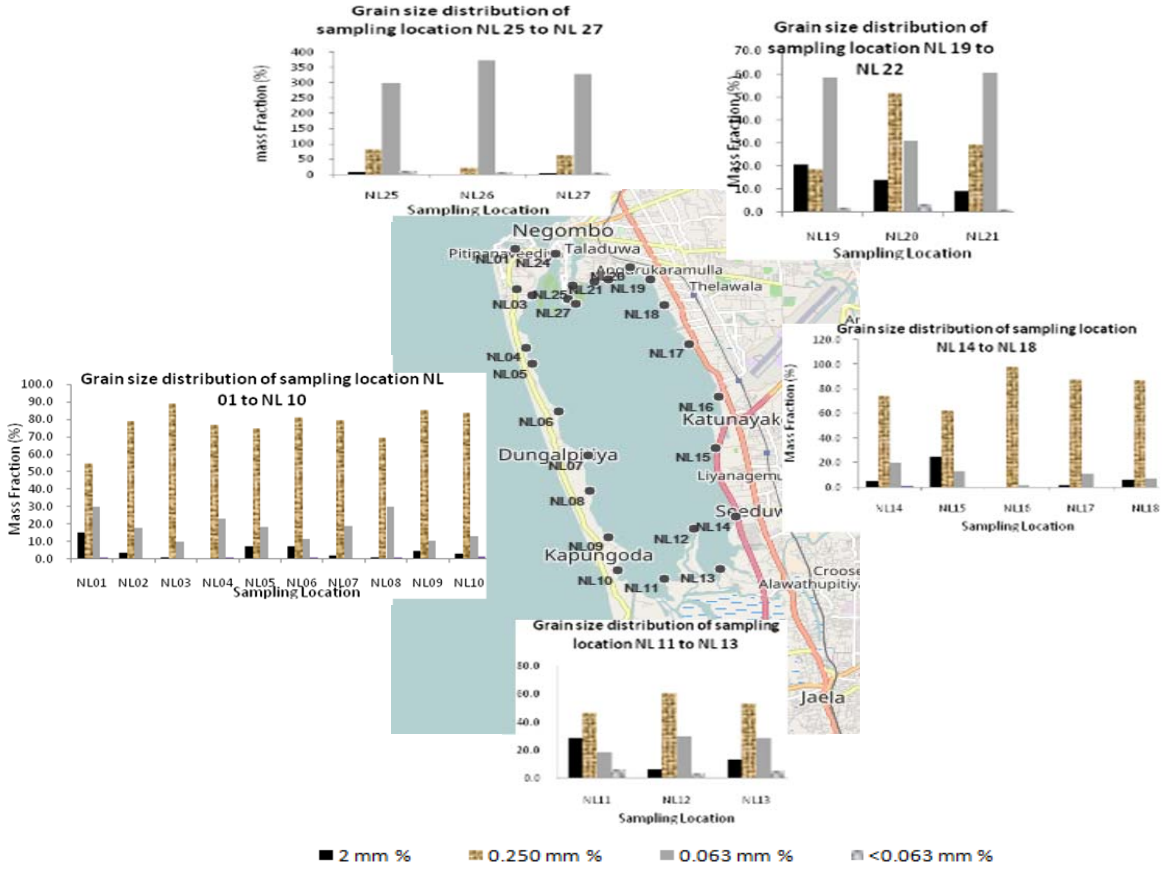


Fig. 3 Weight fraction of sediment samples in different particle sizes

The detector output was connected to a Multi-Channel Analyzer (Canberra, MCA Type DSA-LX). The energy and efficiency calibration of the spectrometer were carried out using Canberra Industries' Laboratory Source-less Calibration Software (LabSOCS) mathematical efficiency calibration approach and Geometry composer software. The counting times for each sample and background were 72000 s and 50000 s, respectively.

III. Results and Discussion

A. The Activity Concentrations of Interested Gamma Emitters in Sediments

The dry weight activity concentrations of the main gamma emitting radio nuclides of the U series, Th series, 40K, 235U, 210Pb and 137Cs in the sediment samples are shown in Table I.

The average concentrations of 238U, 232Th, 40K, 235U, 210Pb and 137Cs were found to be 23.6 ± 3.5, 67.3 ± 8.8, 181.2 ± 10.3, 3.5 ± 0.4, 59.1 ± 7.6 and 0.47 ± 0.08 Bq/kg (dry weight) in sediment samples, respectively.

