ABC Research Alert
Vol 7, Number 3
Published Online: 07 December 2019
https://abc.us.org/ojs/index.php/abcra

Environmental Radioactivity Monitoring and Assessment of Excess Lifetime Cancer Risk to People in Demra Thana, Dhaka, Bangladesh

[1]Shahadat Hossain, [2*]Mohammad Sohelur Rahman, [3]Selina Yeasmin

[1]Lecturer, Department of Physics, American International University-Bangladesh, Dhaka, **Bangladesh**
[2*]Chief Scientific Officer, Health Physics Division, Atomic Energy Centre, Dhaka, **Bangladesh**
[3]Chief Scientific Officer and Head, Health Physics Division, Atomic Energy Centre, Dhaka **Bangladesh**

*(msrahman74@gmail.com)

Abstract

Objective: The quality of life is influenced by the environment quality and one of the major factors that require a continuous monitoring is the level of radiation. Radiation protection is required to minimize the health effects due to radiation. It is essential to know real-time gamma radiation dose rates and calculation of annual effective dose of a country in order to generate the baseline database.
Methods: The radiation monitoring was performed using real-time portable digital radiation monitoring device. This real-time digital portable radiation monitoring device meets all European CE standards as well as the American "FCC 15 standard". The portable radiation monitoring device was placed at 1 meter above the ground on tripod and data acquisition time for each monitoring point (MP) was 1 hour. 35 MPs were selected for collection of radiation dose rates at different outdoor locations in Demra Thana, Dhaka from October-November 2019.
Results: The measured dose rates due to natural radionuclides were ranged from 0.133 ± 0.022 μSv.h^{-1} to 0.251 ± 0.016 μSv.h^{-1} with an average of 0.187 ± 0.032 μSv.h^{-1}. The annual effective dose to the population from outdoor environmental gamma radiation was varied from 0.232 ± 0.038 mSv to 0.440 ± 0.029 mSv with an average of 0.328 ± 0.057 mSv. Excess Lifetime Cancer Risk (ELCR) are also calculated which is ranged from 0.9×10^{-3} to 1.7×10^{-3} with an average value of 1.3×10^{-3}, which is 4.5 times greater than world average of 0.29×10^{-3}.
Conclusion: This kind of study is required to detect the presence of natural radionuclides and artificial radionuclides (if any) releasing from nuclear and radiological facilities in the country or from neighboring countries for normal operations or in case of accident/incident. From this study, it can be concluded that there is no radiation burden to the environment due to man-made sources.

Keywords

Ionizing Radiation, Outdoor, In-Situ, Effective dose, Cancer

INTRODUCTION

Human beings are exposed to ionizing radiation that stems both from natural and man-made sources. In general, approximately 85% of the annual total radiation dose of any person comes from natural radionuclides of both terrestrial and cosmogenic origin (Belivvermis M. et al., 2010). Exposure to extraterrestrial origin radiation, galactic cosmic rays and energetic particles from solar particle events depends mostly on geographical characteristics of a place such as altitude, latitude and solar activity (ATSDR, 1999), (UNSCEAR, 2000).One of the main external sources of irradiation to the human body is represented by the gamma radiation (terrestrial environmental background radiation) emitted by naturally occurring radioisotopes. The most prominent naturally occurring radioisotopes are ^{40}K and the radionuclides from the ^{232}Th and ^{238}U series with their decay products, which exist at trace levels in all ground formations. During the last decades, extensive surveys have been carried out worldwide to determine activity concentration levels and associated dose rates due to terrestrial gamma radiation (Wilson, 1994), (H.L. Beck et al., 1972). In situ gamma-ray spectrometry is a measurement technique that provides radionuclide concentrations and other related quantities such as the activity per unit area and exposure rate directly at a field site or indoor. Both laboratory and in-situ gamma spectroscopy are often used for monitoring and assessment of radioactivity and radiation dose rates in the environment due to both natural and anthropogenic sources (QUARTO M. et al., 2013), (AL-SALEH, 2007). In-situ techniques for measuring the activity concentration resulting from the gamma radiation and characterizing its sources with gamma ray spectrometer have been used successfully in the outdoor environment (CLOUVAS A. et al., 2004), (E. Svoukis et al., 2006).The presence of naturally occurring radionuclides in the environment may result in an external and internal dose received by a population exposed to them directly and through the ingestion and inhalation pathways. The assessment of the radiological impact on a population as a result of the radiation emitted by these radionuclides is important since they contribute to the collective dose of the population (UNSCEAR, 1982). The In-situ gamma-ray dose rate measurement is highly reliable in indoor and outdoor environments (HAZRATI S. et al., 2010), (J. F. B. Ateba et al., 2010). In most developed countries with an advanced health care system, medical exposures are now the most important single source of ionizing radiation (UNSCEAR, 2008). Radiation from hospitals and medical research institutes has been of great concern because of the known effects of high dosages. Exposure of patients to radiographic examination (computerized tomography, fluoroscopic procedures, dental diagnosis, and routine exposure to X-rays), radioisotope procedures and radiation therapy have contributed to increase in background radiation and radiation levels of patients and many occupational workers (NCRP Report No. 160, 2009).It is mentionable that several largest Jute Mills, notably Karim Jute Mill is situated within the boundary of Demra Thana and Latif Bawany Jute Mill is situated in the Demra Thana. All most 15 thousand workers involved in jute industries in this area, In addition, many people with their children used to visit Shitalakshya River and Amulia Model Town for recreation. These two sites are also located in the Demra Thana. The aim of the present study is to measure the environmental terrestrial gamma radiation dose rate at Demra Thana in Dhaka city and to determine the annual effective radiation doses to which people are exposed from terrestrial gamma radiation.

