CHAPTER 6

URANIUM CONCENTRATION IN WATER AND BIOKINETIC MODELLING

This chapter deals the measurement of uranium concentration in water collected from different sources of water (surface water and underground water) using LED Fluorimeter. To understand its impact, the lifetime average daily dose (LADD) and hazard quotient (HQ) has been calculated. Further, Biokinetic modelling using Hair compartment model has been done for dose estimation to various organs in humans due to intake of water. In addition, the physicochemical parameters in water has been also measured. The detailed introduction about the topic, measurement procedure, formula used for calculations, results, discussion and conclusion have been discussed in this following section.

6.1 INTRODUCTION

Naturally radioactive element Uranium occurs in dispersed form in earth's crust. Uranium forms ions with the oxidation states of +4 (UO_2 and U^{4+}) and +6 (UO_3 and UO_2^{2+}) (Banks et al., 1995). Under aerobic conditions uranium is soluble in water because it forms bond with oxygen to form uranyl ion (UO_2^{2+}) or uranium oxide (UO_2). Uranium present in groundwater is because of the water coming out of the rocks and soils which contain uranium. The concentration of uranium in water depends upon several factors such as lithography, geomorphology and other geological conditions of the region (Sridhar Babu et al., 2008) as well as the amount of uranium present in rock through which the water has been passes. Nuclides of uranium emit alpha rays of high ionization power which may cause harmful effects to the human beings if inhaled or ingested. Uranium accumulation in humans result in chemical and radioactive effects. Chronic exposure of uranium has potential health risk (ATSDR, 1999). Mainly kidneys, liver and bones are the principal sites of the human body where uranium is mainly deposited (ATSDR, 1990; Mehra et al., 2007). The toxicity of uranium is function of the route of exposure, particle solubility, contact time and route of elimination (ATSDR, 1999). According to various estimations, 15% uranium can be ingested through food while 85% through drinking water (Cothern and Leppunbusch, 1983). Uranium has radiological toxicity with the two important target organs being the kidneys and lungs (WHO, 2004).

Exposure to uranium can cause two types of health risks: radiological risk and chemical risk. Radiological cancer risk is expressed in the terms of excess cancer risk

(ECR). The chemical/noncarcinogenic risk for uranium has been expressed in terms of lifetime average daily dose (LADD) and hazard quotient (HQ). LADD is defined as the quantity of uranium ingested per kilogram of body weight per day. Hazard quotient (HQ) is defined as the ratio of the lifetime average daily dose (LADD) of the uranium to its reference dose ($R_f D$) or tolerable daily intake (TDI) of 1 $\mu g kg^{-1} d^{-1}$ (USEPA, 1989; WHO, 1998, 2004).

The biokinetics of uranium in the mammalian body has been the subject of extensive experimental and epidemiological investigation over the past few decades and numerous biokinetic models have been developed (Lipsztein 1981; Durbin 1984; Wrenn et al. 1985; Legett and Harrison 1995). Latest model in this series is the Compartmental Model of Uranium in Human Hair proposed by Li et al., 2009 by modifying ICRP's Biokinetic model for uranium (ICRP, 1995). This model describes the kinetics of ingested uranium and illustrates the deposition of uranium from blood stream to other compartments, transformation of uranium from one organ to another and similarly its reabsorption, back from organs to blood following final excretion via urine, faeces and hair.

The absorption of uranium from gastrointestinal tract is controlled by the solubility of uranium compound (Berlin and Rudell, 1986), previous food consumption (La Touche et al., 1987) and the concomitant administration of oxidizing agents (Sullivan et al., 1986). After entering the plasma, the uranyl ion complexed with bicarbonate, citrate anions and plasma proteins is dispersed in body tissues (Keith et al., 2007). Chemical toxicity, metabolic toxicity, and physiologically dynamic toxicity are among the numerous known adverse effects of uranium consumption on health. Additionally, recent research indicates that there may be injury to the brain, reproduction, embryonic development that is aberrant or sluggish, and gene expression. An individual's overall dose is influenced by a variety of factors, such as:

- The amount of the contaminant that was inhaled or ingested.
- A portion of the contaminant entered the GI or respiratory tracts.
- The quantity of the contaminant transported by bodily fluids.
- The quantity of the contaminant deposited in the organs or target tissues.

Hydrochemistry plays an important role to decide the groundwater quality and suitability of water for drinking purposes for which determination of physico-chemical parameters like Electrical Conductivity (EC), pH, Total Dissolved Solids (TDS) in water is important. These water quality parameters also helps in studying the modelling of speciation of radio nuclides and various other contaminants present in aquatic environment due to various anthropogenic and natural activities. Measurement of pH signifies the presence of hydrogen ion concentration which further denotes the degree of acidity and alkalinity. Although it has no immediate negative health implications, a number below 7 will have a sour taste, and a value above 7 will have an alkaline taste. pH is an important monitoring parameter to assess health of aquatic ecosystem, irrigation sources and discharges, livestock, drinking water sources, industrial discharges and intakes. The capacity of water to carry an electric current is determined by its electrical conductivity (EC). This capacity mostly depends on the anions and cations present in the water as well as on ion mobility, valence, and temperature.