TABLE I
ACTIVITY CONCENTRATIONS OF RADIO NUCLIDES IN SEDIMENTS

Country	Range (Mean) activity in Bq/kg			Reference
	Ra-226	Th-232	K-40	
India	(5.31)	(34.04)	(401.11)	[1]
Bangladesh	(38)	(66)	(272)	[16]
China	18-135 (50)	35-228 (90)	281-711 (524)	[17]
Japan	5-130	5-185	75-1400	[18]
Italy	42–70	31–37	410–475	[19]
Nigeria	(16)	(24)	(35)	[20]
Saudi Arabia	4.4-19.3	5.3-58.9	324.6-1133	[21]
Kuwait	18.6–21.4	14.0–17.1	351.2–404.0	[22]
Oman	11.8–22.7	10.7–25	223–535	[23]
Egypt	(17)	(18)	(316)	[24]
USA	(64)	(36)	(472)	[25]
World	10-50 (25)	7-50 (25)	100-700 (370)	[12]
Sri Lanka	6-55 (24)	10-182 (70)	32-454 (181)	present work

The worldwide concentrations of the radio nuclides 238U, 232Th, and 40K have averages in the sediment samples of 25, 25, and 373 Bq/kg, respectively [16]. The results show that the mean activity concentrations of 40K radio nuclides is low and mean activity concentrations of 232Th and 238U are high and similar, and respectively comparable with the worldwide concentrations. For comparison, the activity concentrations of 238U, 232Th and 40K for river and coastal environmental sediments of different countries are presented in Table II.

The 232Th and 238U radio activity concentrations of the lagoon sediments were high compared to the 40K concentration. This result proves the fact of uranium and thorium nuclides are associated with heavy minerals and 40K is concentrated with clay minerals. The average sediment sample collected from Negombo lagoon bank contained maximum mass fraction of sand and find sand (over 90%) and very less mass fraction of fine silt+clay (1.3%). The relationship of distribution of 40K and percentage clay in the sediments is illustrated in Fig. 4.

TABLE II
ACTIVITY CONCENTRATIONS FOR RIVER AND COASTAL ENVIRONMENTAL SEDIMENTS OF DIFFERENT COUNTRIES

Sample Code	40K Bq/kg	137Cs Bq/kg	210Pb Bq/kg	238U Series (Bq/kg)			232Th Series (Bq/kg)			235U Bq/kg
				214Bi	214Pb	214Pb	212Pb	208Tl	228Ac	
NL01	313 ± 26	0.30 ± 0.05	73 ± 12	35 ± 3	39 ± 4	39 ± 4	125 ± 13	103 ± 10	120 ± 10	5.13 ± 0.59
NL02	81 ± 4	ND	9 ± 2	7 ± 1	9 ± 1	9 ± 1	21 ± 2	17 ± 1	19 ± 1	1.19 ± 0.14
NL03	170 ± 8	ND	38 ± 6	29 ± 2	33 ± 3	34 ± 3	110 ± 9	79 ± 5	92 ± 5	4.06 ± 0.41
NL04	84 ± 4	ND	26 ± 4	18 ± 1	20 ± 2	21 ± 2	55 ± 4	45 ± 3	52 ± 3	2.98 ± 0.29
NL05	77 ± 6	ND	22 ± 4	14 ± 1	15 ± 1	15 ± 2	38 ± 4	31 ± 3	36 ± 3	2.12 ± 0.25
NL07	63 ± 3	ND	14 ± 2	8 ± 1	9 ± 1	9 ± 1	23 ± 2	19 ± 1	23 ± 1	1.41 ± 0.16
NL08	55 ± 3	ND	25 ± 4	17 ± 1	18 ± 1	19 ± 2	28 ± 2	23 ± 1	29 ± 2	2.34 ± 0.24
NL09	83 ± 6	ND	17 ± 3	11 ± 1	12 ± 1	12 ± 1	31 ± 3	25 ± 2	30 ± 2	1.64 ± 0.19
NL10	158 ± 14	0.54 ± 0.14	58 ± 10	23 ± 2	26 ± 3	25 ± 3	71 ± 8	58 ± 6	67 ± 6	4.78 ± 0.58
NL11	152 ± 11	0.26 ± 0.04	46 ± 7	32 ± 3	36 ± 4	36 ± 4	124 ± 12	89 ± 8	104 ± 8	5.37 ± 0.58
NL12	106 ± 8	ND	11 ± 2	8 ± 1	8 ± 1	9 ± 1	24 ± 2	20 ± 2	22 ± 2	1.21 ± 0.16
NL13	154 ± 12	ND	29 ± 5	19 ± 2	21 ± 2	22 ± 2	59 ± 6	49 ± 4	59 ± 5	3.47 ± 0.41
NL14	32 ± 2	ND	15 ± 3	4.8 ± 0.4	6 ± 1	6 ± 1	11 ± 1	10 ± 1	10 ± 1	1.29 ± 0.15
NL15	36 ± 3	ND	26 ± 4	18 ± 2	21 ± 2	20 ± 2	76 ± 8	61 ± 5	73 ± 6	2.95 ± 0.35
NL16	37 ± 2	0.09 ± 0.03	19 ± 3	12 ± 1	14 ± 1	14 ± 1	39 ± 3	32 ± 2	37 ± 2	1.87 ± 0.18
NL17	63 ± 4	0.33 ± 0.08	340 ± 6	27 ± 2	31 ± 3	29 ± 2	120 ± 10	98 ± 6	114 ± 5	4.18 ± 0.43
NL18	138 ± 15	0.58 ± 0.15	63 ± 11	7 ± 1	8 ± 1	7 ± 1	24 ± 3	21 ± 2	20 ± 2	2.9 ± 0.4
NL19	137 ± 13	0.45 ± 0.09	49 ± 9	15 ± 2	17 ± 2	18 ± 2	46 ± 5	37 ± 4	41 ± 4	2.71 ± 0.36
NL20	256 ± 12	0.96 ± 0.13	121 ± 18	18 ± 1	19 ± 2	17 ± 2	56 ± 5	45 ± 3	51 ± 3	4.48 ± 0.45
NL21	447 ± 21	ND	50 ± 9	30 ± 2	33 ± 3	33 ± 3	102 ± 8	81 ± 5	102 ± 5	4.42 ± 0.56
NL22	300 ± 14	ND	37 ± 7	42 ± 3	46 ± 4	46 ± 4	161 ± 13	135 ± 8	164 ± 8	5.58 ± 0.61
NL23	349 ± 15	1.2 ± 0.1	206 ± 30	23 ± 1	26 ± 2	25 ± 2	85 ± 7	66 ± 4	66 ± 3	4.8 ± 0.5
NL25	435 ± 19	ND	77 ± 12	50 ± 3	56 ± 4	54 ± 4	184 ± 15	148 ± 9	176 ± 8	7.33 ± 0.71
NL26	454 ± 21	ND	67 ± 11	51 ± 3	56 ± 4	57 ± 5	196 ± 16	160 ± 10	192 ± 9	6.53 ± 0.71
NL27	351 ± 17	ND	40 ± 8	30 ± 2	33 ± 3	35 ± 3	103 ± 8	87 ± 6	103 ± 5	4.0 ± 0.5

