Distribution of ^{40}K, ^{232}Th and ^{238}U in Soils of Southern and Western Coasts of Viti Levu, Fiji

Sitaram Garimella and Umawatti Prasad
Department of Physics, University of the South Pacific Suva, FIJI
E-mail: garimella_s@usp.ac.fj, Umawati.Prasad@usp.ac.fj

Abstract

A 10 cm (diameter) x 7.5 cm NaI(Tl) gamma-ray spectrometer was used to measure the concentrations of ^{40}K, ^{232}Th and ^{238}U in 50 samples of top soils of the southern and western coasts of Viti Levu, the largest island of the Republic of Fiji Islands. The average activities of ^{232}Th, ^{238}U and ^{40}K in soils of this region were 2.8, 3.6 and 160 Bq kg^{-1}, respectively. The average external gamma-dose, which is likely to be delivered to the local population in this region, is estimated to be 10.3 nGy h^{-1}, well below the world average.

***Keywords**: natural gamma-rays, NaI(Tl) detector, soils, coastal Fiji, gamma dose*

1 General Introduction

The natural radioactivity of soils is weak and is due to the presence of the elements uranium, thorium and potassium. These elements emit energetic and highly penetrating radiation (known as gamma radiation) which is capable of destroying or causing mutations in cells of living beings. If available in high concentrations in environment, these elements could pose community health problems. For this reason, most countries of the world measure their concentrations in the environment (soil, vegetation, air, etc.). The concentrations of these elements in the environment could also alter in course of time due to human activities such as industrialisation.

The present work measured the concentrations of the above elements in coastal soils of Viti Levu, and calculated the radiation dose that would be delivered to living beings from such soils. The finding was that the dose in coastal regions of Fiji is smaller than the world average by a factor 5. By comparison, some islands in the South Pacific (like Marshall Islands and the Federated States of Micronesia) have similar dose rates, while others – notably Niue and parts of Guam, which are volcanic in origin ─ have values that are unusually higher than the world average.

2 Introduction

Investigations of radiation dose rates in natural environments are important for community health, as well as for radiation protection matters. The natural radioactivity in soils, which mainly contributes to these dose rates, is due mainly to the members of the ^{238}U series, ^{232}Th series and the isotope ^{40}K. Exposure dose rates from gamma rays emitted by these radionuclides were investigated in several countries. According to a United Nations report (UNSCEAR, 1993), the exposure rates in 42 countries, where three-fifths of the world population lives, vary in the range of 24 - 160 nGy h^{-1} with a population weighted average exposure rate of 58 nGy h^{-1}. Studies by Greenhouse and Miltenberger (1981) and Nelson (1977) demonstrated that, in the Pacific Ocean region, where several islands are coralline atolls or of volcanic origin, exposure rates are relatively low. In Majuro in Marschall Islands (mainly coralline atolls), the contribution to the natural radiation environment is due mainly to ^{40}K and is around 14 nGy h^{-1}. In contrast, the exposure rate in Caroline Islands (high volcanic islands) is due mainly to ^{238}U series and ^{232}Th series and the gamma dose there is about twice that of the coralline islands.

The investigation of the natural radioactivity levels in Fijian soils began in 1996 using a NaI gamma-ray spectrometer (Garimella and Kumar, 1997). The present study extends their work and reports on the concentrations of the above mentioned radionuclides in soils of the coastal regions of southern and western Viti Levu. A systematic study of natural radioactivity of Fijian soils has not been undertaken previously, although Marsden (1964) casually mentions that the natural radiation dose for Fiji is about 29 nGy h^{-1}.

2.1 The Island of Viti Levu in Fiji

The Fiji Islands are located in the South Pacific (12°20′S - 19°40′S and 176°20′E - 178°50′W). The two largest islands of the Group, Viti Levu and Vanua Levu, are encircled by about 300 smaller islands. On the eastern edge of the north Fiji Basin, Fiji has lain at a bend in the boundary between the Indo-Australia and the Pacific plates since the early Oligocene (See Rodda (1994) for geology of the Fiji Islands). Parts of Fiji have undergone considerable fragmentation, displacement and rotation, during their geological evolution. Rotation of the Fiji Platform ceased approximately 2.5 Ma ago. The age of rocks in Fiji lies in the range from Recent to Late Eocene (40 Ma). Table 1 outlines the geology of the region investigated in this work.