The total amount of dissolved salts in water directly affects its electrical conductivity. Water contains minute amounts of organic materials and inorganic salts, which are together referred to as TDS. TDS comprises various inorganic salts such as Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, CO_3^{2-}, HCO^{3-}, Cl^{-}, SO_4^{2-} and organic ionic species. Natural sources of TDS include rocks, air, mineral springs, salt deposits etc. and anthropogenic sources include sewage, urban run-offs and industrial effluents. High value of TDS influences the taste, hardness and corrosive property of water. Humans who consume water with high TDS levels for an extended period of time may develop kidney stones and heart problems. High TDS levels may induce gastrointestinal distress in humans (Jain et al., 2018). Although, till date no agency has claimed the adverse health effects because of low TDS levels but surely it will be lacking in minerals such as calcium, magnesium and zinc etc. The highest recommended value of TDS is 500 mgl^{-1} below which the water is recommended to be suitable for drinking purposes (USEPA, 2011).

The aim of this study is to measure the concentration of uranium in water samples and hence to find out the biological risks which affects the living beings in this area under investigation and their relative comparison of different source of water such as groundwater, canal water, water works tanks, ponds. Also, dose estimation to various organs using biokinetic modelling and various physicochemical parameters has been calculated in the collected water samples.

6.2 METHODOLOGY

6.2.1 Sample Collection and Lab Work

Total 200 water samples were collected from different sources of water underground water (like handpump, borewell and submersible) and surface water (like canal water, water works tanks, ponds) from different villages in the studied area of Barnala (100 samples) and Moga (100 samples) districts according to grid pattern to cover the whole area. Before collecting the samples, the tap or handpump was made to run for few minutes to collect the fresh water and then collected the water sample in polythene bottles which were properly cleaned with 5% nitric acid to breakdown uranium complexes and then rinsed with distilled water.

In the lab, the buffer solution was prepared using sodium pyrophosphate ($Na_4P_2O_7.10H_2O$) solution (5%) in distilled water and a pH value of 7.0 was adjusted by adding dilute (10% vol/vol) phosphoric acid solution drop wise (Rathore et al., 2004). LED Fluorimeter has been calibrated with standard samples containing 10, 50 and 100 μgl^{-1} of uranium against observed values of fluorescence. The lower detection limit of instrument is 0.1 ± 10% μgl^{-1} (LED Fluorimeter manual).

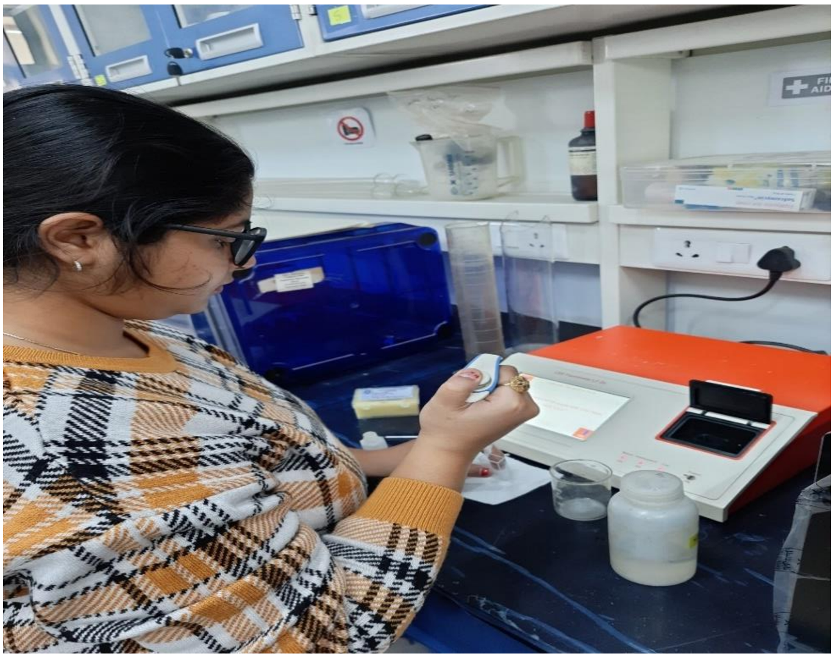


Figure 6.1: Measurement of uranium concentration in water samples using LED Fluorimeter (Environment Science & Technology lab, Central University of Punjab, Bathinda)

After calibration, the cuvette was rinsed with distilled water before filling the new sample of water. Cuvette was filled with 6 ml of water sample with 10% of fluren added in it with the help of pippete. Then cuvette was inserted in the cuvette chamber in the LED fluorimeter and then the value of uranium concentration in μgl^{-1} is obtained on the screen (Figure 6.1).

6.2.2 Biokinetic Modelling

A mathematical simulation provided by Li et al. (2009)'s "Hair compartment model" describes the passage, absorption, translocation, retention in different organs and tissues, and excretion routes of uranium in an adult human following chronic intake through ingestion. One directly from plasma and the other from soft tissue with intermediate turnover are assumed to be the two input channels for the hair compartment, with transfer rates as described in the model. Using the "Uranium Biokinetics Calculator Version B" available online at http://www.wise-uranium.org/cubkb.html, the residual uranium retention and excretion were calculated. The calculator is based onportions of the ACTLITE code by Eckerman (1999). The hair model is adopted from Li 2009. The Hair model is only applicable when "Ingestion" serves as the adult's intake route. The following parameters are beforehand set in the calculator:

Water consumption rate	= 1.4 $Lday^{-1}$ (EPA, 1997)
Body weight	= 68.831 kg
Kidney mass	= 310 g
Urine volume	= 1.38 $Lday^{-1}$
Faeces mass	= 135 $gday^{-1}$

6.2.3 Physiochemical Parameters

The physico-chemical water quality parameters like pH, electrical conductivity (EC) and total dissolved solids (TDS) in drinking water samples have been measured. For this, pH meter and EC/TDS meter were dipped in collected water and readings were noted on the spot.