The natural radio nuclides', 238U, 232Th and 40K, activities did not show a uniform distribution depending on radioactivity values of the rocks, forming the geological structure of this region. The heat maps generated using ArcGIS visualize the distribution of radionuclides of 238U, 232Th and 40K. All the interested radionuclides have been concentrated in the mouth of lagoon where the water is salty and blackish.

The distribution of 238U, 232Th and 40K activity concentrations of sediment samples in Negombo lagoon bank are shown in Figs. 5 (a)-(c).

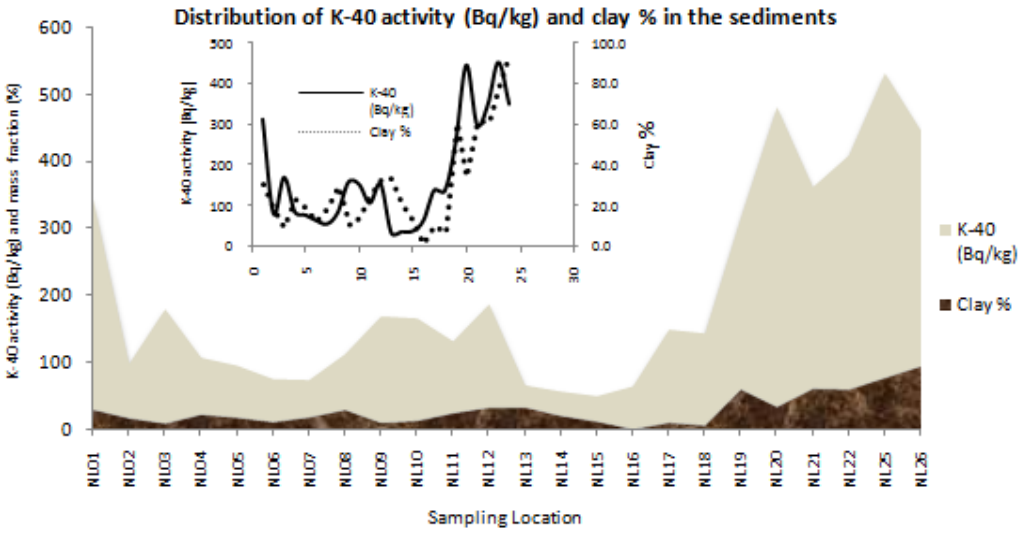
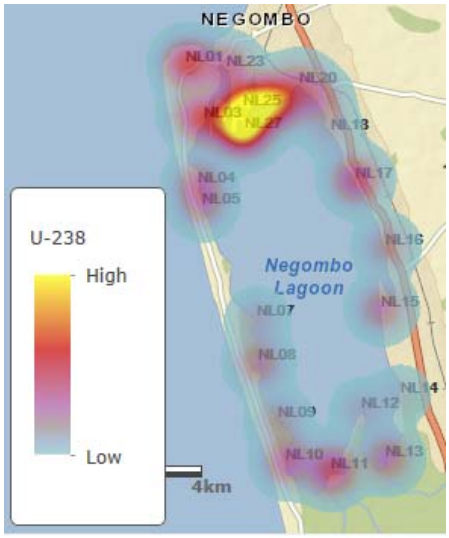
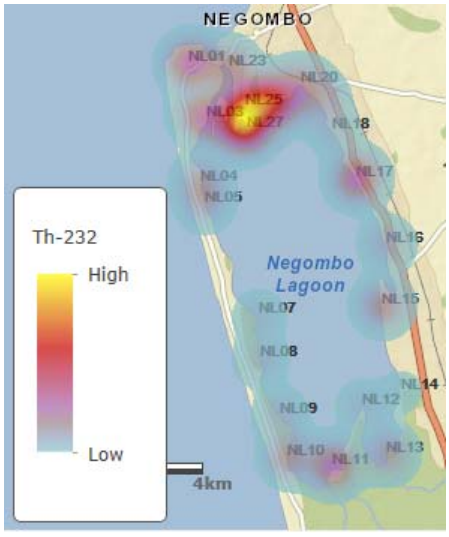


