Journal of Radiation and Nuclear Applications
An International Journal

http://dx.doi.org/10.18576/jrna/040206

Natural Radioactivity Levels and Radiological Risk Assessment of Surface Water of Wetland Tanguar Haor, Sunamganj District, Bangladesh

M.A. Hossain Bhuiyan[1], *K. Asaduzzaman*[2], *A. Kowser*[2], *S.A.M. Shariar Islam*[1], *M.R. Islam*[1], *S.A. Kakoly*[1], *M. Begum*[2] and *M. Khondker*[1]

[1] Department of Botany, University of Dhaka, Dhaka-1000, Bangladesh.
[2] Institute of Nuclear Science and Technology, Atomic Energy Research Establishment, Savar, Dhaka -1349, Bangladesh.

Received: 23 Mar. 2018, Revised: 12 Apr. 2019, Accepted: 24 Apr. 2019.
Published online: 1 May 2019.

Abstract: The water has an importance in environmental studies because of its daily usage by human and its ability to transport pollutants, such as radionuclides that can pose a health risk to human. In the present investigation, the radioactivity in the surface water of wetlands Tanguar haor (two study stations, namely Ruar station and Watch tower station), Sunamganj, Bangladesh was carried out. The Tanguar Haor of Sunamganj bears a value since it has been declared as a Ramsar Site. The Study is made of the presence of the natural-series indicator radionuclides ^{226}Ra (^{238}U) and ^{228}Ra (^{232}Th) and the non-series radionuclide ^{40}K, the gamma radiation exposure also being evaluated. Measurement was made employing gamma-ray spectroscopy system using High Purity Germanium (HPGe) detector and the radioactivity concentrations of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in surface water of both study stations ranged from 0.52±0.33 to 10.36 ± 0.21 Bql^{-1}, 1.02±0.19 to 5.18 ± 0.55 Bql^{-1} and 8.21±1.59 to 84.8 ± 1.60 Bql^{-1}, respectively. Comparatively higher level of radioactivity was noticed in March, April, July, September, and December of the year. No linear pattern of changes of radioactivity with physicochemical parameters was observed in haor surface water. The annual effective dose (3.25 to 12.60 µSv y^{-1}) caused by the haor surface water was well below the upper dose criterion limit of 1 mSvy^{-1}. Hence, yet pose no significant threat to the ecosystem, public health, and aquatic lives.

Keywords: Tanguar haor, Surface water, Radionuclide, Radioactivity, Annual effective dose.

1 Introduction

Natural decay series radionuclides such as ^{238}U and ^{232}Th and non-series radionuclide ^{40}K having long half-life comparable to the age of the earth are ubiquitous in the earth's crust and atmosphere since its creation, and are concentrated in all environmental substances and surface water body [1–3]. These radionuclides that are associated with igneous and sedimentary rocks, are transferred into the environment through several possible pathways, such as the aquatic systems, atmosphere and soil sub-compartments, each contributing to human radiation exposure [4,5]. Natural series and non-series sources of radiation contribute mostly to the collective dose experienced by the global population. About 83% of annual effective dose experienced by individuals due to the natural decay series radionuclides while 16% is contributed by the primordial ^{40}K, and the remaining 1% is from the artificial radionuclides [6,7]. Long-term exposure to these radionuclides increases the risk of developing several diseases such as lymphoma, bone cancer, and diseases that affect the formation of blood, such as leukemia and aplastic anemia.

Natural radioactivity in the environment can be heightened through the human activities, such as agricultural inputs (e.g. use of fertilizers, fungicides, insecticides and herbicides), combustion of fossil fuel, rapid urbanization, coal, oil, and gas exploration and exploitation and disposal of radioactive wastes and industrial effluents etc. [8–10]. It can also be enriched in regions with deposit of mineral resources such as uranium ores and phosphate. Materials from the deposit may be brought to the surface soil or water through processes such as weathering of rocks soil formation and flood water runoff which leads pollution far

*Corresponding author e-mail: asad.ie.baec@gmail.com

away from the source. The presence of radioactivity in surface water can be enhanced by such activities, posing an additional radioactive loading with consequences for human health. Hence, the increasing concern to monitor the radionuclide contents in aquatic environment.