MATERIALS AND METHODS

Description of the site

The study location was marked out using GARMIN eTrex HC series personal navigator. The unit uses the proven performance of Garmin high-sensitivity GPS and full-featured mapping to create an unsurpassed portable GPS receiver (Owner’s Manual-GARMIN eTrex HC Series, 2007). The study site is located from E90^{0}27.896' to E90^{0}30.851' and from **N**23^{0}40.922' to **N**23^{0}44.780’; locations were selected for measurement of outdoor environmental gamma radiation dose rates at Demra Thana in Dhaka city. Demra thana area 19.36 sq.km, population 125,312 (male: 69,232 and female: 56,080), population density 6,473/sq.km (Bangladesh Bureau of Statistics, 2011). Demra Thana is surrounded by Shitalakshya and Balu River. The main income of the Demra Thana is from Jute mills. Besides, there are jamdani Hats, Important installations of Demra Thana are Karim Jute Mill (1954), Latif Bawany Jute Mill (1953), Samsul Haque Khan School and College, Titash Gate, Demra Police Station, Rani Mohol, Demra University College, Demra Bazar, Mala Market, Rajakhalighat, Amulia Model Town, Model Livestock Institute and Staff Quarter.

Description of the apparatus

A real-time digital portable radiation monitoring device which is known as GAMMA SCOUT was used for this study. GAMMA SCOUT is German designed and manufactured, built with a solid Novadur exterior. An optional stylish leather holster with belt strap can further protect the GAMMA SCOUT from the elements. The GAMMA SCOUT meets all European CE standards as well as US FCC 15. All units come with an industry leading 2-year manufacturer's warranty and a serialized test certificate. The GAMMA SCOUT is a fully featured Geiger counter with a form fitting ergonomic shape. The unit has a battery indicator, multiple unit conversion, real-time dose rate and cumulative dose display functions and programmable logging and alert functions. Advanced functions include PC data download via USB cable and an ultra-low current power circuit for extended battery life (User Manual-GAMMA SCOUT, 2014). The measurements were performed 35 MPs from October-November 2019. For each location, the real-time digital portable radiation monitoring device (GAMMA SCOUT) was placed on tripod at 1 m height and time for dose rate measurement was 1 h. Fig. 1 shows the location of Demra Thana in Dhaka city where outdoor environmental gamma radiation measurement was performed using a digital portable radiation monitoring device through In-situ technique. Table 1 gives the description of monitoring points (MPs). This site was marked out using Global Positioning System (GPS) navigation.