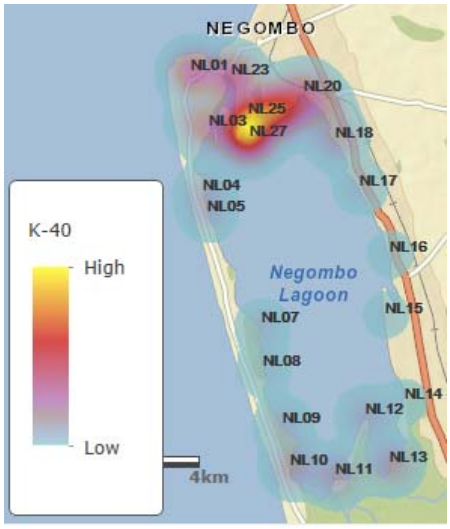
Fig. 4 Relationship of the distribution of 40K radioactivity and percentage mass fraction of clay in the sediments



(a)



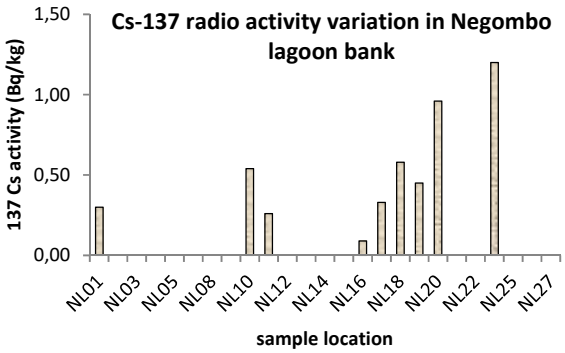
(b)



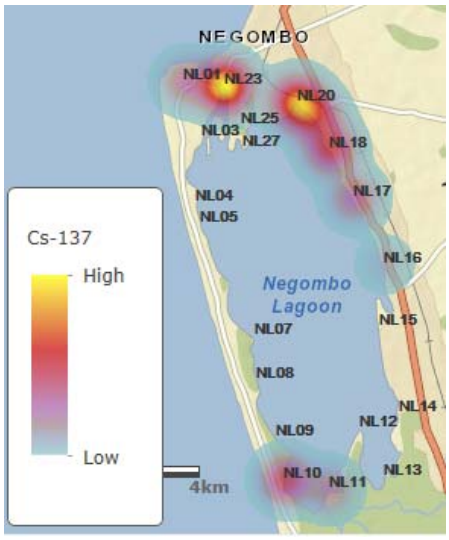
(c)

Fig. 5 The distribution of 238U, 232Th and 40K activity concentrations of sediments

The geological compositions of the sampling points from NL 19 to NL 27 consist of a higher percentage of fine silt+ clay than other sampling points, as shown in Fig. 3. Because of this variation of geologic composition, there is a significant difference among the concentration levels of natural radio nuclides existing. As well, 137Cs is released into the environment of the South Asian region as fallout radionuclide due to nuclear power plant accidents at Chernobyl, Ukraine in April 1986 and Fukushima, Japan in March 2011, as well as from atmospheric nuclear weapon tests conducted by several countries. Significant differences in 137Cs activity in sediment samples were observed in this study as in Fig. 6. The recorded 137Cs activities in sediment samples varied from 0.09 to 1.2 Bq/kg and average 137Cs activity was found to be 0.52 Bq/kg in 09 out of 25 sampling points.



