Environmental dose rate assessment from an active fault zone in Western Anatolia, Turkey: towards retrospective epidemiology

Mithat Kiyak,[1] George S. Polymeris,[2] Nafiye G. Kiyak[2]

[1]Department of Health Management, Okan University, Istanbul;
[2]Department of Physics, Isik University, Istanbul, Turkey

Abstract

In this study we present data regarding natural radioactivity from a populated active tectonic area based on site measurements using a field gamma spectrometer. The results will provide data to the scientists for dating studies as well as epidemiological studies towards ancient human life, also termed as retrospective epidemiology. The study area covers an active tectonic region in western Anatolia surveyed using on-site gamma spectrometer. More than 500 sites were measured across the region on a 150-km grid. Radiation background shows relatively non-homogenous level of radiation in the area. The gamma dose rate measured in Gediz graben was found in the range between 0.8120-1.7540 $mGya^{-1}$ (94-203 $nGyh^{-1}$) with an average value of 1.2292 mGy/a (142 $nGyh^{-1}$), whereas it was in the range between 0.5530-1.1491 mGy/a (64-133 $nGyh^{-1}$) with an average value of 0.8397 mGy/a (97 $nGyh^{-1}$) across Buyuk Menderes graben. The relative contribution of ^{238}U decay chain to gamma dose rate is between 0.2002-0.4630 $mGya^{-1}$, of ^{232}Th decay series is 0.3089-0.8136 $mGya^{-1}$, and of ^{40}K is 0.1270- 0.3468 $mGya^{-1}$ in the whole studied area. The average annual effective dose equivalents from the calculated outdoor terrestrial gamma radiation was between 90-215 μSva^{-1}, above world average of 70 μSv per year, and the measured outdoor dose rate (terrestrial plus cosmic) on the ground was between 133-257 μSva^{-1}. The significance of all these numbers is discussed in the framework of epidemiological studies, in order to correlate these enhanced dose rate values directly to specific diseases such as cancer.

Introduction

Natural background radiation is the main source of exposure for the people on the Earth. Worldwide average effective dose rate from cosmic rays and terrestrial isotopes is about 2.4 mSv per year (UNSCEAR, 2000), nearly 85% of which comes from natural background radiation. Furthermore, this number is reduced to less than 1 mSv if man-made sources and the internal exposure to Radon daughters are excluded. This value may vary with location on the Earth and the activity concentrations of the radionuclides in soils are directly relevant to the outdoor exposure. Therefore outdoor dose rate derives from the decay of naturally occurring radionuclides present in the Earth crust, such as potassium-40 (^{40}K) and members of the uranium and thorium decay series, together with the contribution from cosmic rays. As the effective dose rate due to natural radiation is far greater than artificial radiation exposure, changing from 1.5 to 3.5 mSv per year on Earth surface, the level of background radiation in some areas of the world is significantly higher than average, from 50 mSv and up to 260 mSv. Such areas reported are Ramsar in Iran (260 mSv per year), Bazar coastal areas in Bangladesh, Guarapari in Brazil, Kerala in India and Yangjiang in China (Sohrabi *et al.*, 1995). Recently Baranwal *et al.* (2006) reported a high natural radiation zone in a geothermal region of Eastern Ghats Mobile Bacidelt (EGMB) of Orissa state in India.

However, there is no significant evidence of increased cancers or other health problems arising from this high level natural radiation background. Thus, epidemiological studies have failed to show any adverse health effects in the populations living in the terrestrial high background radiation areas so far. The United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) suggests that only cohort and case/control studies should be used in quantitative assessments of radiation risks. The studies to propose are of ecological design in which data are aggregated over a population. Related projects in some countries have been conducted as national survey of natural radiation level (Van Dongen and Stoute, 1985; Wang, 2002; Wei and Sugahara, 2002).

In this preliminary study we present data regarding natural radioactivity from a populated active tectonic area in the Western Anatolia, Turkey, based on site – *in situ* measurements using a field gamma spectrometer. The area covers a 150 km grid and is noted for intense tectonic activity. The results of this study will provide data to the scientists for future epidemiological studies. Furthermore, the present study suggests an alternative use of dose rate measurements, towards retrospective epidemiology studies.