Calibration of GAMMA SCOUT

The GAMMA SCOUT was calibrated inbuilt by the manufacturer. The GAMMA SCOUT is also calibrated at the Secondary Standard Dosimetry Laboratory under Bangladesh Atomic Energy Commission using gamma-ray standard sources such as ^{137}Cs, ^{60}Co, etc. and X-ray Unit. The SSDL of BAEC has been available since 1991, which is traceable to the Primary Standard Dosimetry Laboratory (PSDL) of National Physical Laboratory (NPL), UK. The SSDL of BAEC has X-ray Unit (30 kV-225 kV) for radiation generating equipments calibration. The performance of BAEC's SSDL is maintained according to the requirements of the International Atomic Energy Agency (IAEA)/World Health Organization (WHO) network of SSDLs. Therefore, the evaluated doses are traceable to the International measurement system. The GAMMA SCOUT accurately measure dose rate in the range of 0.01-5000 μSv/hr (User Manual-GAMMA SCOUT, 2014).

Data taking process and formula for dose calculation

Environmental gamma radiation dose rates were measured in the area of Demra Thana under Dhaka city. The measurement was performed using a digital portable Gamma-Scout detector from October-November 2019. The digital portable Gamma-Scout detector was placed at 1 m above the ground on tripod and data acquisition time for each monitoring point (MP) was 1 h. Total 35 MPs were selected for collection of gamma-ray dose rates in the outdoor environment at the area of Demra Thana as shown in Fig. 1. The MPs were marked-out using Global Positioning System (GPS) navigation as shown in Table 1.

UNCEAR 1988 (UNSCEAR, 1988) recommended the outdoor occupancy factor of 0.20 to population. This occupancy factor is the proportion of the total time during which an individual is exposed to a radiation field at outdoor. The outdoor annual effective dose to population due to gamma radiation is calculated according to the following equation

$$\text{Annual effective dose } (\mu Sv) = \text{dose rate } (\mu Sv.h^{-1}) \times 0.2 \times 8760 \text{ h.yr}^{-1} \qquad (1)$$

Excess lifetime cancer risk (ELCR)

Excess life-time cancer risk factor (ELCR) is calculated by using the following equation:

$$ELCR = AED \times DL \times RF \qquad (2)$$

Where AED is annual effective dose to people, DL is the duration of life of Bangladeshi people (http://en.worldstat.info/Asia/Bangladesh, 2019) and RF is the risk factor (Sv-1), it is a fatal cancer risk per Sievert. For stochastic effects from low dose radiation, ICRP 103 suggested the value of 0.057 for the public exposure (ICRP, 2007).