(a)



(b)

Fig. 6 137Cs radio activity variation in sediment samples

B. Calculation of Radiation Hazard Parameters

Different known radiation health hazard indices analyses have been used in radiation studies to arrive at a better and safer conclusion on the health status of a radiated or irradiated person and environment. These indices, due to the radiation concentrations of top surface sediments of the Negombo lagoon, can be estimated using the results obtained from this study.

1. Absorbed Dose Rate in Air (D)

Absorbed dose is a physical dose representing the mean energy imparted to matter per unit mass by ionizing radiation. The contribution of natural radio nuclides to the absorbed dose rate in air (D) at 1 m above the ground depends on the natural specific activity concentration of 238U, 232Th and 40K. The absorbed dose rate in air can be calculated using (1) [26], [11]:

$$D\left(\frac{nGy}{h}\right) = 0.427A_U + 0.662A_{Th} + 0.0432A_K \quad (1)$$

where D is the dose rate at 1 m above the ground, A_U, A_{Th} and A_K are the activity concentrations of 238U, 232Th and 40K, respectively, in the samples. The conversion factors of 238U, 232Th and 40K are 0.427, 0.662 and 0.0432 nGy/h per Bq/kg, respectively [27]. The absorbed dose rates in air at Negombo lagoon varied from 10.1 to 154.6 nGy/h and the average dose rate was 60.8 nGy/h. The absorbed dose rates in air for the areas under investigation are listed in Table III. The average dose rate value in Negombo lagoon sediment is higher than the international recommended absorbed dose rate value of 55 nGy/h [11].

2. Radium Equivalent Activity (Ra_{eq})

The Gamma-ray radiation hazards due to the specified radio nuclides 226Ra, 232Th and 40K were assessed by different indices. Radium equivalent (Ra_{eq}) is a common index used to compare the specific activities of materials containing 226Ra, 232Th and 40K by a single quantity, which takes into account the radiation hazards associated with them [28]. Radium equivalent activity is a widely used hazard index and it provides a useful guideline in regulating the safety standard dwellings. The radium equivalent activity represents a weighted sum of activities of the above-mentioned natural radio nuclides and is based on the estimation that 1 Bq/kg of 226 Ra, 0.7 Bq/kg of 232 Th, and 13 Bq/kg of 40 K produce the same radiation dose rates. The Ra-equivalent activity (Ra_{eq}) can be calculated using (2) [29]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of 226Ra, 232Th and 40K in Bq/kg respectively. Ra_{eq} was estimated for the collected sediment samples and given in Table III. The values of Ra_{eq} varied from 22.7 to 348.8 Bq/kg and average value of Ra_{eq} was found to be 137.3 Bq/kg. The estimated average values of Ra_{eq} in the present work were lower than the recommended maximum value of 370 Bq/kg [28]. While comparing the measured mean values from some of the other countries, it was observed that the values of this work were lower than the measured values of 493.8 Bq/kg in the Eastern Desert of Egypt [30], 366.9 Bq/kg in the southeast part of Eskisehir (Turkey) [31] and 266 Bq/kg in Xiazhuang Granite Area (China) [32].

3. External Hazard Index (Hex)

Many naturally occurring radio nuclides produce an external radiation field to which all human beings are exposed. In terms of dose, the principal primordial radio nuclides are 232Th, 238U and 40K. The external hazard index, H_{ex} was calculated for the sediment samples using (3) [29]:

$$H_{ex} = A_{Ra/370} + A_{Th/259} + A_{K/4810} \leq 1 \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of 226Ra, 232Th and 40K in Bq/kg, respectively. The results of Hex based on the criterion equation (3) are given in Table III. The results range from 0.06 to 0.95 and average value was found to be 0.4. All the values estimated for Hex in the present work are lower than 1. The average values of Hex were found to be 2.03 for Eastern Desert of Egypt [29], 0.99 for the

southeast part of Eskisehir (Turkey) [31] and 0.84 for Xiazhuang Granite Area (China) [32].