Correspondence: Mithat Kiyak, Department of Health Management, Okan University, Ballica Cd, 34959 Istanbul, Turkey.
Tel. +90.0216.677.1630 - Fax: +90.0216.677.1630.
E-mail: mithat.kiyak@okan.edu.tr

Key words: gamma radiation, effective dose equivalent, decay chain, radioactivity.

Citation: Kiyak M, Polymeris GS, Kiyak NG, 2014. Environmental dose rate assessment from active fault zone in Western Anatolia, Turkey: towards retrospective epidemiology. In: RH Tykot (ed.), Proceedings of the 38th International Symposium on Archaeometry – May 10th-14th 2010, Tampa, Florida. Open Journal of Archaeometry 2:5256.

Presented at the 38th International Symposium on Archaeometry – May 10th-14th 2010, Tampa, Florida.

Open Journal of Archaeometry 2014; 2:5256
doi:10.4081/arc.2014.5256

Materials and Methods

Study area

The study area is the most geologically active fault zone (Figure 1) and includes both Büyük Menderes and Gediz grabens, main tectonic features of Western Anatolia. These grabens are about 150 km in length from the Aegean Sea coast in the west to the Denizli Basin in east, are bounded by active normal faults acting as a *bridge* between the Aegean coast and Central Anatolia. This region is noted for one of the most tectonically active regions of the World and large earthquakes occurred in this area during the historical period with heavy damage to settlements located along the grabens.

Gamma dose rates were measured in the settlements located in each graben. Alasehir and Sarigol are settlements in Gediz graben; Guzelkoy, Umurlu, Morali, Kosk, Aydin and Atca settlements in Büyük Menderes graben. Due to the inhomogeneous soil content in the area each settlement was divided into about 5 or 6 sites to record gamma spectra. For gamma dose rate measurements a single measurement can not be representative for each site unless the area is very homogeneous media, therefore gamma dose rate measurements were conducted at various points within the sites. Gamma dose rate was measured directly at each measurement point, ten times for 15 s each and then averaged. A total of 500 points were measured across the region on a 150-km grid, including 10 settlements. In the mean time, a gamma spectrum was recorded at each site as well as gamma dose rate measurements, to calculate the relative contribution of terrestrial radioisotopes to effective dose rate.

Methods

The gamma spectrometer used in the study (model Target-IdentiFINDER) is a complete digital gamma spectroscopy equipment, including standard NaI(Tl) detector and dose rate system, integrating multi-channel analyser, amplifier, high voltage power supply, and memory with an integral scintillation detector. Up to 50 spectra of 1024 channels each can be stored in the unit and directly transferred to any PC for further and advanced analysis. Counting duration for each gamma spectrum was between 2-3 hours, depending on the radioactivity of the environment. Measurements were conducted while the detector is placed on ground and 1 m above it. In order to determine the concentrations of uranium, thorium and potassium in the environment, the corresponding peaks of the resulting spectrum of gamma energies were separately analysed one by one. Afterwards, the contribution of terrestrial isotopes to dose rate was obtained using gamma dose rate and conversion factors presented by Olley *et al.* (1996). The altitude, latitude and longitude of each location were used to estimate the corresponding cosmic ray component of the dose rate (Prescott and Hutton, 1994).