3 Sampling and Measurement

From a land area of about 350 km^2, 50 undisturbed but easily accessible sites between Suva and Ba were selected in the coastal region (Figure 1) for analysis of natural radioactivity. Since the coastal region is heavily cultivated, only one soil sample from each site was collected. Samples, normally from a depth of 6-30 cm (6-15 cm where soil cover was thin), were

initially dried at room temperature and then in an oven at 85°C for 24 h. After removal of stones and vegetation, the samples were ground to a fine powder and homogenised by thorough mixing. The samples were stored in air-tight Marinelli beakers (mild steel, capacity 1178 cm^3) for at least one month before counting began, to ensure radioactive equilibrium between ^{226}Ra and its short-lived daughters. The average mass of the dried samples was about 1.2 kg. A radioactive equilibrium between ^{238}U and ^{226}Ra in the samples is assumed, although this is not possible in many cases.

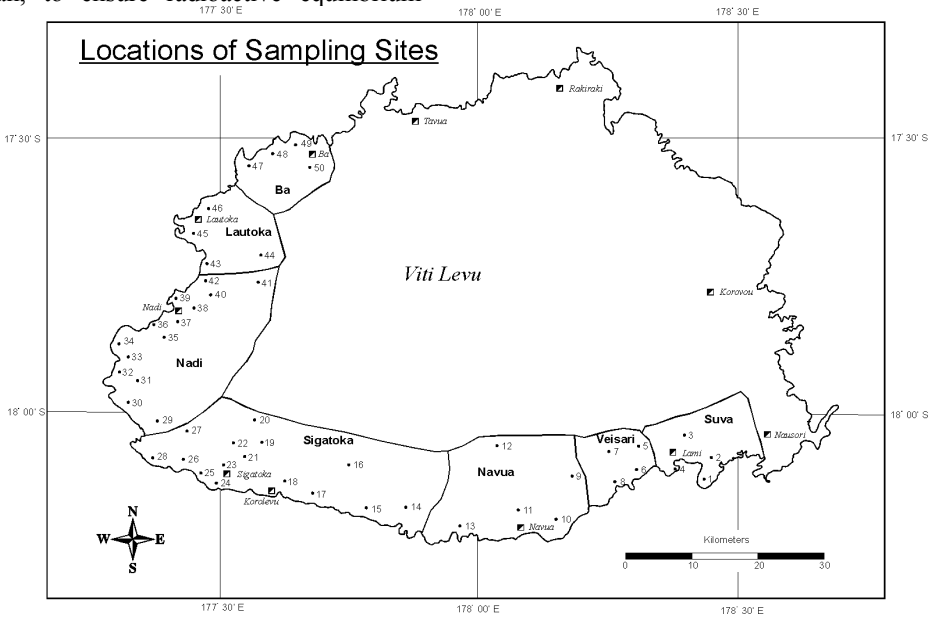

Figure. 1. Sampling sites (the borders of regions shown are unofficial, and drawn for convenience only)

Table 1 Sampling sites, rock types and ages

Region	Sample Nos.	Description
Suva	1 - 4 (4 samples)	Fine and course marine sediments uplifted (early Pliocene), volcanic flows (early Pliocene) and volcanic flows (early Miocene). Some rain forest, cleared for cultivation
Veisari	5 - 8 (4 samples)	Geology same as for Suva region (Mid-Miocene to early Pliocene rocks), coastal ranges, coastal strip for cultivation
Navua	9 - 13 (5 samples)	Marine sediments (Pliocene), volcanics - late Miocene flows, river delta leading up to coastal ranges
Sigatoka	14 - 28 (15 samples)	Geology varies: Miocene stocks, Upper Oligocene volcanics and sediments, Upper Miocene sediments - some metamorphosed limestones. Undulating, drier, grassland area much under pine cultivation, with sugarcane
Nadi	29 - 42 (14 samples)	Geology - ranges from Miocene stocks, older Oligocene Yavuna stock, and primitive basalts, to Upper Miocene sediments. Flat coastal rising to ranges east of Nadi Town (andesite flows). Flat land under sugarcane
Lautoka	43 - 46 (4 samples)	Pliocene shoshonitic or calc-alkaline basalt flows; Upper Miocene to Holocene sediments. Several caldera remnants with occurring *Au* mineralisations. Flat coastal rising to easterly ranges (andesite flows)
Ba	47 - 50 (4 samples)	Main outcrops of Ba Volcanic Group (Pliocene/Late basalts and andesites, some younger (Late Miocene) sediments. Coastal flats under sugarcane cultivation, with ranges rising to the south of Ba Town.