4. Annual Gonadal Dose Equivalent (AGDE)

The gonads, bone marrow and bone surface cells are considered as organs of interest [11]. The AGDE for the residents of a building using a material with a given activity concentration of 226Ra, 232Th and 40K was calculated using (4) [33]:

$$AGDE\left(\frac{\mu Sv}{year}\right) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (4)$$

The obtained values of AGDE are listed in Table III. The values of AGDE varied from 70.4 to 1078.4 μSv/year and the average value was found to be 425.3 mSv/year. The average value of AGDE was found to be 2398 mSv/year for Eastern Desert of Egypt [30]. This value of AGDE is higher than the result in this study.

5. Annual Effective Dose Equivalent (AEDE)

To estimate the annual effective doses, it is taken into account the conversion coefficient from absorbed dose in air and the outdoor occupancy factor. A value of 0.7 Sv/Gy was used for the conversion coefficient from absorbed dose in air to effective dose received by adults, and 0.2 for the outdoor occupancy factor [12]. The annual effective dose equivalent was calculated from (5) [34]:

$$AEDE\left(\frac{\mu Sv}{year}\right) = D\left(\frac{nGy}{h}\right) \times 8760\left(\frac{h}{year}\right) \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \times 10^{-3} (5)$$

TABLE III
RISK INDICES OF NATURAL RADIO NUCLIDES FOR THE SEDIMENT SAMPLES

Sample Code	DR (nGy/h)	Raeq Bq/kg	Hex Bq/kg	AGDE (μSv/year)	AEDR (μSv/year)
NL01	100.69	226.95	0.62	704.19	123.48
NL02	18.73	41.55	0.11	131.75	22.97
NL03	78.35	178.68	0.49	546.40	96.09
NL04	43.29	98.95	0.27	301.86	53.09
NL05	31.33	71.15	0.19	218.94	38.43
NL06	0.00	0.00	0.00	0.00	0.00
NL07	19.88	44.73	0.12	139.24	24.39
NL08	26.78	60.49	0.16	185.92	32.84
NL09	26.30	59.20	0.16	184.11	32.26
NL10	57.36	129.58	0.35	400.32	70.34
NL11	86.09	197.40	0.54	599.64	105.58
NL12	21.54	47.17	0.13	150.90	26.42
NL13	49.61	110.87	0.30	344.32	60.84
NL14	10.11	22.66	0.06	70.74	12.40
NL15	52.97	123.73	0.33	369.03	64.96
NL16	29.52	68.15	0.18	205.57	36.20
NL17	82.73	192.87	0.52	575.79	101.46
NL18	22.17	48.10	0.13	156.97	27.19
NL19	38.32	85.95	0.23	269.07	47.00
NL20	49.71	109.51	0.30	351.32	60.97
NL21	90.90	200.17	0.55	639.52	111.47
NL22	125.90	286.56	0.78	878.20	154.40
NL23	69.81	153.70	0.42	491.69	85.62
NL25	145.11	328.60	0.90	1017.47	177.96
NL26	154.60	348.84	0.95	1078.74	189.60
NL27	88.91	197.31	0.54	620.62	109.04

The results of the calculation are given in Table III. The annual effective dose rate values varied from 12.4 to 189.6 mSv/year and the average value was found to be 74.6 mSv/ year. The world average AEDE from outdoor terrestrial gamma radiation is 70 mSv/year [11], [35]. So, the obtained value is little bit higher than the world average value. The average AEDE value was calculated to be 152 mSv/year in the Xiazhuang Granite Area (China) [32], 314.1 mSv/year in the southeast part of Eskisehir (Turkey) [31], 69.8 mSv/year in Istanbul (Turkey) [36]. These average values are generally higher than the results of the current study.

A summary of the aforementioned radiation hazard parameters is presented in Table IV.

TABLE IV
COMPARISON OF PRESENT RESULTS WITH THE CORRESPONDING WORLD AVERAGE VALUES

Radiological parameters	Present results (Average)	World average	Ratio of the Present average/ world average
^{238}U Bq/kg	24	25	0.96
^{232}ThBq/kg	70	25	2.8
^{40}K Bq/kg	181	370	0.4
Absorbed dose rate in air	60.8	55	1.1
Radium equivalent activity	137.3	370	0.4
External hazard index	0.4	1	0.4
AEDE	74.6	70	1.1

IV. CONCLUSION

The activity levels and distribution of natural and anthropogenic terrestrial radionuclides of 238U, 226Ra, 232Th, and 40K were measured by gamma-ray spectrometry system for top surface sediment samples collected from Negombo lagoon, Sri Lanka. The activity concentrations of uranium, potassium and radium in the studied sediments are found to be normal, whereas thorium is having slightly greater value. The mean concentrations of the radio nuclides 238U, 232Th, 137Cs, and 40K in sediment samples determined in this study have been compared with literature values.