Results and Discussion

Terrestial gamma dose rate

Gamma dose rates measured in Gediz graben (Alasehir and Sarigol settlements) and in Büyük Menderes graben (Guzelkoy, Umurlu, Morali, Aydin, Kosk and Atca settlements) are presented in Table 1. Measurements were conducted at a total of 10 settlements, providing with more than 500 measurement points in the entire study area. The dose rates measured in each graben show relatively similar distribution as presented in Table 1, however, a sig-

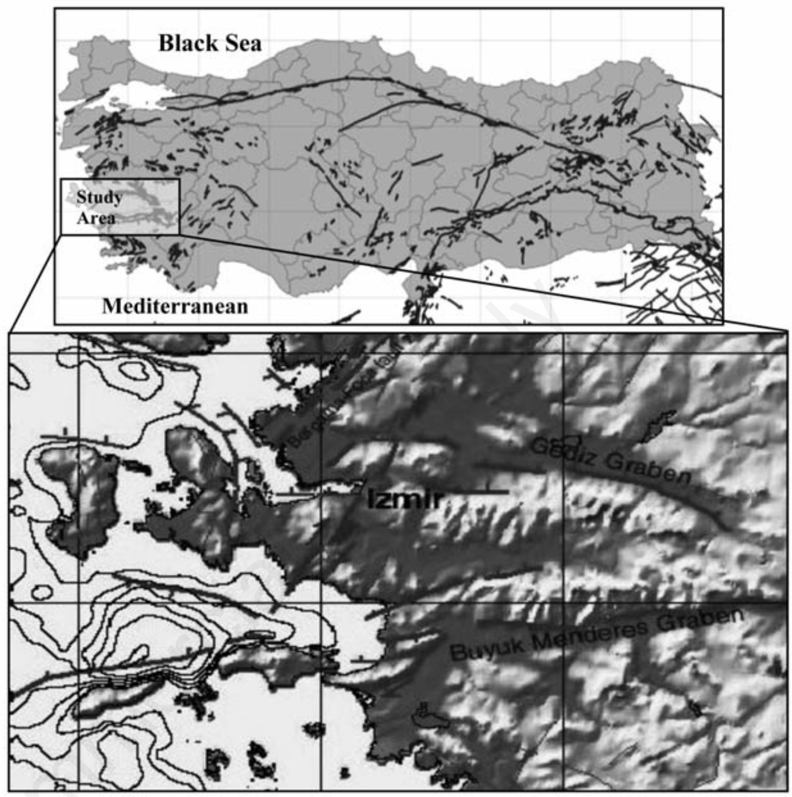

Figure 1. Map showing the study area.

Table 1. Gamma dose rates measured across the study area.

Location	Gamma dose rate Average (nGyh⁻¹)	(mGya⁻¹)	Minimum value (nGyh⁻¹)	(mGya⁻¹)	Maximum value (nGyh⁻¹)	(mGya⁻¹)
Gediz graben						
Sarigol						
Bereketli	119.4±3.6	1.03±0.03	94	0.8120	146	1.2610
Derbent C	175.3±2.6	1.51±0.02	147	1.2700	203	1.7540
Alasehir						
Bereketli	147.5±1.9	1.27±0.02	130	1.1232	173	1.4947
Delemenler	126.4±5.5	1.09±0.05	100	0.8640	144	1.2442
Buyuk Menderes graben						
Aydin						
Guzelkoy	92.1±3.0	0.79±0.03	71	0.6134	120	1.0368
Umurlu	90.4±2.7	0.78±0.02	69	0.5962	126	1.0886
Morali	94.9±2.7	0.82±0.02	70	0.6048	127	1.0973
Aydin-centre	117.3±1.2	1.01±0.05	108	0.9331	133	1.1491
Kosk	79.9±4.4	0.69±0.05	64	0.5530	105	0.9072
Atca	108.5±2.1	0.94±0.04	93	0.8035	142	1.2269

nificant difference in terrestrial gamma dose rates (consequently in soil content) was observed between them. As the gamma dose rates measured in Gediz graben were ranging between 94-203 nGyh^{-1} (0.8120-1.7540 mGya^{-1}), in Büyük Menderes graben these values were found to be relatively lower, between 64-133 nGyh^{-1} (0.5530-1.1491 mGy/a). A similar study regarding outdoor gamma survey using a portable Geiger-Muller tube was previously conducted in Manisa (close to the study area). According to the latter, the minimum and maximum of average exposure rates was found to be 78.30 and 135.72 nGy/h respectively (Eree *et al*., 2006). These values are well satisfied with our results. The obtained gamma dose rates presented in this study are well above the world average value of 30-70 nGyh^{-1} (Ramli, 1997).