6.3 FORMULAE USED

6.3.1 To Calculate Radiological Risk Assessment

The measured values of uranium concentration have been used to calculate the radiological risk assessment for the local population using following formulae as given by USEPA, 2000:

- ***Excess cancer risk (ECR)***=Activity of uranium conc. (Bql^{-1}) × RF × IGW × ED (1)

Unit conversion factor 1 μgl^{-1} = 0.0252 Bql^{-1}

RF is the risk factor (per Bql^{-1}),

IGW is ingestion rate of water = 2 $lday^{-1}$ (WHO, 2011),

ED is exposure duration = 70 years (70 ×365 = 25550 days) (WHO, 2011).

- ***Excess Cancer Mortality Risk:***

Activity of uranium conc. (Bql^{-1}) × Mortality cancer risk coefficient (2)

- ***Excess Cancer Morbidity Risk:***

Activity of uranium conc. (Bql^{-1}) × Morbidity cancer risk coefficient (3)

According to the USEPA (1999), the mortality and morbidity cancer risk coefficients of 1.13 × 10^{-9} Bql^{-1} and 1.73 × 10^{-9} Bql^{-1}, respectively.

6.3.2 To Calculate Chemical Risk Assessment

Chemical risk has been accessed using the measured uranium concentration. Following formulae has been given by USEPA (2000):

- ***Lifetime average daily dose (LADD) ($\mu gkg^{-1}d^{-1}$):***

$$LADD((\mu g)kg^{-1}d^{-1}) = \frac{(CU \times IR \times EF \times ED)}{(AT \times BW)} \quad (4)$$

Where, CU is the concentration of uranium in groundwater (μgl^{-1}),

IGW is ingestion rate of water (2 $lday^{-1}$) (WHO, 2011),

EF is the exposure frequency (365 $daysy^{-1}$) (USEPA, 2011),

ED is the lifetime exposure duration (70 y) (USEPA, 2011),

BW is the body weight (70 kg) (ICRP, 1975; USEPA, 2011) and

AT is the average exposure time for non-carcinogens (70 × 365 d) (USEPA, 2002).

❖ ***Hazard quotient (HQ) (USEPA, 1989):***

$$HQ = \frac{LADD}{R_f D} \tag{5}$$

Where, R_f D is reference dose (i.e.1 μgkg^{-1}d^{-1}) (WHO, 2011).

6.3.3 To Calculate Annual Effective Ingestion Dose

The annual effective ingestion dose for various age groups has been determined as follows (USEPA, 2000).

$$\text{Ingestion Dose (Svy}^{-1}) = \text{Activity of uranium conc. (Bql}^{-1}) \times IGW \times DCF \times 365 \tag{6}$$

Where, IGW is the ingestion rate of water for various age groups recommended by WHO (2011),

DCF is the dose conversion factor for various age groups (SvBq^{-1}) given by the IAEA (2011).

6.4 RESULTS AND DISCUSSION

6.4.1 Uranium Concentration in Water

Table 6.1 shows the measured uranium concentration in water samples and associated cancer morbidity, mortality risk, hazard quotient in both the districts of the studied area. In **Barnala district,** the uranium concentration in water samples varies from a minimum value of 28.5 µgl^{-1} (Barnala) to maximum value of 234.7 µgl^{-1} (Bhadalwad) with an average value of 111.43 µgl^{-1}. The measured average value is higher than the 30 µgl^{-1} as recommended by WHO (2011), 100 BqL^{-1} by WHO (2004) and 60 µgl^{-1} by AERB (2004). The calculated cancer mortality risk and cancer morbidity risks varies from 4.15 × 10^{-5} to 34.15 × 10^{-5} with an average value of 16.21 × 10^{-5} and 6.35× 10^{-5} to 52.29 × 10^{-5} with an average value of 24.82 × 10^{-5}, respectively. The measured values are lower than the recommended limits of 1.67 × 10^{-4} (AERB, 2004). The life time daily average dose (LADD) of uranium due to ingestion of water ranged between 0.81 to 6.70 µgkg^{-1}day^{-1} with an average value of 3.18 µgkg^{-1}day^{-1} and hazard quotient according has same numerical values as that of LADD because the value of reference dose is unity (WHO, 2011).

In **Moga district,** the measured uranium concentration varies from a minimum value of 33.4 μgl^{-1} (Dharamkot) to maximum value of 135.1 μgl^{-1} (Badhni) with an average value of 73 μgl^{-1}. The measured average value is higher than the 30 μgl^{-1} as recommended by WHO (2011), 100 BqL^{-1} by WHO (2004) and 60 μgl^{-1} by AERB (2004). The calculated cancer mortality risk and cancer morbidity risks varies from 4.86×10^{-5} to 19.66×10^{-5} with an average value of 10.62×10^{-5} and 7.44×10^{-5} to 30.10×10^{-5} with an average value of 16.26×10^{-5}, respectively. The measured average values are lower than the recommended limits of 1.67×10^{-4} (AERB, 2004). The life time daily average dose (LADD) of uranium due to ingestion of water ranged between 0.95 to 3.86 $\mu gkg^{-1}day^{-1}$ with an average value of 2.08 $\mu gkg^{-1}day^{-1}$ and hazard quotient according has same numerical values as that of LADD because the value of reference dose is unity (WHO, 2011).