Water has an importance in environmental studies because of its daily usage by human and its ability to transport pollutants. Water may contain some radionuclides that can pose health risk to human. For this reason, its quality should be strictly controlled. Water that originates in or moves through geologic deposits containing naturally-occurring radionuclides could result in radioactivity being carried to the water bodies. Radioactivity in surface water comes mainly from the radionuclide of the natural decay chains of ^{238}U, ^{232}Th and ^{40}K in soil and run-offs from industrial wastes/effluents and other maritime activities [10]. Most rural communities depend on these surface water, river water, creeks and so on for their daily water needs. Consequently, radionuclides are also transported to the food chain through irrigation water from the sources mentioned above.

Naturally, the concentration level of radionuclides in surface waters and ground waters are mainly dependent on uranium and thorium bearing soil and rock mineral or with uranium, thorium and radium deposits. Therefore, the dispensation of natural radioactivity in water depends on the local geological characteristics of the source, soil or rock [11]. Studies related to the naturally occurring radioactivity of uranium and thorium decay series and primordial potassium in aquatic environment provide information on the environmental pollutants in water bodies, whereas aquatic flora and fauna deliver an easy incorporation of radiation exposure into human body succeeding their consumption [12]. Furthermore, aquatic organisms have the capacity of bioaccumulating more radionuclides and toxic elements from water into their body biomass. This happens due to the physical and chemical nature of the body surface and feeding behavior of the organisms in their respective habitats. Thus, the determination of radioactivity in water bodies assumes greater importance [13,14].

Wetlands have great importance in economic, socio-economic, ecological and commercial sectors of Bangladesh. Wetlands have rich components of biodiversity like flora and fauna of important local, national and regional significance [15,16]. The purposes of wetlands include: support for food chains, fisheries production, biomass production, water transport, water recharge and discharge at the ground, habitat for wildlife, recreation, natural heritage values, storage of flood water, shoreline stabilization and reduction of erosion, sediment trapping, nutrient retention/removal, and support for biodiversity preservation and micro-climate stabilization [17]. Tanguar Haor, Sunamganj, Bangladesh, the present study area, is one of the most significant wetlands in South Asia. It is a significant wetland ecosystem of Bangladesh and has an international focus. Because of its critical condition and over-exploitation of its natural resources, the Government of Bangladesh declared Tanguar haor as an ecologically critical area in 1999 and was declared as a Ramsar Site in the year 2000 [18]. Tanguar haor is a very rich depository of vegetation's, aquatic plants, reeds, algae and phytoplankton [19]. Notable occurrence of the rich biodiversity and colonization and visit by the members of the wildlife especially water fowl is most significant in this haor. This feature has enabled Tanguar haor to gain the designation as a Ramsar Site. Inland water bodies are susceptible to pollution because of their widespread accessibility for disposal of contaminants through natural processes and anthropogenic interventions caused by various industrial and agrarian activities. Consequently, freshwater ecosystems has severely been degraded globally. Since Tanguar haor constitute one of the most important inland ecosystems, prevention and control the pollution is crucial. Therefore, regular monitoring of water quality parameters such as radioactivity is necessary to assess the health of the aquatic ecosystems. Evaluation of natural radioactivity recognizes temporal variations which could be useful for improving adverse effects through effective management.

In the late March of 2017, an onrush of upstream hill water and excessive rain submerged a vast tract of back swamp in Sunamganj and a few other north eastern haor zones (wetland) including Tanguar haor in the country. It was rumored that the upstream from West Khasi Hills into the Ranikor River carrying an elevated level of uranium from the nearby open-pit uranium mining to the haor areas could cause the death of the aquatic species. To our knowledge, there is no radiological data present in the literature of the study area. Hence, this study on the radiological parameter can provide important information regarding the uranium contamination in the waters of Bangladesh region, because the whole sampling of the present investigation was carried out at the same time. The data could also become a vital tool for consultation in future loading of the radioactive materials in the water area of Bangladesh and could also be useful for citation purposes.

2 Materials and Methods

2.1 Study Area

Wetland Tanguar haor is located within 25º06`- 25º11`N and 91º01`- 91º06`E of Sunamganj district, Sylhet (Fig. 1). Physically, the Haor is located in the Dharmapasha and Tahirpur Upazillas of Sunamganj district. Two permanent sampling stations called Rauar Station and Watch Tower Station of Tanguar haor were set for carrying out the sampling program in the haor. The Watch Tower Station is situated in the central location and at the deepest part of the haor and Rauar Station is located ~2 km north from the Watch Tower Station. These selected sampling points were deep and perennial in nature, thus facilitate the sampling

through out the year of the study. The haor did consist a number of shallow depressions of which the studied stations are relatively deeper and real tectonic depressions which a haor ecosystem must possess.