Table 2 Characteristics of the NaI (Tl) gamma-ray spectrometer*

Element measured	Isotope used	Gamma Energy (MeV)	Energy Region (MeV)	Efficiency (%)	Background (cpm)	MDA** (Bq kg^{-1})
K	^{40}K	1.46	1.34 - 1.58	4.1	13.5	3.3
U	^{214}Bi	1.76	1.65 - 1.87	2.5	6.2	0.6
Th	^{208}Tl	2.62	2.49 - 2.74	2.1	3.7	0.6

* NaI(Tl) detector dimensions: 10 cm diameter, 7.5 cm height

** for a 1.2 kg sample and 20,000 s counting period.

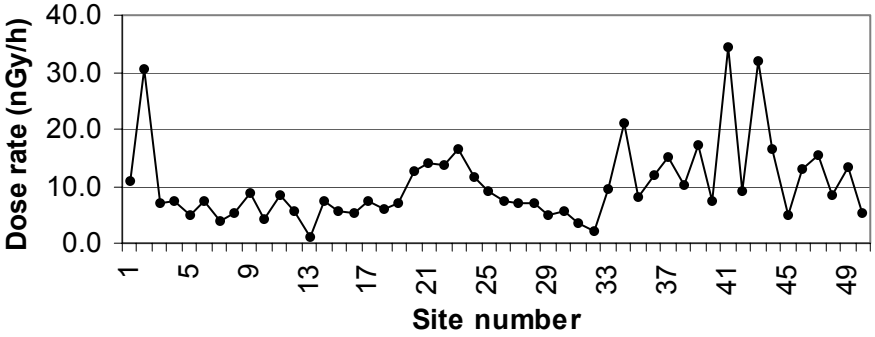

Figure 2 Gamma dose rate given out by ^{232}Th series, ^{238}U series and ^{40}K in soils of the southern and western coastal Viti Levu (Site locations given in Fig.1)

3.1 Gamma-ray spectrometer

The main components of the gamma-ray spectrometer used in this work are a 10 x 7.5 cm NaI(Tl) crystal and a 256 channel pulse height analyser. The detector was surrounded by a low background shield consisting of 10 cm thick lead walls. Details about the experimental set-up and the method of measurement are given by Garimella and Kumar (1997). The system was calibrated using bulk standard sources RGU-1, RGTh-1 (IAEA, 1987) and KCl (reagent grade, purity 99.8%) which were mixed with silica. The soils and standards were counted under identical conditions of sample-detector geometry and counting time (20,000 s). Table 2 gives the important characteristics of the system, including the minimum detectable activities (MDA) for the various nuclides.

From measurement of the standard sources, following empirical equations were established (Garimella and Kumar, 1997) to relate the mass M of Th (mg), U (mg) and K (g) in a soil sample to the background-subtracted count rates R (cpm) in their respective gamma peaks:

$$M_{Th} = 1.8\, R_{Th}$$
$$M_{U} = 8.0\, R_{U} - 5.6\, R_{Th}$$
$$M_{K} = 7.5\, R_{K} - 8.2\, R_{U} - 0.24\, R_{Th}$$

4 Results and Discussion

Calculated masses of Th, U and K were converted into specific activities (Bq kg^{-1}) of the nuclides ^{232}Th, ^{238}U, and ^{40}K. (Table 3, see Appendix). The activities of ^{232}Th, ^{238}U, and ^{40}K are in the ranges <0.6-8.2, <0.6-13.3, and 10-619 Bq kg^{-1}, respectively. The errors (due different densities of soils and the standards and due to counting statistics) in these figures were in the range of 15-20%.

The external gamma dose rates that are likely to be delivered to the population of the region from natural radioactivity were computed from the calculated masses of Th, U and K in soils using the dose conversion rates given by UNSCEAR (1982).

Figure 2 shows that the average total dose rates for the southern coastal regions of Suva, Veisari, Navua and some parts of Sigatoka are in the range of 4-10 nGy h^{-1}, while those in the western regions (Nadi, Lautoka and Ba) are generally above 10 nGy h^{-1}. The coast from Suva to Sigatoka is fringed by reefal units with the landward side featuring exposures of conglomeritic basalts, Upper Miocene sediments and some older Wainimala rocks. Some parts of Sigatoka (sites 19 - 24), located in steep slopes but in the vicinity of the Sigatoka river, are also characterised by dose rates above 10 nGy h^{-1}. The dose rate exceeded 25 nGy h^{-1} at sites 2, 41 and 43, the highest dose rate being 34.3 nGy h^{-1} at Sabeto. The surroundings of all three regions are hilly, while Vuda (site 43) is located in a volcanic region (extinct since 6 Ma BP).