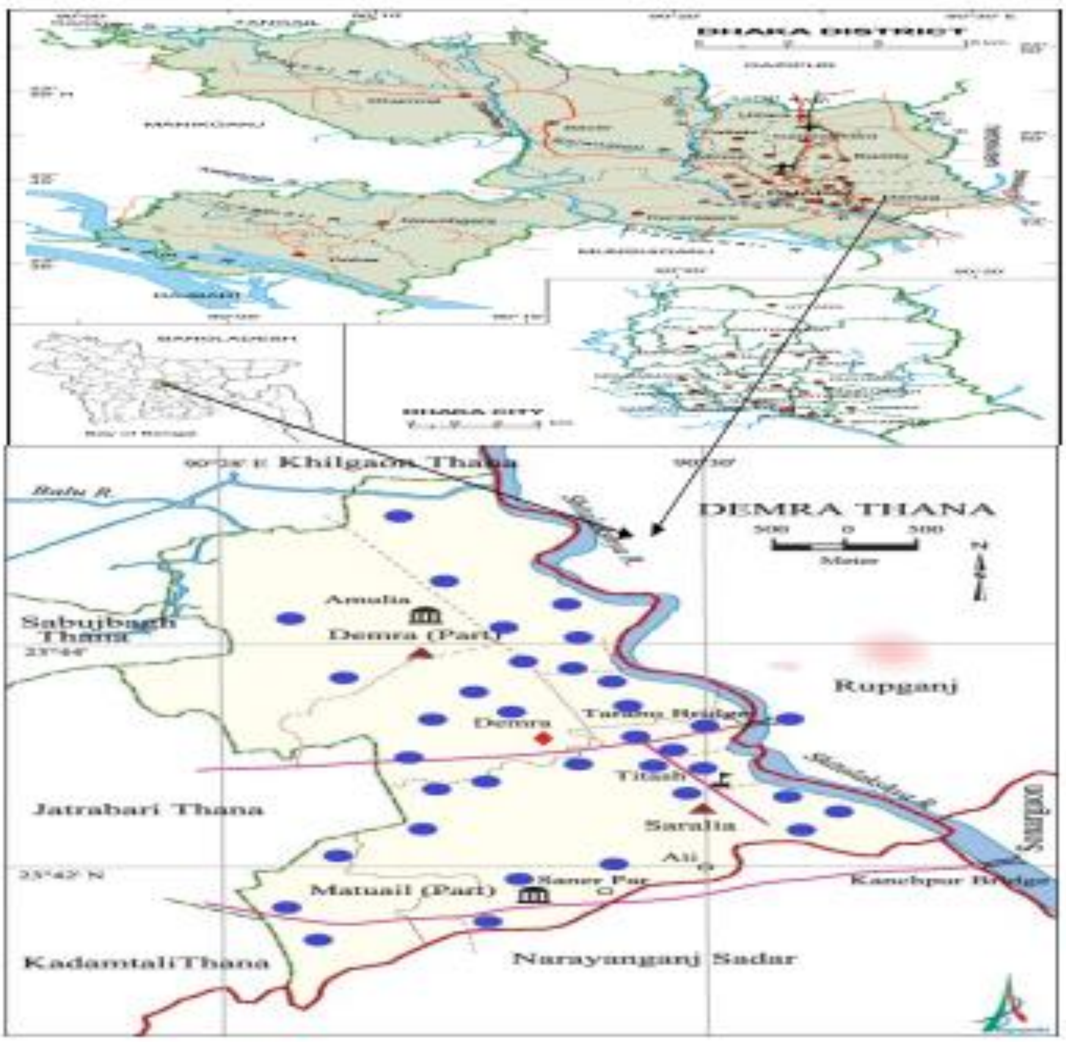

Fig.1: Shows the location (•) of the Demra Thana in Dhaka city where environmental gamma radiation monitoring was performed

RESULTS AND DISCUSSION

Collection of field gamma-ray dose rate

Monitoring of outdoor environmental gamma radiation dose rate was carried out at the area of Demra Thana in Dhaka city from October-November 2019 following In-Situ technique. The contribution of dose rates in all monitoring points arising from natural radionuclides.

Absorbed dose rate and annual effective dose

The measured dose rates due to natural radionuclides were ranged from 0.133 ± 0.022 µSv.h^{-1} to 0.0.251 ± 0.016 µSv.h^{-1} with an average of 0.187 ± 0.032 µSv.h^{-1}. Using the conversion factor of 0.7 Sv.Gy^{-1} as recommended by UNSCEAR 2000 (UNSCEAR, 2000) and considering that people in Bangladesh spend approximately 20 % of their time outdoor and remaining 80% of time indoor. The annual effective dose received by people in Dhaka city due to the environmental gamma radiation is given in Table 1. The annual effective dose rates of the population due to the outdoor environmental gamma radiation were also calculated and it was varied from 0.232 ± 0.038 mSv to 0.440 ± 0.029 mSv. The mean annual effective dose was found to be 0.328 ± 0.057 mSv. Moreover, environmental radiation and radioactivity monitoring is crucial to generate the baseline database from natural sources before starting operation of the country's first nuclear power plant. The national baseline database is very important for comparison before and after operation of the nuclear power plant. This study is very useful to know the artificial radionuclides releasing (if any) to the environment from man-made sources like hospitals. Therefore, real-time gamma radiation measurement is very vital in and around radiological facilities (hospitals) for the safety of the public.