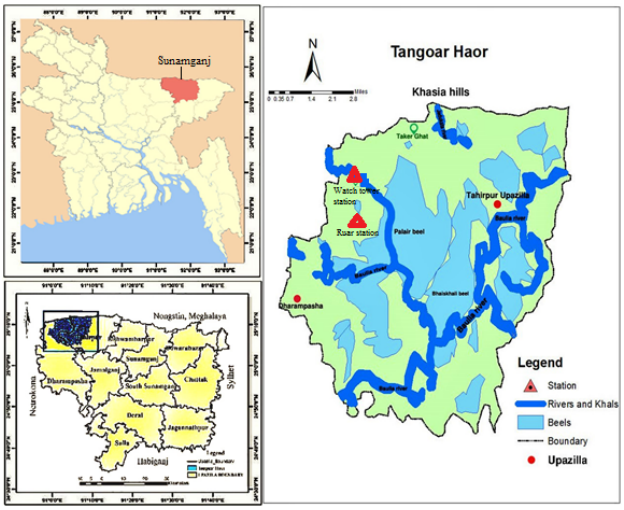

Fig. 1: Map of the sampling area situated at Tanguar Haor in Sunamganj District.

2.2 Sampling at the Study Site

Bimonthly water samples were collected from the aforementioned two study stations of Tanguar haor from April 2017 to March 2018. The period did cover the climatic seasons of Bangladesh as proposed by Bramer (2002) [20]. All water samples were preserved in an insulated igloo box using cool packs and transported to the laboratory.

2.3 Phyco-chemical Parameters and Meteorological Data

On each visit of sample collection, physical and chemical variables namely, air and water temperature, water depth, Secchi depth, pH, conductivity and total dissolved solids (TDS) were measured *in situ* using relevent field instruments. Results on the biological and physicochemical parameters from Tanguar haor have been published elsewhere [21,22].

2.4 Sample Preparation for Radioactivity Measurement

The collected water samples were taken to the radiotion monitoring laboratory at Health Physics and Radioactive Waste Management Unit, Institute of Nuclear Science and Technology, Atomic Energy Research stablishment, Ganakbari, Savar, Dhaka. About 260 ml of each water sample was transferred to 280 ml clean plastic containers of similar geometry and sealed with electrical tape. All the samples were labeled (with its code, preparation date, weight etc.) properly and stored for at least 4 weeks (7 half-life of ^{222}Rn) at room temperature to allow secular equilibrium of ^{226}Ra, ^{232}Th with their progenies prior to the radiometric analysis with a gamma-ray spectrometry system [7].

2.5 Measurement of Radioactivity

The activity concentrations of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in the samples were determined by γ-ray spectrometry system using high purity germanium (HPGe) detector from Canberra having a relative efficiency of 20% and an energy resolution of 1.8 keV-FWHM at the 1332.5 keV peak of ^{60}Co shielded by a cylindrical lead. Energy calibration of the detector was performed using the standard gamma-ray source of ^{60}Co with the known peak at 1173 keV and 1332 keV and using the ^{137}Cs with the peak at 661 keV. The efficiency calibration of the detector was done by 260 ml cylindrical pot geometry standard liquid source (prepared by ^{152}Eu gamma ray emitting reference source) obtained from the International Atomic Energy Agency (IAEA). The sample container has the same geometry as the standard ^{152}Eu gamma reference source to ensure the reliability and accuracy of the energy range in the measurement of respective radionuclides. The samples were counted for 20,000 s and the background counts for the same counting time were deducted from the sample counts to obtain the net counts. The uranium and thorium decay series, the ^{226}Ra (^{238}U) and ^{228}Ra (^{232}Th) activities were determined indirectly via the activities of their short-lived progenies. In order to minimize the error in activity concentration, only adequately discriminated and strong characteristic gamma lines of the respective radionuclides were used to determine the activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K. Based on such criteria, the content of ^{226}Ra was measured using the characteristic gamma-lines of 351.92 keV (35.6%) from ^{214}Pb, 609.32 keV (45.49%) and 1120.29 keV (14.92%) from ^{214}Bi. Likewise, the concentration of ^{228}Ra was determined using the gamma-lines of 238.63 keV (46.6%) from ^{212}Pb, 583.19 keV (85.0%) from ^{208}Tl and 911.16 keV (25.8%) from ^{228}Ac. The single gamma line 1,460.822 keV (10.66%) was used to determine the activity concentrations of ^{40}K. The activity concentrations were calculated based on the weighted mean value of their respective decay products.