Spectroscopic analysis and relative contribution of radioisotopes

The gamma spectra were recorded at each site for 2 or 3 h due to the radioactivity of the environment and then contribution of radioactive isotopes to the dose rate was calculated from spectral analysis. First the concentrations of the major radioactive isotopes of the uranium and thorium series and of potassium were obtained from separated, corresponding peaks of the gamma spectra and subsequently they were used in order to estimate their relative contributions to dose rates. The radionuclides whose separable peaks were used for activity level determinations were ^{208}Tl isotope at 2614.7 KeV and ^{214}Bi at 1764.5 KeV, respectively (Table 2). The isotope ^{40}K, which is not a decay element, appears at 1460 KeV in the spectra. Then, the contributions of radioactive isotopes from ^{238}U and ^{232}Th decay series and ^{40}K to the dose rate were calculated using conversion factors with the assumption of secular equilibrium (Olley *et al*., 1996; Adamiec and Aitken, 1998).

The contributions from radionuclides of the decay chains and of potassium to the terrestrial gamma dose rate are listed in Table 3 in mGya^{-1} and in nGyh^{-1} obtained at each location. As presented in Table 3, the relative contributions of ^{238}U decay chain to gamma dose rate in Gediz graben were found to vary between (0.2748- 0.4630 mGya^{-1}) while the corresponding of ^{232}Th decay series between (0.3984- 0.8136 mGya^{-1}) and ^{40}K from 0.2887 to 0.3468 mGya^{-1}. In Büyük Menderes graben, gamma contribution to dose rate due to ^{238}U decay chain is found to vary from 0.2459 to 0.2000 mGya^{-1}, while due to ^{232}Th decay series from 0.3090 to 0.5030 mGya^{-1}. For the case of ^{40}K the effective dose rate ranges between 0.1270 and 0.2060 mGya^{-1}. The terrestrial radioactivity for the gamma radiation comes mainly from the Th decay elements (36-53% of total gamma dose rate) and from the U decays elements (19-31%) and ^{40}K (13-24%). The gamma dose rate was found relatively high in Gediz graben between 1.0313-1.5146 mGya^{-1}, whereas in Büyük Menderes graben gamma dose rates were lower and between 0.6360-1.0350 mGya^{-1}.

Cosmic ray contribution to dose rate

It is also necessary to estimate the cosmic ray contribution to dose rate in order to find the effective dose rate in the air. Cosmic contribution is about 300 μGya^{-1} at sea-level and also dependent on altitude as well as geographic latitude (Prescott and Hutton 1988, 1994). The cosmic component was calculated as with these parameters: latitude of 27-29°E and longitude 37-39°N, altitudes between 189 and 200 m. With these input parameters the cosmic dose-rate was calculated to be for the case of hard component is between 0.215-0.217 mGya^{-1} and for the soft component is 0.086-0.087 mGya^{-1} and totally 0.301-0.303 mGya^{-1} (34.33-34.55 nGyh^{-1}), with uncertainty of 0.015 mGya^{-1}. In a study of national survey of natural radiation conducted by The Ministry of Health, China, outdoor average absorbed dose rate from cosmic radiation was reported at 37.4 nGyh^{-1} and the highest average absorbed dose rate from cosmic radiation was found in Tibet as 116.2 nGyh^{-1} depending on its altitude (Wang, 2002).

The total dose rate assessment presented in this study covers gamma dose rate and cosmic ray component. The external alpha and beta dose rate have no significant contribution to the total dose rate in the air because especially alpha rays have only a very short range affected in meters in the air. In this environment the contribution from cosmic component to dose rate was about 16-27% and from the remaining

Table 2. The measured radionuclides used for activity level determinations of ^{232}Th, ^{238}U and ^{40}K .

