ABSTRACT

Earth has been radioactive ever since its existence four and half billion years ago as it contains many radioactive elements such as radium, uranium, potassium, thorium etc. Human beings are exposed to radiations which are produced naturally as well as artificially. Natural ionizing radiations are available mostly from the decay series of radioactive elements like U-238, Th-232. Radiological pollution is a concern for health hazard to worldwide population due to continuous exposure of radiations. The ionizing radiations may be harmful to the humans depending upon exposure time, concentration, dose received etc. Mainly two kinds of effects of radiation on the tissues i.e., the ‘Deterministic and Stochastic effects’ have been observed. Chronic exposure of uranium radionuclide through drinking water poses health risk to the consumers. Due to hazardous health effects of radiation exposure, many researchers individually as well as in groups have conducted survey of different geographical areas at national and international level to find out the activity concentration of radioactive elements in natural environment and to estimate related health effects.

From the literature survey it has been found that uranium exhibits chemical and radiological toxicity which effects mostly to the two vulnerable organs kidneys and lungs. Chemical toxicity is the side reactions of ingested molecules with DNA and the interference with enzymatic system. This toxicity can be caused by breathing air containing uranium dusts or by eating substances containing uranium, which then enters the bloodstream. Once in the bloodstream, the uranium compounds are filtered by the kidneys, where they can cause damage to the kidney cells. Radiological toxicity deals with the effects of radiations emitted by radioactive elements when it accumulates in the body. Higher uranium intake can cause uranium to accumulate in organs like the kidney, bones, GI Track, soft tissues which can be cancerous. In addition to being toxic heavy metal, it is also a radioactive element and can cause several adverse health effects ranging from renal failure, diminished bone growth and damage to DNA when consumed in high quantities as reported by ICRP in 1975. Cancer of lungs, bladder, skin, stomach, and breast is the most notable uranium-related disease. In addition to above, reproductive and respiratory systems are also affected by uranium exposure.

The presence of radon/thoron gases in soil, water and indoor environment has been considered as matter of concern for the radiological health risk. Approximately

1-5% of the radon in indoor air was estimated to originate from water. Radon in soil which escapes into outdoor atmosphere have high risk potential to human health. Radon/ thoron progenies may get attached to aerosols present in ambient air and are inhaled during breathing. These may stick to alveoli and could expose cells of bronchial and pulmonary epithelium in the lungs, thereby damaging the cells, DNA and may cause lung cancer. Henshaw claimed in 1990 that the indoor radon exposure has been linked to the development of leukaemia and other malignancies such as melanoma, kidney and prostate cancers, as well there is 16 percent increase in relative lifetime lung cancer risk per 100 Bqm^{-3} due to chronic radon inhalation. A radon concentration of 50 Bqm^{-3} can cause 25% of leukaemia cases in children and adults of all ages. Inhalation of short-lived decay product of radon (Po-214), responsible for 40% of the total radiation dose received by the population, is a major contributor to problems of respiratory system, lung cancer, and damage to sensitive cells in the skin and causes skin cancer. Radon and its progeny leads to about 69% of the total annual effective dose in contrast to another natural sources. For non-smokers radon is the primary cause of lung cancer while for smokers it is secondary, encompassing an approximated 3-20% of deaths due to lung cancer globally. Indoor radon causes 21,000 (13.4%) lung cancer deaths in the United States each year, with 2900 of these being non-smokers.

Considering the importance of these radiations, Bhabha Atomic Research Centre (BARC), Mumbai, India has undertaken various research projects to monitor these radiation levels and associated health effects throughout the country for mapping. The land of Punjab is highly fertile and useful for agriculture. Over the past few decades the land has been used for crop production with excessive use of fertilisers and pesticides. As a result, the land and water has been contaminated with phosphate fertilisers which are the major source of uranium. Over use of water leads to depletion of groundwater level. The study area has many thermal power plants in its surrounding and the fly ash from these plants is used in the formation of cement which is the major component of building materials. So, these factors make the residents of the area vulnerable to the exposure of natural radiation through ingestion and inhalation. Although plenty of literature related to radiological health risk assessment is available for the state of Punjab but the data is still scarce for the Barnala and Moga districts which falls in the Malwa region of Punjab known for having highest cancer rate in the country. Hence the present study has been carried out using grid pattern to measure the radon/thoron and their progeny and uranium concentration in the environs of studied area to understand the radiological impact by comparing the measured data with the recommended values by various agencies.