2.5.1 Activity Concentration of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in water samples

The activity concentrations of the radionuclides in the surface water samples were calculated using the following formula used elsewhere [23]

$$A = \frac{CPS \times 1000}{\varepsilon_\gamma \times I_\gamma \times W(gm)} \qquad (1)$$

where, A is the activity of the sample in Bq l^{-1}, CPS is the net counts per second = cps for the sample – cps for background value, ε_γ is the detection efficiency of the γ-ray

spectrometer at each respective γ-ray energy, I_γ is the emission probability of the corresponding γ-ray energy, W is the samples net weight (in gm).

The combined uncertainty of the activity concentration was estimated using the following equation [24].

$$\left(\frac{\Delta A}{A}\right) = \sqrt{\left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta I_\gamma}{I}\right)^2 + \left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta T}{T}\right)^2} \qquad (2)$$

where, ΔA is the uncertainty of the sample measurement and ΔN, ΔI_γ, Δm, and ΔT are the uncertainties of the count rate, gamma-ray intensity, sample weight and counting time, respectively.

2.5.2. Absorbed Dose Rate (D_r) and Annual Effective Dose (A_{ed})

The quantities generally used for estimation of external exposure due to terrestrial radionuclides are absorbed dose rate in air and annual effective dose. The external absorbed dose rates D_r (nGyh^{-1}), in outdoor air can be calculated from terrestrial radionuclide activities using the following equation [25, 26].

$$D_r(nGyh^{-1}) = 0.462 \times A_{Ra} + 0.604 \times A_{Th} + 0.042 \times A_K \qquad (3)$$

where 0.462, 0.604, and 0.042 are respectively the dose conversion factors transforming the activity concentrations of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K (A_{Ra}, A_{Th}, and A_K) into dose-rates (in nGyh^{-1} per Bql^{-1}) [27].

The annual effective dose equivalent can be estimated from the absorbed dose-rate, applying the conversion factor of 0.7 Sv Gy^{-1} for absorbed dose-rate to the effective dose received by an adult and an outdoor occupancy factor of 0.2 [27]. The annual effective dose (in mSv y^{-1}) to an individual has been estimated by the use of the following equation [23,26].

$$A_{ed}(mSvy^{-1}) = D_r(nGyh^{-1}) \times 8760hy^{-1} \times 0.7(SvGy^{-1}) \times 0.2 \times 10^{-6} \qquad (4)$$

taking 8760 h as the number of hours per year and with 10^{-6} the nano- to milli conversion.

3 Results and Discussion

3.1 Activity Concentration of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K Radionuclides

The measured radioactivity concentration (together with uncertainties) in the surface water samples collected from the Rauar Station of Tanguar Haor (Table 1) from April 2017 to March 2018 were found to be varied from 0.9 ± 0.30 to 10.36 ± 0.21 Bql^{-1} with an average value of 4.54 ± 3.59 Bql^{-1} and 1.55 ± 0.46 to 5.18 ± 0.55 Bql^{-1} having average value 3.07 ± 1.52 Bql^{-1} as well as 23.1 ± 1.60 to 84.8 ± 1.60 Bql^{-1} with an average of 46.80 ± 25.44 Bql^{-1} for ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K, respectively. Whereas, the respective values for Watch tower station (Table 2) were ranged between 0.52±0.33 to 6.29±0.29 Bql^{-1} (average: 3.05±2.21 Bql^{-1}), 1.02±0.19 to 4.74±0.37 Bql^{-1} (average; 2.63±1.24 Bql^{-1}) and 8.21±1.59 to 82.02±1.59 Bql^{-1} (average: 39.67±25.26 Bql^{-1}).

The activity concentrations (Table 1 and 2) of radiologically important radionuclide ^{226}Ra (^{238}U) in both the study stations of the Tanguar Haor were found to be slightly higher (but not significant) than that of ^{228}Ra (^{232}Th), which may be attributed to the fact that ^{226}Ra is more soluble than ^{228}Ra (^{232}Th) in water. Whereas, the concentrations of ^{40}K was very much higher than ^{226}Ra (^{238}U) and ^{228}Ra (^{232}Th) because of its natural abundance. Potassium is an abundant element in all environmental media including water. However, the isotope ^{40}K is radiologically less important compared to radium isotopes because it is homeostatically controlled in the human body and also an essential element [8].