Average dose rates for the different regions are given in Table 4. For each region, the largest dose rate comes from ^{40}K. For the entire area of study, the average contributions of Th, U and K to the total dose rate are 18%, 15% and 67%, respectively. The average dose rate of 10.3 nGy h^{-1} measured in this work for the southern and western coastal Viti Levu agrees well with the dose rate of 11.9 nGy h^{-1} previously reported for the south-eastern Viti Levu region (Garimella and Kumar, 1997).

The natural radiation dose rates reported in this paper are generally much lower than the world average of about 44 nGy h^{-1} (Kogan, 1971; UNSCEAR, 1988). Table 5 compares the activities of the nuclides ^{232}Th, ^{238}U, and ^{40}K in the Fijian soils (present study) and the calculated dose rates with the corresponding values for other locations in the Pacific region.

The average total gamma dose in coastal Viti Levu (Table 5) is the lowest so far measured for the Pacific region, though similar in magnitude to that in Micronesia, Tonga, Christmas Island and Samoa. Marsden's (1964) reported gamma doses of 29 nGy h^{-1} at Fiji agrees reasonably well with the dose rates reported here for Nadi, Lautoka and Ba regions. In comparison, Fiji's southern coast, which is dominated by sedimentary rocks, has lower dose rates. In contrast, some volcanic Pacific islands in the region (Niue, Rarotonga and parts of Guam) exhibit very high dose rates (UNEP, 1984). The highest rate obtained in this study for Fiji is only 34.3 nGy h^{-1}. The possibility is not ruled out, that radiation levels in the interior of Viti Levu (which is covered by largely inaccessible thick forests and mountains) could be higher.

Table 4. Average gamma dose rate likely to be received by population from natural radioactivity in soils of southern and western coasts of Viti Levu, Fiji

Region	Dose rate (nGy h^{-1})			
	^{232}Th series	^{238}U series	^{40}K	Total
Suva	3.2	3.8	7.0	14.0
Veisari	1.1	1.5	2.6	5.2
Navua	0.8	1.0	3.8	5.6
Sigatoka	1.4	1.1	6.7	9.2
Nadi	2.2	1.7	7.6	11.5
Lautoka	2.9	2.1	11.8	16.8
Ba	1.8	0.7	8.1	10.6
Average	**1.9 ± 0.9**	**1.7 ± 1.0**	**6.8 ± 3.0**	**10.4 ± 4.2**

Table 5. Comparison of results of this work with some locations in the Pacific region

Location	Average concentrations (Bq kg^{-1})			Gamma Dose (nGy h^{-1})	Reference
	^{232}Th	^{238}U	^{40}K		
Viti Levu, Fiji	2.8	3.6	160	10.3	Present work
Micronesia:					
Majuro	ND	29	26	13	Nelson (1979)
Ponape	37	22	<8	33	Greenhouse
Truk	23	27	<8	26	and
Palau	16	7	-	14	Miltenberger (1981)
Samoa	ND	ND	ND	46	Marsden (1964)
Tonga	ND	ND	ND	23	Marsden (1964)
Guam	ND	ND	ND	46	UNEP (1984)
Rarotonga	ND	ND	ND	200	Marsden (1964)
Niue	ND	ND	ND	456 - 2967	Marsden (1964)
Christmas Is.	-	28	-	11	Nelson (1977)
New Zealand	100	63	1000	57	UNEP (1984)
Australia	-	-	-	93	UNSCEAR (1993)
World Average	25	20	443	44	Kogan (1971)
	25	25	380	44	UNSCEAR (1988)

Key: ND = No data reported

5 Acknowledgements

This work was supported by a financial grant from the University of the South Pacific. Father John Bonato, Coordinator of Earth Science Unit, has kindly provided the geological description of coastal Viti Levu for this report.

References

Garimella, S. & Kumar, A. 1997. Natural radioactivity levels in soils of south-eastern Viti Levu, Fiji. *South Pacific J. Nat. Sci*., **15**, 21-36

Greenhouse, N.A. & R.P. Miltenberger. 1981. An intercomparison of naturally and technologically enhanced background radiation levels in Micronesia. Proceedings of the Second Special Symposium on Natural Radiation Environment, Bombay, India, January 19-23, p. 453-458

IAEA. 1987. IAEA Gamma spectrometry reference materials RGU-1, RGTh-1 and RGK-1. IAEA/RL/148, International Atomic Energy Agency, Vienna.

Kogan, R.M., Nazarov & Fridman, Sh.D. 1971. Gamma spectrometry of natural environments and formations, Israel Program for Scientific Translations.

Marsden, E. 1964. Radioactivity of some rocks, soils, plants and bones. In: *The Natural Radiation Environment*, J.A.S. Adams and W.M. Lowder (Eds.). Univ. of Chicago Press, 807-824.