From the measured values, the average values of absorbed dose rate in air (D), radium equivalent activity (Ra_{eq}), external hazard index (Hex), AGDE and AEDE were calculated. The outdoor air absorbed dose rates (D) due to terrestrial gamma rays for sediment have been calculated because of agricultural area and living in the surrounding. The radium equivalent activity (Ra_{eq}), external hazard index (Hex) and AGDE are calculated to assess the radiological hazard of sand mixed with sediment since sand is used as construction materials in this region. The AEDE is higher than the world average. Nevertheless, the health effects due to natural radiation from the sediment of the Negombo lagoon are low and thus, the health hazards are insignificant. This study can be used as a baseline for future investigations and the data obtained in this study may be useful for natural radioactivity mapping. It seems necessary to determine the radioactivity concentrations in sediments of other coastal marine environments of Sri Lanka. The results may also be used as reference data for monitoring possible radioactivity pollution in the future.

ACKNOWLEDGMENT

H.M.N.L. Handagiripathira would like to thank V.A. Waduge, M.C.S. Seneviratneand T.N. Attanayakeof Life Sciences Division of Sri Lanka Atomic Energy Board for all the guidance and support given for this study.

REFERENCES

[1] S. Murugesan, S. Mullainathan, V. Ramasamy and V. Meenakshisundaram. Radioactivity and radiation hazard assessment of Cauvery River, Tamilnadu, India. Iran. J. Radiat. Res., 2011; 8(4): 211-222

[2] V. Kannana, M.P. Rajana, M.A.R. Iyengara, R. Rameshb. Distribution of natural and anthropogenic radionuclides in soil and beach sand samples of Kalpakkam (India) using hyper pure germanium (HPGe) gamma ray spectrometry. Applied Radiation and Isotopes 57 (2002) 109–119

[3] D. E. Walling, Q. He & T. A. Quine, Use of caesium-137 and lead-210 as tracers in soil erosion investigations. Tracer Technologies for Hydrological Systems (Proceedings of a Boulder Symposium, July 1995). IAHS Publ. no. 229, 1995

[4] Taskin H, Karavus M, TopuzogluA, Hindiroglu S, Karahan G (2009). Radionuclide concentrations in soil and Lifetime cancer risk due to the gamma radioactivity in Kirklareli, Turkey. J. Environmental Radioactivity. 100: 49-53

[5] Shams Issa, Mohamed Uosif, Reda Elsaman. Gamma radioactivity measurements in Nile River sediment samples. Turkish J EngEnvSci (2013) 37: 109 – 122

[6] He, Q., Walling, D.E., 1996. Interpreting particle size effects in the adsorption of 137Cs and unsupported 210Pb by mineral soils and sediments. J. Environ. Radioact. 30, 117-137.

[7] Schulling, R.D., De Meijer, R.J., Riezebos, H.J., Scholten, M.J., 1985. Grain size distribution of different mineral in a sediment as a function of their specific activity. Geology enMijnbouw 64, 199-203.

[8] Ligero, R.A., Ramos-Lerate, I., Barrera, M., Casas-Ruiz, M., 2001. Relationships between sea-bed radionuclide activities and some sedimentological variables. J. Environ. Radioact. 57, 7-19.

[9] Cho, Y.H., Jeong, C.H., Hahn, R.S., 1996. Sorption characteristics of 137Cs on to clay minerals: effect of mineral structure and ionic strength. J. Radioanal. Nucl. Chem. 204, 33-43.

[10] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1982.

[11] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1988. Sources, effects and risks of ionizing radiation. Report to the General Assembly, With Annexes, United Nations, New York.

[12] United Nations Scientific Committee on Effects of Atomic Radiation, "Exposures from Natural Radiation Sources", UNSCEAR Report, New York, 2000.

[13] Silva, E. I. L.; Katupotha, J.; Amarasinghe, O.; Manthrithilake, H.; Ariyaratna, R. 2013. Lagoons of Sri Lanka: from the origins to the present. Colombo, Sri Lanka: International Water Management Institute (IWMI). 122p. doi: 10.5337/2013.215

[14] IAEA 1989 Technical Report Series No. 295 Measurement of Radionuclides in Food and the Environment: a Guidebook (Vienna: IAEA)

[15] Technical specification sheet of Broad Energy Germanium Detectors (BEGe) issued by Canberra Industries Inc. (www.canberra.com, BEGe-SS-C40426-BE5030 detector details)

[16] Mantazul IC, Alam MN, Hazari SKS (1999) Distribution of radio nuclides in the river sediments and coastal soils of Chittagong Bangladesh and evaluation of the radiation hazard. Applied Radiation and Isotopes, 51: 747755. 29

[17] Ziquiang P, Yin Y, Mingqiang G (1988) National radiation and radioactivity in China. Radiation Protection Dosimetry, 24: 29-38

[18] Megumi K., Oka T., Doi M., Kinura S., Tsujimoto T., Ishiyama T. &Katsurayama K., 1988 Relationships between the concentration of natural Radionuclides and the Mineral composition of the surface soil. Radia. Protect. Dosim, 24, 69-72

[19] Doretti, L., Ferrar, D., Barison, G., Gerbasi, R., Battiston, G., 1992. Natural radionuclides in the muds and waters used in thermal therapy in AbanoTerme, Italy. Radiat. Prot. Dosim. 45 (1), 175–178.