Table 1: Activity concentrations (Bq l^{-1}) of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in the surface water samples of Rauar station of Tanguar Haor and radiation dose received by individual.

Sample collection period	Activity concentration (Bq l^{-1})			Absorbed dose-rate, Dr (nGyh^{-1})	Annual effective dose, Aed (μSv y^{-1})
	^{226}Ra (^{238}U)	^{228}Ra (^{232}Th)	^{40}K		
Apr	0.9 ± 0.30	5.18 ± 0.55	31.5 ± 1.60	4.80	5.97
Jul	10.36± 0.21	2.15 ± 0.48	37.18 ± 1.59	7.60	9.38
Sep	1.07 ± 0.38	1.55 ± 0.46	72.69 ± 1.59	4.48	5.50
Dec	5.38 ± 0.28	2.65 ± 0.58	84.8 ± 1.60	7.64	9.38
Jan	3.25 ± 0.33	2.12 ± 0.55	23.1 ± 1.60	3.75	4.60
Mar	7.95 ± 0.26	4.74 ± 0.32	31.54 ± 1.47	10.27	12.60
AM± SD	4.54 ± 3.59	3.07 ± 1.52	46.80± 25.44	6.42 ± 2.50	7.90 ± 3.06

AM denotes arithmetic mean, SD denotes standard deviation.

Table 2: Activity concentrations (Bq l^{-1}) of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in the surface water samples of Watch tower station of Tanguar haor, Sunamganj and radiation dose received by individual.

Sample collection period	Activity concentration (Bq l^{-1})			Absorbed dose-rate, Dr (nGyh^{-1})	Annual effective dose, Eed (μSv y^{-1})
	^{226}Ra (^{238}U)	^{228}Ra (^{232}Th)	^{40}K		
Apr	4.55± 0.31	2.46± 0.19	34.12± 1.59	5.02	6.16
Jul	0.52± 0. 33	1.02± 0.19	47.25± 1.60	2.84	3.48
Sep	3.78± 0.29	1.94± 0.23	82.02± 1.59	6.36	7.80
Dec	1.17± 0.31	2.92± 0.23	8.21± 1.59	2.65	3.25
Jan	1.96± 0.35	2.7±0.2 1	44.1± 1.60	4.39	5.38

Mar	6.29± 0.29	4.74± 0.37	22.34± 1.58	6.71	8.23
AM±SD	3.05± 2.21	2.63± 1.24	39.67± 25.26	4.66± 1.71	5.72± 2.10

AM denotes arithmetic mean, SD denotes standard deviation

Approximately, similar concentrations were observed in both study stations, which may be attributed to the similar geological setting of the investigated areas. These levels of radioactivity are not significant for environmental consequences including the health of human and aquatic lives by the utilization of haor water for irrigation or other purposes except drinking.

The seasonal variation of radioactivity in haor water is shown in Fig. 2. Somewhat higher levels of ^{226}Ra (^{238}U) were observed in July, March, and December in Ruar station and April, September and March in water samples of Watch tower station, while ^{228}Ra (^{232}Th) was noticed comparatively elevate in March and April of the year in Ruar station and March and December in Watch tower station. On the other hand, relatively increased levels of ^{40}K were found in September of the year in both the study stations of Tanguar Haor. Variation of radioactivity with water physicochemical parameters were illustrated in Fig. 3. No linear pattern of changes in radioactivity was observed with physicochemical parameters of haor water. Pearson's correlation (Table 4) also confirm this statement. For the water samples of the present investigation, the potential association and relationships existing between the radionuclides and water physicochemical parameters were evaluated by means of Pearson's correlation analysis (Table 4). Table 5 reveals the existence of significant positive correlation (r = 0.830) between air temperature and ^{228}Ra (^{232}Th). Similar relationship (r =0.957) was also observed between ^{40}K and Secchi depth and alkalinity in the pelagic zone of the haor water. In the correlation analysis, other physicochemical parameters showed weak and negative correlation which indicates that the activity concentrations of the natural radionuclides in the haor water samples does not affect by physicochemical parameters.