Radionuclides	Measured radionuclides	Photon energy intensity (%)	(keV)
^{232}Th	^{208}Tl	36.0	2614.7
^{238}U	^{214}Bi	16.1	1764.5
^{40}K	^{40}K	10.7	1460.8

Table 3. Contribution of decay isotopes and K-40 to gamma dose rate (mGya^{-1}).

Location	Sarigol-1	Sarigol-2	Alasehir-1	Alasehir-2	Guzelkoy	Umurlu	Morali	Aydin	Kosk	Atca
U-decay elements										
U-238	0.0098	0.0127	0.0166	0.0127	0.0090	0.0088	0.0092	0.0117	0.0072	0.0106
U-234	0.0022	0.0028	0.0036	0.0028	0.0020	0.0019	0.0020	0.0026	0.0016	0.0023
Th-230	0.0018	0.0024	0.0031	0.0024	0.0017	0.0017	0.0017	0.0022	0.0013	0.0020
Ra-226	0.0009	0.0012	0.0016	0.0012	0.0008	0.0008	0.0009	0.0011	0.0007	0.0010
Rn-222	0.2597	0.3347	0.4376	0.3360	0.2369	0.2325	0.2439	0.3082	0.1892	0.2790
Pb-210	0.0003	0.0004	0.0005	0.0004	0.0003	0.0003	0.0003	0.0004	0.0002	0.0003
Total	0.2748	0.3542	0.4630	0.3555	0.2506	0.2459	0.2581	0.3261	0.2002	0.2952
Th-decay elements										
Th-232	0.1796	0.3125	0.1925	0.1530	0.1485	0.1458	0.1529	0.1933	0.1186	0.1750
Rn-220	0.2881	0.5012	0.3088	0.2454	0.2382	0.2338	0.2453	0.3100	0.1902	0.2806
Total	0.4677	0.8136	0.5013	0.3984	0.3867	0.3795	0.3982	0.5032	0.3089	0.4556
K-40	0.2887	0.3468	0.3101	0.3427	0.1587	0.1557	0.1634	0.2065	0.1267	0.1869
Total	1.0313	1.5146	1.2744	1.0966	0.7960	0.7812	0.8196	1.0358	0.6358	0.9377

Table 4. Outdoor dose rate and effective annual dose rate.

Effective location	Terrestial+cosmic (mGya⁻¹)	(mSva⁻¹)
Sarigol-1	1.3390	0.189
Sarigol-2	1.8257	0.257
Alasehir-1	1.5829	0.223
Alasehir-2	1.4038	0.198
Guzelkoy	1.1002	0.155
Umurlu	1.0872	0.153
Morali	1.1260	0.159
Aydin	1.0422	0.147
Kosk	0.6404	0.090
Atca	0.9445	0.133

fraction about 49-65% of radiation dose rate from radioisotopes in the uranium and thorium decay chains. Finally, about 13-24% of the radiation dose comes from potassium.

Annual effective dose equivalent and radiological hazard indices

The dose rates due to terrestrial gamma radiations in air on the ground surface due to the naturally occurring radionuclides are presented in Table 1. To estimate the annual effective dose rates, the gamma absorbed doses in $nGyh^{-1}$ have to be converted into annual effective doses in $mSva^{-1}$ using the conversion factor of 0.7 $SvGy^{-1}$ and the outdoor occupancy factor of 0.2 proposed by UNSCEAR (2000). The outdoor terrestrial effective dose rate in each area is shown in Table 4. The relevant effective dose rate plus cosmic contribution is also shown. The terrestrial effective annual dose rate in $mSva^{-1}$ in air is ranging between 146 and 215 $mSva^{-1}$. The world average annual effective dose equivalent from outdoor terrestrial gamma radiation is 70 μSv per year (UNSCEAR, 2000). In Gediz graben outdoor terrestrial gamma radiation is almost two-three times higher than the world average and in Buyuk Menderes graben this value is 90-147 $mSva^{-1}$.

A retrospective approach

In trivial trapped charge dating approaches, two different physical quantities are required; the total accumulated dose during the past, termed as paleodose or equivalent dose, as well as the rate at which this energy-dose is accumulated, termed as dose rate. The ratio of these two quantities, *i.e.* the paleodose over the dose-rate, represents the age of the sample in kilo-years (ka).