MP No.	Name of Place	Latitude/ Altitude	Gamma dose rate ($\mu Sv.h^{-1}$)			Mean annual effective dose due to gamma radiation (mSv) ± SD
			Range	Mean	SD	
1	Bamoil Bus Stand	N23^{0}43.114' E090^{0}29.056'	(0.13-0.19)	0.158	0.020	0.277 ± 0.035
2	Basherpool	N23^{0}43.018' E90^{0}28.456'	(0.15-0.21)	0.181	0.020	0.317 ± 0.034
3	Konapara Bus Stand	N23^{0}42.984' E90^{0}28.149'	(0.20-0.25)	0.214	0.025	0.375 ± 0.044
4	Sasul Haque Khan School	N23^{0}42.397' E90^{0}28.232'	(0.13-0.12)	0.169	0.024	0.295 ± 0.041
5	Islam Nagar	N23^{0}41.950' E90^{0}27.896'	(0.14-0.20)	0.163	0.021	0.285 ± 0.037
6	Matuail Bus Stand	N23^{0}41.711' E90^{0}27.993'	(0.12-0.22)	0.165	0.032	0.289 ± 0.056
7	Paradogar	N23^{0}41.599' E90^{0}28.541'	(0.13-0.22)	0.171	0.028	0.299 ± 0.048
8	Sign Board	N23^{0}41.629' E90^{0}28.775'	(0.15-0.20)	0.187	0.030	0.328 ± 0.053
9	Sanar Par	N23^{0}41.701' E90^{0}29.397'	(0.16-0.23)	0.195	0.026	0.342 ± 0.046
10	Mouchak	N23^{0}41.740' E90^{0}29.707'	(0.17-0.25)	0.219	0.036	0.384 ± 0.062
11	Golakata	N23^{0}42.454' E90^{0}30.103'	(0.15-0.20)	0.181	0.021	0.317 ± 0.037
12	Sukashi	N23^{0}42.550' E90^{0}30.851'	(0.14-0.20)	0.175	0.029	0.307 ± 0.051
13	Pathor Ghat	N23^{0}42.722' E90^{0}30.479'	(0.15-0.21)	0.180	0.020	0.315 ± 0.034
14	Titash Gate	N23^{0}42.643' E090^{0}30.007'	(0.20-0.27)	0.238	0.022	0.416 ± 0.039
15	Rani Mohol	N23^{0}42.755' E90^{0}29.926'	(0.10-0.17)	0.133	0.022	0.232 ± 0.038
16	Saralia Bazar	N23^{0}42.964' E90^{0}29.774'	(0.20-0.26)	0.233	0.026	0.408 ± 0.045
17	Karim Jute Mill	N23^{0}43.068' E090^{0}29.697'	(0.12-0.17)	0.162	0.042	0.283 ± 0.075
18	Demra Circle	N23^{0}43.218' E90^{0}29.599'	(0.13-0.19)	0.167	0.025	0.293 ± 0.045
19	Tarabo Bridge	N23^{0}43.249' E90^{0}29.680'	(0.14-0.20)	0.189	0.041	0.330 ± 0.072
20	Shitalakshya River	N23^{0}43.313' E90^{0}30.047'	(0.15-0.22)	0.183	0.020	0.321 ± 0.036

21	Tarabo Bazar	**N**23^{0}43.347' E90^{0}30.401'	(0.16-0.22)	0.194	0.028	0.340 ± 0.049
22	Latif Bawany Jute Mill	**N**23^{0}43.326' E90^{0}29.705'	(0.20-0.27)	0.240	0.025	0.420 ± 0.043
23	Demra Police Station	N23^{0}43.496' E90^{0}29.704'	(0.18-0.26)	0.217	0.026	0.379 ± 0.045
24	Demra University College	**N**23^{0}43.640' E90^{0}29.902'	(0.20-0.27)	0.244	0.021	0.427 ± 0.037
25	Demra Bazar	**N**23^{0}43.753' E90^{0}29.909'	(0.10-0.17)	0.130	0.018	0.228 ± 0.033
26	Derma Bridge	**N**23^{0}43.936' E90^{0}29.736'	(0.12-0.20)	0.158	0.024	0.277 ± 0.043
27	Mala Market	**N**23^{0}40.922' E90^{0}29.573'	(0.14-0.20)	0.171	0.024	0.299 ± 0.041
28	Raja khali ghat	N23^{0}44.248' E90^{0}29.481'	(0.13-0.20)	0.166	0.025	0.290 ± 0.043
29	Raja Khali	**N**23^{0}44.200' E90^{0}29.008'	(0.13-0.20)	0.162	0.022	0.284 ± 0.039
30	Mostomaji	**N**23^{0}44.780' E90^{0}28.337'	(0.13-0.23)	0.177	0.036	0.309 ± 0.063
31	Amulia Model Town	**N**23^{0}43.974' E90^{0}29.074'	(0.12-0.26)	0.188	0.020	0.330 ± 0.037
32	Model Livestock Institute	N23^{0}43.928' E90^{0}28.624'	(0.14-0.23)	0.234	0.021	0.411 ± 0.038
33	Mir Para	**N**23^{0}43.786' E90^{0}29.176'	(0.15-0.23)	0.217	0.026	0.380 ± 0.045
34	Staff Quarter	N23^{0}43.245' E90^{0}29.404'	(0.14-0.29)	0.251	0.016	0.440 ± 0.029
35	Paity	**N**23^{0}43.425' E90^{0}28.987'	(0.12-0.19)	0.137	0.023	0.239 ± 0.040