Table 6.2 shows the calculated annual effective dose due to ingestion of uranium in drinking water for various life stage groups having different ages like infants (0-12 months), children (1-8 years), males (9-18 years, adults), females (9-18 years, adults), pregnancy (14-50 years) and lactation (14-50 years) in both the Barnala and Moga districts. In **Barnala district,** the calculated annual effective dose due to ingestion of uranium in drinking water for all the age groups lies in the range of 31.93 to 2112.28 μSvy^{-1} with an average value of 184.89 $\mu Svy^{-1.}$ The measured average value is higher than 100 μSvy^{-1} as recommended by WHO (2011) and the EUCD (2013).

In **Moga district,** the calculated annual effective dose due to ingestion of uranium in drinking water for various age groups lies in the range of 35.92 to 337.55 μSvy^{-1} with an average value of 120.84 μSvy^{-1}. The measured average value is higher than 100 μSvy^{-1} as recommended by WHO (2011) and the EUCD (2013).

Even though infants consume less water than other rest age groups, the annual effective dose is significantly higher than other age groups which may be due to differences in infants metabolism and smaller organ weights, resulting in higher doses for many radionuclides (Patra et al., 2013; Duggal et al., 2020).

In the studied region, the average uranium concentration in 0.5% water samples have lower value than the safe limit of 30 μgl^{-1} as recommended by WHO (2011), 30 μgl^{-1} (USEPA, 2011) and 22% samples have lower value than 60 μgl^{-1} by AERB

(2004). The calculated annual effective dose due to ingestion of uranium in water for various age groups is higher than 100 μSvy^{-1} as recommended by WHO (2011) and 1 mSvy^{-1} as recommended by ICRP (1990). The calculated hazard quotient in 98% of samples is higher than one hence these areas have increased probability of kidney and lung diseases (ATSDR, 2013; Duggal et al., 2013).

6.4.1.1 Frequency Distribution. For **Barnala district**, Figure 6.3 shows a frequency distribution graph for uranium concentration in water samples. It has been observed that concentration in 1% of the samples lie between 0-30 μgl^{-1}, in 14% samples it lies between 30-60 μgl^{-1} and in 27% samples it lies between 60-90 μgl^{-1}and rest of 58% samples lies between 90-240 μgl^{-1}.

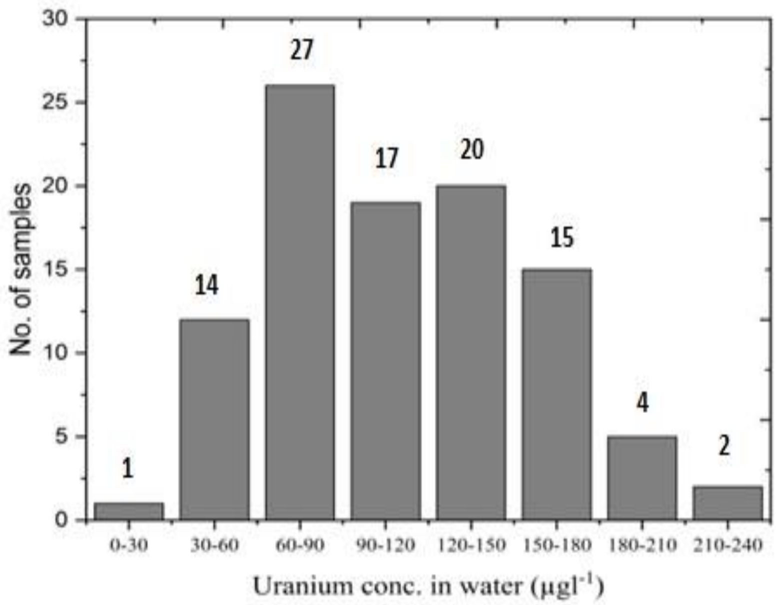


Figure 6.2: Frequency distribution of uranium concentration in Barnala district

For **Moga district,** Figure 6.4 shows a frequency distribution graph for uranium concentration in water. It has been observed that concentration in 34% of the samples lie between 0-60 μgl^{-1}, in 45% samples it lies between 60-90 μgl^{-1} and rest of 21% samples it lies between 90-150 μgl^{-1}.