Equivalent dose is derived using either luminescence or ESR. At the same time, analyses are carried out aiming to determine sample's content in radioisotope's geochemistry, allowing the calculation of the rate that the radioactive dose is absorbed by the included quartz grains and thus enabling dose rate determination in Ga/ky. These analyses usually include thick source alpha counting (TSAC) for the determination of ^{232}Th and natural U concentrations, as well as micro X-ray fluorescence (μ-XRF) and flame absorption atomic spectroscopy (FAAS) techniques for ^{40}K determination.

Towards a retrospective approach, we suggest that the dose rate assessment of pottery samples and artefacts could be an extremely useful tool, providing that the origin of the clay used to manufacture the artefact is well known. Under the assumption that the artefacts are made of local clay, in that case radioisotope geochemistry as well as dose rate assessment in several artefacts of the same origin (area or city) but of wide ranging, and independently well established ages could give insight to the variation of dose rate of the specific area in the past. This study could be of special interest in the case of Izmir, since it will probably enable direct comparison of the presently monitored high dose rate with the corresponding in several different time scales in the past.

Conclusions

About 500 measurement points at 10 settlements located along Gediz and Buyuk Menderes grabens, in western Anatolia, were surveyed using portable gamma spectrometer. A significant difference in radiation background of the two grabens was observed. The dose rate due to outdoor radiation (cosmic and terrestrial) is contributed mainly by the Th decay chain, forming the 28-45% of total outdoor dose rate. The U decay chain elements contribute by 19-29% and 40-K by 14-24%.The cosmic ray contribution was about 16-27% of outdoor dose rate and the remaining fraction about 49-65% of radiation dose comes from radioisotopes in the uranium and thorium decay chains. The effective annual gamma dose rate in $mSva^{-1}$ in the air above the surface for all studied area ranged between 0.90 and 0.215 $mSva^{-1}$.

References

Adamiec G, Aitken MJ, 1998. Dose-rate conversion factors: update. Ancient TL 16:37-50.

Baranwal VC, Sharma SP, Sengupta D, Sandilya MK, Bhaumik BK, Guin R, Saha SK, 2006. A new high background radiation area in the Geothermal region of Eastern Ghats Mobile Belt (EGMB) of Orissa, India. Radiat Meas 41:602-10.

Eree FS, Aközcan S, Parlak Y, Çam S, 2006. Assessment of dose rates around Manisa (Turkey). Radiat Meas 41:598-601.

Olley JM, Murray AS, Robert RG, 1996. The effects of disequilibria in the uranium and thorium decay chain on burial dose rates in fluvial sediments. Quaternary Sci Rev 15:751-60.

Prescott JR, Hutton JT, 1988. Cosmic ray and gamma ray dosimetry for TL and ESR. Nucl Tracks Radiat Meas 14:223-7.

Prescott JR, Hutton JT, 1994. Cosmic ray contribution to dose rates for luminescence and ESR dating: large depths and long-term time variations. Radiat Meas 23:497-500.

Ramli AT, 1997. Environmental terrestrial gamma radiation dose and its relationship with soil type and underlying geological formations in Potantian District, Malaysia. Appl Radiat Isotopes 48:407-12.

Sohrabi M, Mirzaee H, Hosseini T, 1995. Determination of 226Ra in food samples by a new method using polycarbonate detectors. Radiat Meas 25:623-4.

UNSCEAR, 2000. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effect of Atomic Radiation ed., New York.

Van Dongen R, Stoute JRD, 2002. Outdoor natural background radiation in the Netherlands. Sci Total Environ 45:381-8.

Wang Z, 2002. Natural radiation environment in China. Int Congr Ser 1225:39-46.

Wei L, Sugahara T, 2002. Risk assessment based on an epidemiological study in a high background radiation area: a China-Japan cooperative research. Int Congr Ser 1225:267-75.