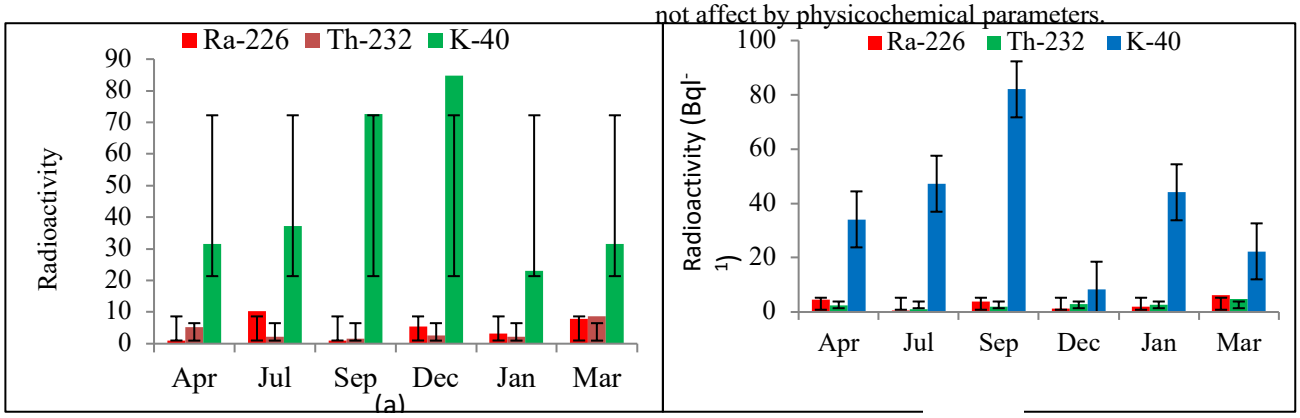

Fig.2: Seasonal variation of radioactivity at (a) Ruar station (b) Watch tower station.

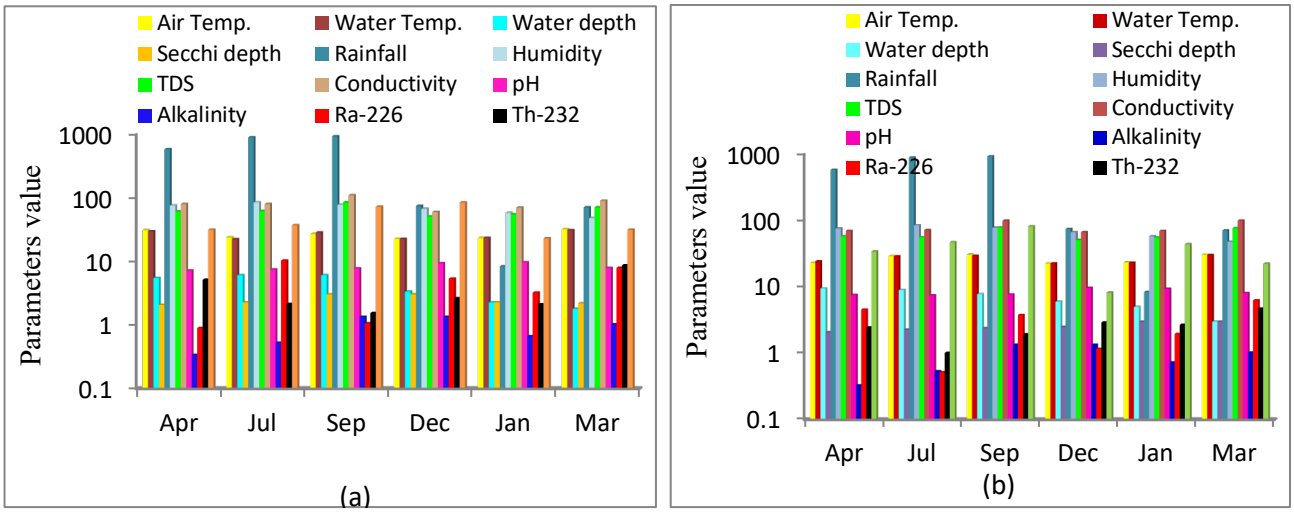

Fig. 3: Variation of radioactivity with water physicochemical parameters (a) Ruar station (b) Watch tower station.

Table 3: Comparison of radioactivity concentration of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K in surface water samples (Present investigation) with the other literature values for surface samples studied elsewhere.