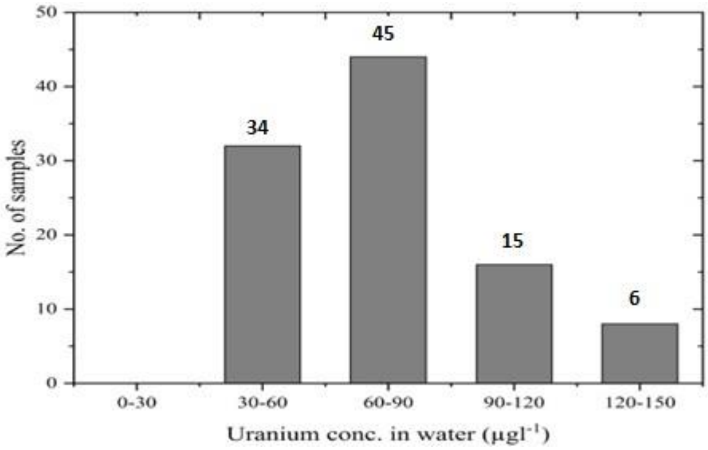


Figure 6.3: Frequency distribution of uranium concentration in Moga district

6.4.1.2 Correlation between Uranium Concentration in Groundwater with Depths (in Meters).

In the studied are, from the measured values, a weak correlation (R^2=0.006) has been found between uranium concentration in underground water samples with the depth (24-183 meter) as shown Figure 6.2. In an oxidizing environment the groundwater in fracture contains an appreciable amount of dissolved oxygen, this oxidizes uranium to hexavalent species which is mobile and easily leaches into water and get transported. Under reducing conditions, uranium is released into tetravalent state leading to low concentration in water as a result of stabilization of the sparingly soluble mineral, uraninite. Hence deeper groundwater would have low concentration of uranium because of more reducing conditions and less uranium solubility.

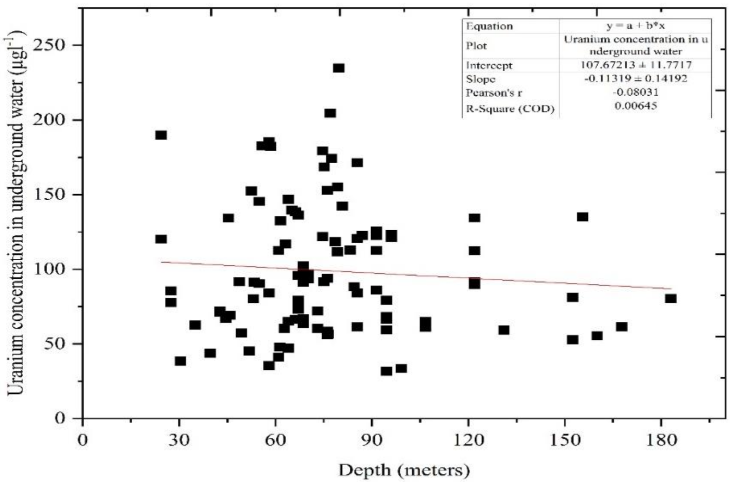


Figure 6.4: Correlation of uranium concentration in underground water with depth (in meters) in studied area

For **Barnala district**, Figure 6.5 shows the average uranium concentration in underground water samples collected from varying depth shallow (having depth <50 m), median (having depth 50m < depth <75m) and deep (having depth >75m). it has been found that the average uranium concentration in median depth samples have higher concentration than shallow and deep depth samples. The high uranium concentration at this depth may be due to leaching through soil by heavy use of fertilisers in the agriculture lands and due to squanders discharged from factories or thermal power plants. Fertilisers may also contain very high level of uranium as phosphate fertilisers are prepared from phosphate rock which are enriched with uranium. Thus, urbanisation and wide spread use pesticides/fertilisers are certainly responsible for the increase in uranium concentration.

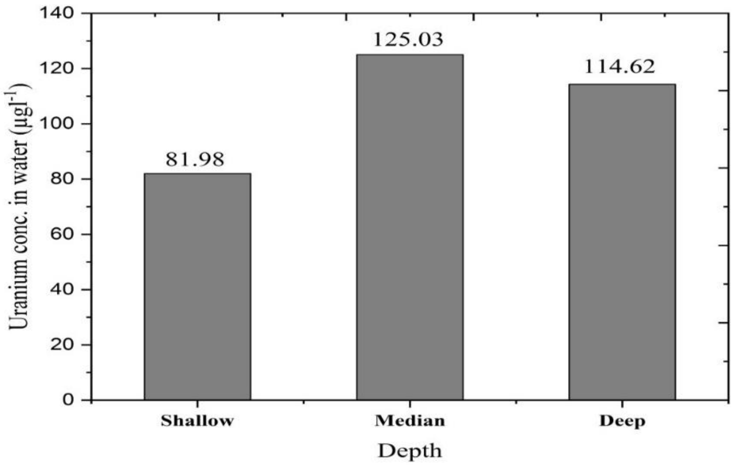


Figure 6.5: Comparison of uranium concentration in underground water taken from different depths in Barnala district

For **Moga district**, Figure 6.6 shows the average uranium concentration in underground water samples collected from varying depth shallow (having depth <50 m), median (having depth 50m < depth <75m) and deep (having depth >75m). it has been found that the average uranium concentration in deep depth samples have higher concentration than shallow and median depth samples.

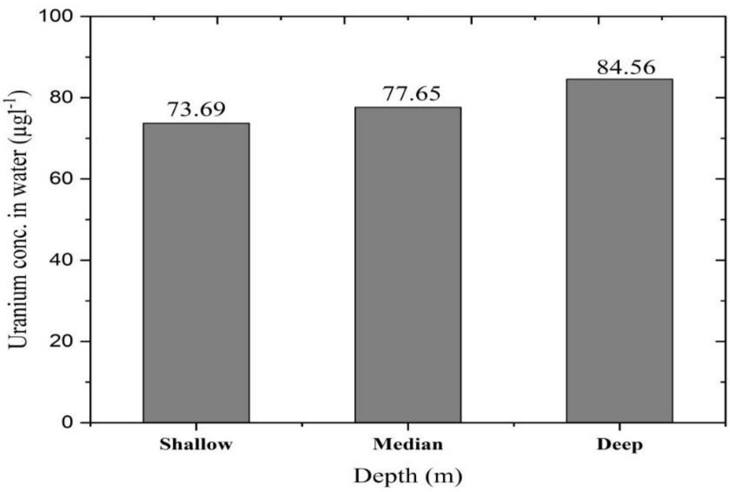


Figure 6.6: Comparison between uranium concentration in underground water taken from different depths in Moga district