Table 1: Outdoor dose rate and annual effective dose due to gamma radiation at Demra Thana in Dhaka city

Fig. 2 shows the outdoor annual effective dose of each monitoring point was normalized to the minimum annual effective dose. From Fig. 2, it can be seen that the difference of annual effective dose of each monitoring point is not high. The reason for this difference might be geographical characteristics of each location.

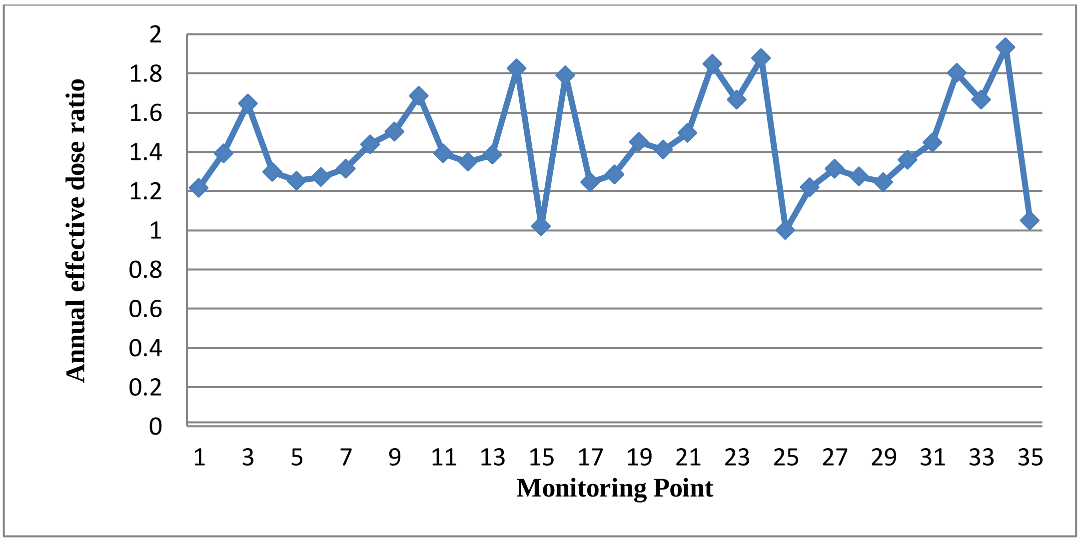

Fig. 2: Outdoor annual effective dose values normalized to the minimum annual effective dose for each MP.

The frequency distribution of the environmental gamma absorbed dose rates in air follow a normal type distribution as shown in Fig. 3.