The measurements of indoor radon/thoron concentration have been carried out by using both passive and active techniques. Single entry pinhole dosimeters (passive technique) has been deployed which is based on the radon thoron discrimination technique and the associated theory by selecting suitable chamber volume and allowed only radon. Smart RnDuo (active technique) has been used which is based on the principle of detection of alpha particles which strike the detector and produces scintillations with ZnS:Ag coating inside the cell. These scintillations are counted by Photo Multiplier Tube combined and converted to radon/thoron activity using inbuilt algorithm. For radon/thoron progeny concentration the deposition based radon/thoron progeny sensors (DRPS/DTPS) has been used. These progeny sensors work on the principle is that the LR-115 detector detects the alpha particles emitted from the deposited progeny atoms. These are made up of passive nuclear track detectors (LR-115 Type-II) mounted with absorbers of appropriate thickness. Smart RnDuo has been used for measuring radon in water, radon mass/thoron surface exhalation rates in soil. For measurement of uranium concentration in water LED Fluorimeter has been used. LED Fluorimeter is based on the principle of detection of fluorescence of uranium complexes in samples. Uranium complexes emit green fluorescence under UV excitations which are detected with the help of sensitive photomultiplier tube. The fluorescence yield is proportional to the intensity of excitation source and concentration of uranium in sample. Measurement of fluorescence gives the information about the concentration of uranium in water samples.

The annual average indoor radon concentration has been found to be 25.17, 33.14 Bqm^{-3}, thoron concentration 53.81, 46.73 Bqm^{-3}, radon progeny concentration 5.31, 11.84 Bqm^{-3}, thoron progeny concentration 0.94, 0.88 Bqm^{-3}, annual effective dose for inhalation 0.94, 1.70 µSvy^{-1} in the Barnala and Moga districts respectively. The annual average value of the equilibrium factor for radon and its progeny is 0.37 which is lower than the recommended value of 0.4 and for thoron and its progeny is 0.02 which is in accordance with the recommended limit of 0.02 by UNSCEAR, 2000. The results of indoor radon, thoron concentrations have been compared for active and passive techniques.

It has been observed that the average concentrations of radon, thoron and their progeny in the studied area are higher in the winter season than in the summer and rainy seasons which may be because of the poor ventilation conditions in winter due to less exchange of gases between indoor and outdoor environments, thereby leading to accumulation of radon gas during winters. The houses in the studied area were divided into categories based on ventilation conditions. A room without a window is regarded as poorly ventilated, a room with one window and a door are considered as partially ventilated and a room with more than two windows and a door is considered as well ventilated. The majority of the dwellings in this area are made of cement and are only partially ventilated. It has been observed that the poor ventilation dwellings have higher concentration than the average and well ventilated dwellings.

The average radon mass exhalation rate in the soil samples have been found to be 24.61, 24.97 $mBqkg^{-1}h^{-1}$ and the average thoron surface exhalation rate is 14.96, 16.29 $kBqm^{-2}h^{-1}$ in the Barnala and Moga districts respectively. The higher thoron exhalation rates may be because of the reason that Northern portion of India has higher thorium rich content in rocks as revealed in the radiation profile map of India. Weak correlation has been found between radon/thoron exhalation rates and indoor radon/thoron concentration which indicates that the soil may not be contributing to the indoor radon but the building materials may be contributing for the same.