The results observed for uranium distribution in present study are compared with those already reported by other researchers in literature for other areas (Table 6.3). The average value in the studied area is more than the 73.5 μgl^{-1} in South Western Punjab (Bathinda, Mansa, Ferozpur, Faridkot districts) (Bajwa et al. 2016) and lower than the 17.66 μgl^{-1} in Jalandhar district (Kumar M et al., 2017), 2.63 μgl^{-1} in Sri Nagar City (Nazir et al., 2020), 0.4 μgl^{-1} in Arunachal Pradesh (Salkia et al., 2021), 2.08 μgl^{-1} in Bihar (Richards et al., 2021), 22.09 μgl^{-1} in Haryana (Sar et al., 2017), 2.75 μgl^{-1} in Maharastra (Kale et al., 2018), 5.4 μgl^{-1} in Tamil Nadu (Thivya et al., 2014) and 3.03 μgl^{-1} in Telangana (Ganesh et al., 2020).

The LADD of uranium observed in the present study is comparatively higher than those reported for Korean groundwater (0.003 µg kg^{-1} d^{-1}) by Ye-shin et al. (2004), Jaduguda region in Jharkhand State, India (0.001-0.32 µg kg^{-1} d^{-1}) by Patra et al. (2013), Bagjata (0.14-0.70 µg kg^{-1} d^{-1}), Banduhurang (0.05-1.8 µg kg^{-1} d^{-1}) mining areas, Jharkhand, India by Giri et al. (2012), however, lower than those reported for western Haryana, India (0.02-18.8 µg kg^{-1} d^{-1}) by Singh et al. (2014), Odeda Area, Ogun State, Nigeria (0.56-7.47 µg kg^{-1} d^{-1}) by Amakom et al. (2010), Bathinda district of Punjab State, India (0.04-43.11 µg kg^{-1} d^{-1}) by Singh et al. (2013), Mansa district of Punjab State, India (0.10-43.66 µg kg^{-1} d^{-1}) by Kumar et al. (2011) and Punjab State, India (0.15-48 µg kg^{-1} d^{-1}) by Kumar et al. (2011).

The annual effective dose to infants is compared with other similar studies in different areas, it has been observed that the dose for infants in present study

243 μSvy^{-1} for (0-6 months), 277 μSvy^{-1} for (7-12 months) of Barnala district and 158 μSvy^{-1} for (0-6 months), 181 μSvy^{-1} for (7-12 months) for Moga district) have higher values than 126 μSvy^{-1} for (0-6 months), 144 μSvy^{-1} for (7-12 months) in Sri Ganganagar, 110 μSvy^{-1} for (0-6 months), 126 μSvy^{-1} for (7-12 months) in Hanumangarh , 88 μSvy^{-1} for (0-6 months), 101 μSvy^{-1} for (7-12 months) in Churu, 46 μSvy^{-1} for (0-6 months), 52 μSvy^{-1} for (7-12 months) in Sikar districts of Northern Rajasthan as reported by Duggal et al., 2020; 0.8 μSvy^{-1} (for 0-6 months), 0.9 μSvy^{-1} (for 7-12 months) in Sri Nagar, Northwest Himalaya as reported by Nazir et al., 2020; 25.14 μSvy^{-1} (for 1 year) in Jalandhar district of Punjab as reported by Manish et al., 2017; 18.80 μSvy^{-1} (for 0-6 months), 21.48 μSvy^{-1} (for 7-12 months) for pre-monsoon and 19.29 μSvy^{-1} (for 0-6 months), 22.02 μSvy^{-1} (for 7-12 months) for post-monsoon in Amritsar; 9.35 μSvy^{-1} (for 0-6 months), 10.68 μSvy^{-1} (for 7-12 months) for pre-monsoon and 10.86 μSvy^{-1} (for 0-6 months), 12.41 μSvy^{-1} (for 7-12 months) for post-monsoon in Gurdaspur; 6.69 μSvy^{-1} (for 0-6 months), 7.64 μSvy^{-1} (for 7-12 months) for pre-monsoon and 7.49 μSvy^{-1} (for 0-6 months), 8.56 μSvy^{-1} (for 7-12 months) for post-monsoon in Pathankot districts of Punjab as reported by Sharma et al., 2018.

6.4.2 Results of Biokinetic Modelling

From the measured concentration of uranium in water samples, the retention, excretion and dose received to various organs has been calculated by using biokinetic model. The biokinetic model provides the pathway of different radionuclides inside the body and allows us to calculate the retention in different organs and tissues. The detailed data of retention, excretion of uranium in different body organs have been calculated using hair compartment model, considering the chronic intake of uranium over a period of 60 years via drinking water pathway.