Site	Activity levels (Bq l^{-1})			References
	^{226}Ra (^{238}U)	^{228}Ra (^{232}Th)	^{40}K	
Tanguar haor sites (Sunamganj, Bangladesh)	0.52±0. 33 - 10.36±0.21	1.02±0.19 - 5.18 ± 0.55	8.21±1.59 - 84.8 ± 1.60	Present study
Habigonj District site (Sylhet, Bangladesh)	1.45 - 13.08	0.0 - 14.02	0.0 - 73.46	[28]
Rooppur RNPP Site (Pabna, Bangladesh)	0.11 – 0.21	0.13 – 0.30	0.30 – 0.47	[29]
Bhawal Garh site (Gazipur, Bangladesh)	0.08 - 0.98	0.10 - 1.62	-	[30]
Ndokwa East, Delta State (Nigeria)	2.37±0.10	4.19±0.23	15.82±2.03	[10]
Hazar Lake (Elazıg Turkey)	0.52±0.02 - 2.02±0.06	-	-	[31]
Lake Bosomtwe (Ghana)	0.42±0.20	0.33±0.31	1.59±1.07	[32]

Table 4: Pearson's correlations between radionuclides and physicochemical parameters.

	^{226}R	^{228}Ra	^{40}K	D_r	E_{ed}	Air temp	Water temp	Water depth	Sacchi depth	Rainfall	Humidity	TDS	Conductivity	pH	Alkalinity
^{226}R	1														
^{228}Ra	.215	1													
^{40}K	-.164	-.406	1												
Dr	.779*	.645	.044	1											
Eed	.779*	.646	.041	1.00**	1										
Air temp	-.176	.830*	-.368	.270	.273	1									
Water temp	-.362	.710	-.199	.133	.134	.958**	1								
Water depth	-.179	-.492	.246	-.356	-.350	-.058	-.036	1							
Sacchi depth	-.226	-.526	.957**	-.096	-.102	-.468	-.252	.173	1						
Rainfall	-.068	-.394	.149	-.253	-.248	.047	.077	.955**	.116	1					
Humidity	-.084	-.630	.272	-.370	-.364	-.288	-.290	.964**	.199	.874*	1				
TDS	-.211	.098	.142	-.020	-.022	.479	.631	.365	.215	.570	.135	1			
Conductivity	-.234	.094	.046	-.081	-.082	.507	.644	.412	.120	.616	.180	.992**	1		
pH	-.054	-.326	.199	-.164	-.172	-.656	-.575	-.646	.343	-.728	-.478	-.552	-.608	1	
Alkalinity	-.064	-.114	.812*	.235	.227	-.185	.019	-.197	.870*	-.154	-.234	.342	.225	.359	1

The mass media reported that the upstream from West Khasi Hills carrying an elevated level of uranium from the nearby open pit uranium mining to the haor areas and causing the death of the aquatic species. But, no high level of uranium found in any of the tested water samples in any seasons of the year.

The results of the present investigation has been compared with other literatures published elsewhere (Table 3). From the comparison, it has been revealed that the radioactivity of the current study is found to be comparable to the study of Nazmun Sakib, 2015 [28] in the nearby Habigonj District site, Bangladesh indicating the similar geological settings of the nearby two areas. Whereas, Mollah *et al*. 2009 [29] (Pabna district, Bangladesh) and Islam, *et al*. 2014 [30] (Gazipur district, Bangladesh), Ononugbo and Anyalebechi, 2017 [10] (Nigeria), Özmen *et al*. 2004 [31] (Turkey) and Darko *et al*. 2017 [32] (Ghana) reported very much lower activity in surface water comparable to our investigated result. This may be due to the dissimilar geological and geographical locations, industrial and human activities, soil amendment, geo-environment conditions and drainage pattern dependencies etc. among the different study regions [7,33,34].

3.2. Absorbed dose rate (D_r) and annual effective dose (A_{ed})

The absorbed dose-rate due to natural radionuclides in the surface water were ranged between 3.75 and 10.27 nGyh^{-1} with a mean of 6.42 ± 2.50 nGyh^{-1} (Table. 1) for Ruar station of Tanguar Haor and 2.65 to 6.71 nGyh^{-1} with a mean of 4.66±1.71 nGyh^{-1} (Table. 2) for Watch tower station of the same haor. These values represents only a small fraction of the world average absorbed gamma dose rate of 55 nGy h^{-1} as stated in the UNSCEAR-2000 report [35].

The estimated annual effective dose received by individuals from the surface water of Ruar station of Tanguar haor varied from 4.60 to 12.60 µSv y^{-1} with a mean of 7.90±3.06 µSv y^{-1} (Table. 1). The respective values for Watch tower station of the same haor were ranged 3.25 to 8.23 µSv y^{-1} with a mean value of 5.72±2.10 µSv y^{-1} (Table. 2) which is very close to the dose of surface water estimated at Ruar station. This may be attributed due to the similar geological and metrological situation and physicochemical parameters of both the study locations, which is also confirmed the Pearson's correlation (Table 4). The annual effective dose (Table. 1 and 2) caused by the haor water is well below the upper dose criterion limit of 1 mSvy^{-1} recommended by ICRP-60 [36]. Hence, pose no significant threat to the ecosystem, public health, and aquatic lives.