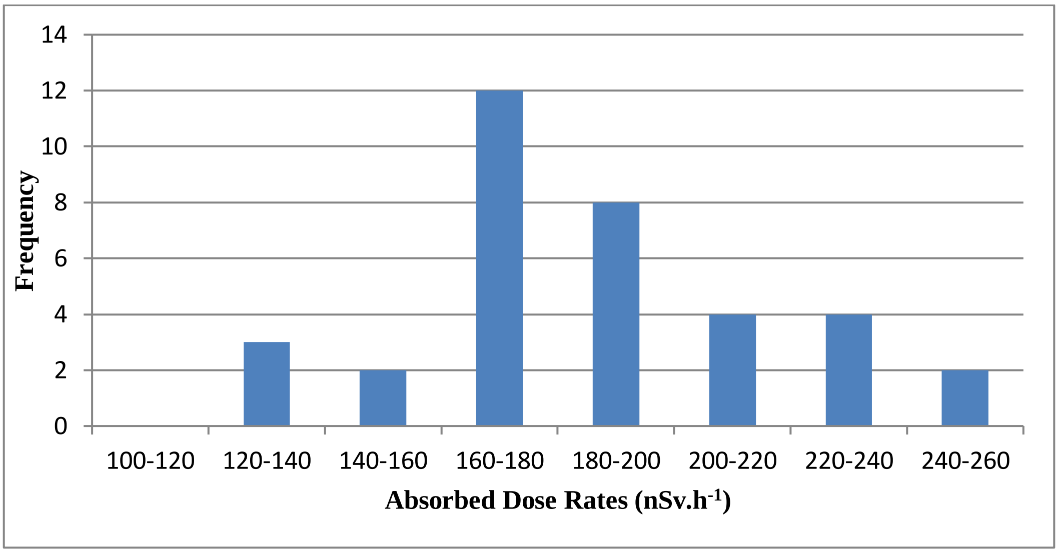

Fig. 3: Frequency distribution of the absorbed dose rates (nSv.h-1) at Demra Thana in Dhaka city

The annual effective dose range due to the outdoor environmental gamma radiation to the population of Dhaka city is tabulated in Table 2. It can be seen from Table 2 that the range of dose rate and annual effective dose to population of Demra Thana is lower than some countries like Indonesia, India, and China and higher than Islamic Republic of Iran, Azerbaijan, Spain, Czech Republic, Bulgaria and Finland. The exact reason for high radiation doses are not known, but might be attributed to geographical, geological, and altitude of cities studied. The average levels of annual effective dose to populations for countries are mostly in the range of 0.30-0.60 mSv (UNSCEAR, 2008). The annual effective dose to population in Dhaka city ranged from 0.232-0.440 mSv which is within the range of worldwide average. The average outdoor environmental gamma radiation dose rate in the study area was found to be 0.187 ± 0.032 μSv.h^{-1} which is almost equal to the Lazio area of Italy (UNSCEAR, 2008).

Country	Range of dose rate (μSv.h^{-1})	Mean Gamma dose rate (μSv.h^{-1})	Range of annual effective dose(mSv)
Finland	0.077 – 0.171	0.103	0.135 - 0.300
Spain	0.050- 0.129	0.085	0.088 - 0.226
Indonesia (Karimu Island)	0.200 - 0.410	0.310	0.350 - 0.718
Islamic Republic of Iran	0.036- 0.130	0.112	0.063 - 0.228
India (Odisha)	0.251 - 0.879	0.449	0.439 - 1.540
Czech Republic	0.006 - 0.245	0.100	0.011 - 0.429
China	0.011 - 0.523	0.815	0.019 - 0.916
Bulgaria	0.075 – 0.140	0.100	0.131 - 0.245
Azerbaijan	0.075 - 0.205	0.140	0.131 - 0.359
Italy (Lazio)	0.120 - 0.270	0.175	0.210 - 0.473
This Study	**0.133 - 0.251**	**0.187**	**0.232 - 0.440**

Table 2: Environmental gamma dose rate range and annual effective dose range due to natural radionuclide sources for selected countries and for this study (UNSCEAR, 2000).

The ELCR for outdoor exposure is ranged from 0.9×10^{-3} to 1.7×10^{-3} with an average value of 1.3×10^{-3}, which is 4.5 times greater than world average of 0.29×10^{-3}. The calculation of ELCR is based on annual effective dose. The annual effective dose due to natural radiation varies from location to location because of geological conditions.

CONCLUSION

The present study has measured the real-time outdoor environmental gamma radiation dose rates at Demra Thana in Dhaka city. The average outdoor environmental gamma radiation dose rate in the study area was found to be 0.187 ± 0.032 μSv.hr^{-1} which is equal to the Lazio area of Italy. Environmental radiation and radioactivity monitoring is crucial to generate the baseline database from natural sources before starting operation of the country's first nuclear power plant. The national baseline database is very important for comparison before and after operation of the nuclear power plant. This study is very useful to know the artificial radionuclides releasing (if any) to the environment from man- made sources like hospitals. Therefore, real-time gamma radiation measurement is very essential in and around radiological facilities (hospitals) for the safety of the public. From this study, it is observed that the assessment of the radionuclide level of the area did not detect the presence of any artificial radionuclides and thus no significant impact of the extensive usage of radioactive materials within and around the area of Demra Thana and no radiation burden to the environment. Such investigations are important not only for assessing population exposure and performing epidemiological studies, but also for serving as a reference to possible environmental contaminations due to human activities. Many countries have already monitored the distribution of natural radioactivity finalized with the construction of the radiometric maps of their territory (USA, Canada, Australia, Switzerland, Slovakia, Slovenia, Czech Republic, and UK, etc). Finally, it can be concluded that adequate safety and radiation protection of nuclear & radiological facilities had been ensured which is required for minimizing of unnecessary exposure to populations from man-made sources.