6.4.2.1 Radiological Contamination/ Retention of uranium in various compartments of human body. Table 6.4 represents the contamination/retention of uranium in GI track, skeleton, blood, kidney, liver, urinary bladder as explained below:

a) In GI Tract. Ingestion is the main pathway of the exposure of the natural radionuclides in water to the general population and the GI tract is the path through which the ingested uranium enters the bloodstream. Small intestine is the main compartment in which the absorption takes place. The average concentration of uranium in the GI tract comes out to be 271.75 μg and 179.26 μg for the habitants of Barnala and Moga district respectively. High concentration of uranium may lead to high retention of uranium in different body organs.

b) In Blood. After ingestion, uranium rapidly appears in the blood stream and the studies available in the literature shows that the large proportion of the uranium is associated with the red blood cells (Fisenne and Perry, 1985). There is equilibrium between the uranyl– albumin complex and ionic uranyl hydrogen carbonate complex in the blood plasma (Moss et al., 1983). The average concentration of uranium that appears in blood plasma is 2.19 and 0.057 μg for the habitants of Barnala and Moga district respectively. Uranium attaches to RBCs from the plasma and with a half time of around 1 day, it returns back to plasma (Leggett, 1994).

c) In Skeleton. In bones, the movement of the uranyl ion is similar to that of the calcium ions. The uranyl ions exchange with the calcium ions at the bone surfaces but these ions do not take part in the crystal formation. The average value of the uranium deposited on the Cortical and Trabecular bone surface is 0.82, 1.02 μg and 0.53, 0.67 μg for the habitants of Barnala and Moga districts respectively. On the other hand, the uranium concentration in the non-exchangeable cortical and Trabecular bone volume is 143.78, 38.95 μg and 95.26, 25.61 μg for the habitants of Barnala and Moga districts respectively. In the ICRP's biokinetic model for uranium, it is assumed that the removal of uranium from the non-exchangeable bone volume is very low and it is also clear from the data that the amount of uranium in the non-exchangeable cortical and Trabecular bone volume is much higher than that in the bone surfaces.

d) In Liver. In the biokinetic model, the compartment of liver is divided into two parts liver 1 and liver 2. The retention half life time of liver 1 and liver 2 is 7 days and 10 years, respectively. Liver 1 receives uranium from plasma and then passes it onto liver 2. The average amount of uranium retained in the Liver compartment is found to be 64.72 and 42.42 μg for the residents of Barnala and Moga district respectively.

e) In Kidney. According to the retention time, this compartment is also divided into two parts kidney 1 and kidney 2. The amount of the uranium filtered by the glomerulus deposits in the kidney 1 and the filtered content goes to the urinary bladder and urine. Uranium enters the kidneys from kidney 2 and it returns the uranium back to plasma rather than to urine. The removal half-life of the other kidney tissues is around 5 years, which results in higher amounts of uranium in kidneys. The average retention of uranium in kidneys is found to be 1.92, 1.26 μg and kidney concentration of 0.006, 0.004 μgg-1 for the residents of Barnala and Moga districts respectively of kidney tissues.

f) In Urinary Bladder. The uranium enters the urinary bladder from the kidney 1 after filtration and directly from the plasma also. The average value of retention of uranium in the urinary bladder is 0.031 and 1.46 μg for the residents of Barnala and Moga district respectively.

6.4.2.2 Removal/Excretion of Uranium from Human Body through Excretory Paths: Hair, Faeces and Urine. Table 6.4 also represents the removal/excretion of uranium through excretory paths. The excretion rate by hair channel shows a range of value from 0.15 to 1.26 $\mu g d^{-1}$ with an average value of 0.6 $\mu g d^{-1}$ and 0.18 to 0.73 $\mu g d^{-1}$ with an average value of 0.39 $\mu g\ d^{-1}$, the excretion rates by other traditional routes like faeces the amount of uranium excreted from the body per day lies from the range of 39.66 to 326.1 $\mu g d^{-1}$ with an average value of 155 $\mu g d^{-1}$ and from 46.48 to 188.10 $\mu g d^{-1}$ with an average value of 101 $\mu g d^{-1}$, and from urine the amount of uranium excreted from the body per day lies from the range of 0.083 to 1.62 $\mu g d^{-1}$ with an average value of 0.336 and from 0.098 to 1.73 $\mu g d^{-1}$ with an average value of 0.229 $\mu g d^{-1}$ for the residents of Barnala and Moga district, respectively. From the above it has been observed that the excretion rate of uranium is much greater through large intestine pathway (faeces) than through urine or hair.

6.4.2.3 Doses to Various Organs of Human Body. Like other heavy metals, uranium has inimical effects on the human body, especially on some internal human body organs like kidneys. These elements with a long biological half-life are noxious at very low doses. Because of low specific radioactivity of natural uranium, its radiological effects are low. The radiological effects of uranium may dominate over its chemical toxicity in the case of exposure to enriched uranium or exposure through inhalation of insoluble uranium compounds if they remain in the body for a longer period. Table 6.5 shows the doses calculated according to dose conversion factors provided by the ICRP (1995) from single uptake and it is not based on distribution of uranium in organs.

a) Bone Surfaces. The radiosensitive cells in the bone are endosteal and epithelial cells on the bone surfaces. These cells are present on all bone surfaces and are between distances of 10 mm from the bone surface. The primary effects of radiation on these cells are cancer but the bones are less sensitive to the radiological effects than other organs. The dose to the bone surface is the highest compared to any other organ or tissue. This dose varies from 18.83 to 155 μSv with an average value of 73.62 μSv and from 22.07 to 89.27 μSv with an average value of 48.23 μSv for the residents of Barnala and Moga districts, respectively.