The average radon concenration in water has been found to be 3.37, 3.26 BqL^{-1} in the Barnala and Moga districts respectively which is below the recommended value of 11 Bql^{-1} by USEPA (1991), 100 Bql^{-1} by WHO (2004). The annual effective dose for ingestion and inhalation has been calculated for various age groups like infants, children and adults which is below the recommended limit of 100 μSvy^{-1}. It has been found that the underground water sources (Handpumps, Submersible and Borewell) have higher levels for radon than surface water sources (Water works, canal water and RO water) which may be because of presence of granite, sands, gravel in the bedrock and also for the reason that underground water directly encounters U-238 rich rocks that releases radon in water and cannot escape to atmosphere, whereas in contrast radon in surface water samples can easily escape to atmosphere due to aeration and agitation in water.

The measured average uranium concentration in water samples has been found to be111.43, 73 μgl^{-1} in the Barnala and Moga districts respectively. The calculated excess cancer risk i.e., mortality risk and morbidity risks in 63.5% samples are higher than the recommended limits of 1.67×10^{-4}. The calculated average annual effective dose due to ingestion of uranium in water for various age groups (infants, children, adults) is higher than 100 μSvy^{-1} and 1 mSvy^{-1}. The calculated hazard quotient in 98% of the samples is higher than reference level of 1 as given by WHO in 2011, hence these areas may have increased probability of kidney and lung diseases. From the measured values, a weak correlation has been found between uranium concentration in underground water samples with the depth (24-183 meter) which may be due to more reducing conditions and less uranium solubility with increasing depth in the underground water.

Even though infants consume less water than older age groups, still the annual effective dose has been found to be significantly higher than other age groups which may be due to differences in infant's metabolism and smaller organ weights, resulting in higher doses for many radionuclides. It has been observed that average uranium concentration in median depth samples have higher concentration than shallow and deep depth samples which may be due to leaching through soil by heavy use of fertilizers in the agriculture lands and due to squanders discharged from factories or thermal power plants in this area.

Biokinetic modelling using Li's hair compartment model (2009) has been done for uranium in take for 60 years via drinking water to depict the retention/absorption of uranium and to understand the risk factor associated with individual organ/tissue with the intake of uranium through water in the various organs of human body (liver, soft tissue, kidneys, GI Track, bones, blood, Skelton, urinary bladder) and therefore it has been observed that highest dose 60.62 μSv has been received by the bone surface as compared to other organs which is inconformity with the earlier findings as reported by Priest et al., (1982). The pH value in all the samples lies in permissible range of 6.5-8.5 by Bureau of Indian Standards (BIS, 2012) and WHO, 2011. 93% samples have higher TDS value than the secondary maximum contaminant level of 500 mgl^{-1} set by USEPA (2011) and BIS (2012) standard. Moreover, 82.5% the samples have higher TDS value than the permissible limit of 600 mgl^{-1} specified by WHO, 2011. The electrical conductivity of 41.5% samples has higher value than 1000 μScm^{-1} as per regulations on drinking water hygiene in India and 22% of samples have higher electrical conductivity than 1500 μScm^{-1} as recommended by World Health Organization. A positive correlation has been observed between uranium concentration with pH, TDS and EC.

The conclusion of this study is that in the studied area 32.5% of the dwellings have higher annual average radon concentration than the recommended value of

40 Bqm^{-3} by UNSCEAR, 2008. All (100%) the dwellings have higher annual average thoron concentration than the world average value of 10 Bqm^{-3}. Only 9% of the dwellings have higher annual average radon progeny concentration (EERC) than the worldwide average value of 15 Bqm^{-3} while 96% of the dwellings have higher annual average thoron progeny concentration (EETC) than the world average value of 0.5 Bqm^{-3}. The measured values of radon mass exhalation rates are lower than 57 $mBqkg^{-1}h^{-1}$ and 98% of samples have higher thoron surface exhalation rates than the worldwide average value of 3.60 $kBqm^{-2}h^{-1}$. Uranium concentration in 99.5% of water samples have higher value than the recommended safe limit of 30 μgl^{-1} and in 79% of samples have higher value than 60 μgl^{-1}. As some of the areas have been found to have higher values than the recommended safe limit hence, such areas may be explored further for radiological health effects to the residents of the area. The available data will contribute for the uranium and radon mapping of the country which is being carried out by BARC Mumbai.