Dose contribution in relation to season and radionuclides has been shown in Fig. 4 and 5, respectively. Among the seasons of the year, March is the highest contributor to the annual effective dose with a contribution of 26% (Fig. 4a) of total dose received by individual, followed by December (20%), July (20%) and so on at Ruar station of Tanguar haor. In the case of Watch tower station of the same haor, again March contribute highest annual effective dose with a contribution of 24% (Fig. 4b) of total dose received by individual, followed by September (23%), April (18%) and so on. Conversely, ^{226}Ra (^{238}U) and ^{228}Ra (^{232}Th) have the same contribution to the effective dose (35% each) trailed by ^{40}K (30%) of total dose at Ruar station of Tanguar haor (Fig. 5a). While, ^{40}K is the principal contributor (Fig. 5b) to the total effective dose (36%) followed by ^{228}Ra (^{232}Th) (34%) and ^{226}Ra (^{238}U) (30%) in Watch tower station of the same haor.

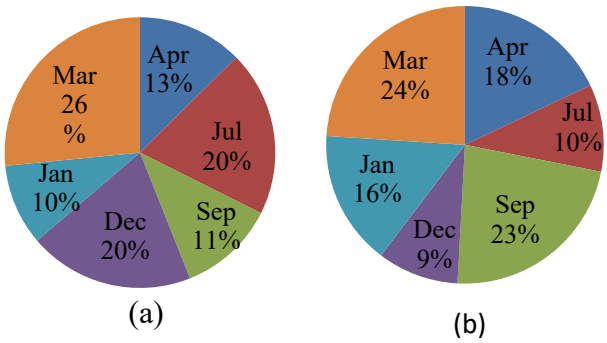

Fig. 4: Dose contribution in relation to season; (a) Ruar station (b) Watch tower station.

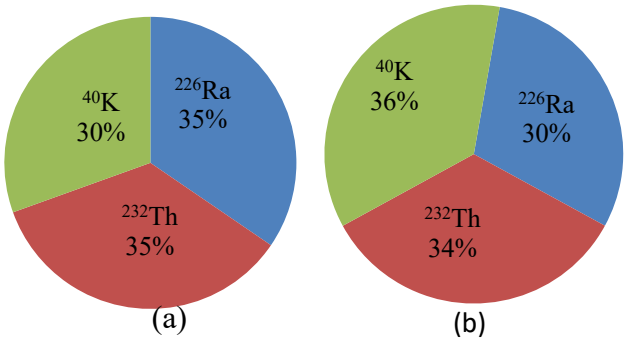

Fig. 5: Dose contribution in relation to radionuclides (a) Ruar station (b) Watch tower station.

4 Conclusions

Natural radioactivity of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K in the surface water of two strategic stations namely Ruar station and Watch tower station of wetlands of Tanguar haor, located at Sunamganj district of Bangladesh which is declared as a Ramsar Site has been investigated. The gamma radiation exposure to population due to utilization of surface water of the study areas also estimated as well. The average activity concentrations in the surface water of Ruar station were measured as 4.54 ± 3.59, 3.07 ± 1.52 and

46.80 ± 25.44 Bql^{-1} for ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K, respectively. The respective values of ^{226}Ra (^{238}U), ^{228}Ra (^{232}Th) and ^{40}K for Watch tower station were found to be 3.05±2.21, 2.63±1.24 and 39.67±25.26 Bql^{-1}. Approximately similar magnitudes of radioactivity of the two study locations indicate analogous geological and geo-environmental settings of the nearby two areas. These levels of radioactivity are not significant for environmental consequences including the health of human and aquatic lives by the utilization of haor water for irrigation or other purposes except drinking. March, April, July, September and December exhibits relatively higher level of radioactivity than the other seasons of the year. Pearson's correlation analysis indicates that the activity concentrations of the natural radionuclides in the studied haor water samples does not affect by physicochemical parameters. The annual effective dose can be credited to individuals due to utilization of haor surface water were ranged 3.25 to 12.60 μSv y^{-1} which is a minor fraction of the upper dose criterion limit of 1 $mSvy^{-1}$. Hence, till now the wetlands Tanguar haor water can be considered safe for ecosystem, public health, and aquatic lives.

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