ACKNOWLEDGEMENT

The authors would like to thank concerned personnel of Health Physics Division, Atomic Energy Center Dhaka (AECD) for their cooperation.

REFERENCES

Al-Saleh, F.S. (2007) "Measurements of indoor gamma radiation and radon concentrations in dwellings of Riyadh city, Saudi Arabia", Appl. Radiat. Isot.65, 843- 848.

ATSDR (1999) "Agency for Toxic Substances and Disease Registry: Toxicological Profile for Ionizing Radiation (Atlanta, GA: US, Department of Health and Human Services, Public Health Service.)

Belivermis, M., Kılıç, N., Çotuk, Y., Topcuoğlu, S. (2010) "The effects of physicochemical properties on gamma emitting natural radionuclide levels in the soil profile of Istanbul", Environ Monitor Assess. 163 (1-4): 15–26.

Clouvas, A., Xanthos, S., and Antonopoulosdomis, M. (2004)" Radiological Maps of Outdoor and Indoor Gamma Dose Rates in Greek Urban Areas Obtaıned by In Situ Gamma Spectrometry"' Radiation Protection Dosimetry. 112 (2), 267–275.

Svoukis E. and Tsertos H. (2006) "Indoor and outdoor In situ high-resolution gamma radiation measurements in urban area of Cyprus", Department of Physics, University of Cyprus, Nicosia, Cyprus.

Beck H. L., Campo J. D. and C. Gogolak. (1972) "In-Situ Ge (Li) and NaI (Tl) Gamma-ray Spectrometry", New York, US DOE, Environmental measurement Lab., HASL-258.

Hazrati, S., Sadeghi, H., Amani, M., Alizadeh, B., Fakhimi, H. and Rahimzadeh, S. (2010) "Assessment of gamma dose rate in indoor environments in selected districts of Ardabil Province, Northwestern Iran", Int. J. Occup. Hyg. 2, 42-45.

ICRP (2007) "Recommendations of the ICRP: Annals of the ICRP (International Commission on Radiological Protection)", Vol. 37, pp.2-4.

Ateba, J.F.B., Ben-Bolie, P.O., Abiama, G.H., Abega, P.E. and Mvondo, S. (2010), "Natural background dose measurements in south Cameroon", Radiat. Prot. Dosim. 140, 81-88. Manual.pdf.

NCRP (2009) "National Council on Radiation Protection and Measurements: Ionizing radiation exposure of the population of the United States (NCRP Report No. 160)", (Bethesda, Md.).

Quarto, M., Pugliese, M. and Roca, V. (2013) "Gamma dose rate measurements in dwellings of Campania region, South Italy", Journal of Environmental Radioactivity. 115, 114-117.

UNSCEAR (1982) "United Nations Scientific Committee on the Effects of Atomic Radiation. Ionizing radiation: sources and biological effects. United Nations Scientific Committee on the Effects of Atomic Radiation", (New York: United Nations E82. IX.8).
UNSCEAR (1988) "United Nations Scientific Committee on the Effects of Atomic Radiation, sources, effects and risks of ionizing radiation", (United Nations, New York).
UNSCEAR (2000) "United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation Report to General Assembly, with Scientific Annexes (New York: United Nations, United Nations Sales Publication E.00.IX.3).
UNSCEAR (2008) "United Nations Scientific Committee on the Effects of Atomic Radiation Sources and Effects of Ionizing Radiation. Report to General Assembly with Scientific Annexes, volume I, Annex A: Medical radiation exposures (New York: United Nations, United Nations Publication Sales No.E.10.XI.3).
User Manual GAMMA SCOUT, available at https://www.gamma-scout.com/EN/Handbuch.php Owner's Manual, GARMIN eTrex HC Series, available at https://static.garmincdn.com/pumac/eTrexLegendHCx_Owners
Wilson, W. F. (1994) "A Guide to Naturally Occurring Radioactive Materials ", Oklahoma, PennWell Books, pp.128.

--0--