[20] Arogunjo AM, Farai IP, Fuwape IA (2004) Dose rate assessment of terrestrial gamma radiation in the delta region of Nigeria. Radiation Protection Dosimetry, 108: 73-77.

[21] Al-Trabulsy, H.A.; Khater, A.E. and Habbani, F.I. (2011): Radioactivity levels and radiological hazard indices at the Saudi coastline of the Gulf of Aqaba. Radiation Physics and Chemistry 80: 343–348

[22] Al-Zamel, A.Z., Bou-Rabee, F., Olszewski, M., Bem, H., 2005. Natural radionuclides and 137Cs activity concentration in the bottom sediment cores from Kuwait Bay. Journal of Radioanalytical and Nuclear chemistry 266, 269-276.

[23] Zare, M.R., Mostajaboddavati, M., Kamali, M., Abdi, M.R., Mortazavi, M.S., 2012. 235U, 238U, 232Th, 40K and 137Cs activity concentrations in marine sediments along the northern coast of Oman Sea using high-resolution gamma-ray spectrometry. Mar. Pollut. Bull. 64 (9), 1956–1961

[24] Ibrahiem NM, Abd El, Ghani AH, Shawky SM, Ashraf EM, Farouk MA (1993) Measurement of radioactivity levels in soil in the Nile Delta and middle Egypt. Health Physics, 64: 297-299.

[25] Delune RD, Jones GL, Smith CJ (1986) Radionuclide concentrations in Louisiana soils and sediments. Health Physics, 51: 239-244.

[26] Beck HL (1972) The physics of environmental radiation fields. Natural radiation environment II. CONF-720805 P2. Proceedings of the Second International symposium on the Natural Radiation Environment.

[27] UNSCEAR, 1988. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effect of Atomic Radiation, United Nations, New York.

[28] Caroline NihinlolaIwetan, IbiyinkaAgboolaFuwape, Adeseye Muyiwa Arogunjo, Ganiyu Obor. Assessment of Activity Concentration of Radionuclides in Sediment from Oil Producing Communities of Delta State, Nigeria. Journal of Environmental Protection, 2015, 6, 640-650

[29] J. Beretka, P.J. Mathew. Natural radioactivity of Australian building materials, industrial wastewaters and by-products. Health Physics, 48 (1985), pp. 87–95

[30] Arafa W (2004) Specific activity and hazards of granite samples collected from the Eastern Desert of Egypt. J Environ Radioact 75:315–327

[31] Orgun Y, Altınsoy N, Gultekin AH, Karahan G, Celebi N (2005) Natural radioactivity levels in granitic plutons and groundwaters in Southeast part of Eskisehir, Turkey. ApplRadiatIsot 63:267–275

[32] Yang HS, Nozaki Y, Sakai H, Nagaya Y, Nakamura K (1986) Natural and man-made radionuclide distributions in Northwest pacific deep-sea sediments: rates of sedimentation, bioturbation and 226Ra migration. Geochem J 20:29–40

[33] K. Mamont-Ciesla, B. Gwiazdowski, M. Biernacka, A. ZakRadioactivity of building materials in Poland. Natural radiation environment, Halsted Press, New York (1982)

[34] I. Akkurt and K. Günoğlu Natural Radioactivity Measurements and Radiation Dose Estimation in Some Sedimentary Rock Samples in Turkey. Research Article | Open Access, Volume 2014 |Article ID 950978 | https://doi.org/10.1155/2014/950978

[35] Faweya E. B., Alabi F. O. and Adewumi T., Determination of radioactivity level and hazard assessment of unconsolidated sand and shale soil samples from petroleum oil field at Oredo (Benin, Niger Delta-Nigeria). Arch. Appl. Sci. Res., 2014, 6 (2):76-81

[36] Y Örgün, N Altınsoy, AH Gültekin, G Karahan, N Celebi. Natural radioactivity levels in granitic plutons and ground waters in Southeast part of Eskisehir, Turkey, Applied Radiation and Isotopes (2005) 63 (2), 267-275