Nelson, V.A. 1977. Radiological survey of plants, animals and soil at Christmas Island and seven atolls in the Marshall Islands. Report NVO-269-32, Laboratory of Radiation Ecology, Univ. of Washington, Seattle, 69 pp.

Nelson, V.A. 1979. Radiological survey of plants, animals and soil at five atolls of Marshall Islands. Report NVO-

269-36, Laboratory of Radiation Ecology, Univ. of Washington, Seattle, 35 pp.
Rodda, P. 1994. Geology of Fiji. In: *Geology and submarine resources of the Tonga-Lau-Fiji region*, SOPAC Technical Bulletin 8, 131-151
UNEP. 1984. Radioactivity in the South Pacific. SPC/SPEC/ESCAP/UNEP: Topic Review No. 14, page 72, South Pacific Commission, Noumea, New Caledonia
UNSCEAR. 1982. Ionizing radiation: Sources and biological effects. United Nations Scientific Committee on the Effect of Atomic Radiation, Report to the General Assembly with Annexes, United Nations Publication, New York
UNSCEAR. 1988. Ionizing radiation: Sources and biological effects. United Nations Scientific Committee on the Effect of Atomic Radiation, Report to the General Assembly with Annexes, United Nations Publication, New York
UNSCEAR. 1993. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effect of Atomic Radiation, Report to the General Assembly with Annexes, United Nations Publication, New York.

Appendix

Table 3 Measured specific activities (Bq kg^{-1}) of ^{232}Th, ^{238}U, and ^{40}K in soils of southern and western coastal Viti Levu, Fiji

Region	Location	Sample No.	^{232}Th Bq kg^{-1}	^{238}U Bq kg^{-1}	^{40}K Bq kg^{-1}
Suva	Raiwai	1	6.5	9.8	58
	Tamavua	2	8.2	9.4	494
	Korobaba	3	2.1	9.2	36
	Lami	4	2.8	6.7	61
Veisari	Naikorokoro	5	0.8	1.6	83
	Naboro	6	3.5	4.2	75
	Wainandoi	7	0.9	3.1	41
	Veivatuloa	8	1.8	4.6	46
Navua	Waiyanitu	9	2.6	3.9	126
	Nayangi	10	<0.6	2.0	73
	Navua	11	1.3	1.9	155
	Namosi Road	12	1.1	3.6	75
	Ngalo	13	<0.6	<0.5	10
Sigatoka	Naboutini	14	<0.6	<0.6	164
	Korolevu	15	<0.6	<0.6	119
	Tagage	16	0.9	1.5	95
	Sovi Bay	17	0.8	1.9	141
	Olosara	18	2.7	3.0	69
	Nadrala	19	1.3	1.6	130
	Kavanagasau	20	2.1	3.2	231
	Yalava	21	3.7	2.4	250
	Sandhill	22	2.1	2.4	263
	Kulukulu	23	6.1	0.9	283
	Yadua	24	2.2	13.3	105
	Yanuda	25	2.9	4.2	127
	Cuvu	26	1.5	0.8	139
	Batiri	27	1.7	2.3	111
	Lomowai	28	2.6	1.6	103

Table 3. (continued): Measured specific activities (Bq kg^{-1}) of ^{232}Th, ^{238}U, and ^{40}K in soils of southern and western coastal Viti Levu, Fiji

Region	Location	Sample No.	^{232}Th Bq kg^{-1}	^{238}U Bq kg^{-1}	^{40}K Bq kg^{-1}
Nadi	Navutu	29	1.8	5.0	36
	Tau	30	4.1	3.3	33
	Mbavu	31	<0.6	0.7	72
	Waica Road	32	1.6	0.8	13
	Savusavu	33	5.9	5.6	76
	Momi	34	5.0	3.1	379
	Nawai	35	2.9	1.6	125
	Uciwai	36	3.3	4.0	187
	Korovutu	37	3.1	2.9	273
	Yako	38	1.2	3.8	181
	Wailoaloa	39	2.5	3.2	330
	Votualevu	40	2.3	4.3	94
	Sabeto	41	6.6	7.4	619
	Nasoso	42	4.2	8.2	68
Lautoka	Vuda	43	8.1	9.6	523
	Wairambetia	44	4.8	5.4	252
	Dreketi	45	1.1	2.4	76
	Drasa	46	2.8	1.6	243
Ba	Tuvu	47	2.0	1.2	319
	Raviravi	48	2.2	1.1	152
	Sarava	49	2.7	1.4	253
	Yalalevu	50	4.3	3.0	27