b) Red Bone Marrow. The red bone marrow consists of haemopoietic and fat cells. In the case of radiation protection, attention must be paid to the red bone marrow because the irradiation of it is clearly linked with the induction of leukemia. We have also observed that the red bone marrow receives a higher dose than many other organs. The value of the average dose received by the red bone marrow comes out to be 9.39 and 6.15 μSv for the residents of Barnala and Moga districts respectively.

c) Thyroid. The radiological effects may dominate in the case of exposure to the thyroid gland due to its sensitivity of induction of cancer from irradiation. The average dose received by the thyroid due to ingested uranium is 653.7 and 428.2 nSv for the residents of Barnala and Moga district respectively.

d) Breast. These are the one of the most radiosensitive tissues present in the human body. But in the case of exposure to the ingested uranium, its sensitivity is equivalent to that of the thyroid gland. The dose received by the breast of an average public adult has an average value of 653.7 and 428.2 nSv for the residents of Barnala and Moga district respectively.

e) Skin. Reddening of the skin is the major effect that occurs when skin is exposed to radiation. The average dose received by the skin of the public adult from exposure of uranium in drinking water is 653.7 and 428.2 nSv for the residents of Barnala and Moga district, respectively.

f) **Oesophagus.** Oesophagus is one of the upper parts of the alimentary tract. The average dose acquired by the esophagus of the public adult is 653.7 and 428.2 nSv for the residents of Barnala and Moga district, respectively.

g) **Stomach and Colon.** Stomach and colon are very important organs of the GI tract of the human body. The stomach wall consists of an outer mucosa and inner submucosa, muscularis externa and serosa. The observed value of an average dose received by the stomach wall and colon is 665.6, 436.1 nSv and 962.8, 630.8 nSv, respectively for the residents of Barnala and Moga district respectively.

h) **Liver.** It is the largest organ of the human body. The dose received by the liver is also quite higher than that received by some other internal human body organs. The average dose received by the liver is 12.95 and 8.489 µSv for the residents of Barnala and Moga district, respectively.

i) **Bladder Wall.** The human bladder wall consists of detrusor muscle fibers. The bladder collects the urine excreted by the kidneys. The average dose received by the bladder wall of the public adult of the studied area is 657.9 and 431 nSv for the residents of Barnala and Moga district respectively.

For **Barnala district**, the annual effective ingestion dose to whole body varies from 904.8 nSv to 7.45 µSv with an average of 3.53 µSv which is very less than the recommended limit of 100µSv (WHO, 2004). Figure 6.7 depicts the distribution of effective pecentage dose to organs/tissues of paramount importance. Bone surfaces bear the maximum share of dose (63.5%) due to uranium and its daughters, liver (11.17%), stomach wall (8.1%).

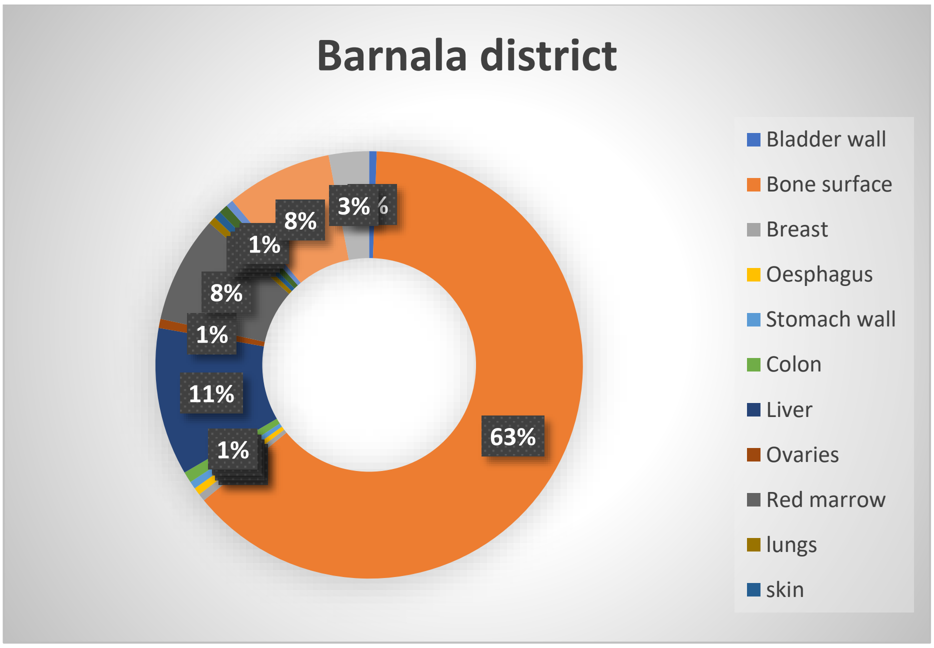


Figure 6.7: Dose percentage to various organs using biokinetic model in Barnala district

For **Moga district**, the annual effective ingestion dose to whole body varies from 1.06 µSv to 4.28 µSv with an average of 2.31 µSv which is very less than the recommended limit of 100µSv (WHO, 2004). Figure 6.8 depicts the distribution of effective percentage dose to organs/tissues of paramount importance. Bone surfaces bear the maximum share of dose (62.69%) due to uranium and its daughters, liver (12.32%), stomach wall (7.99%).

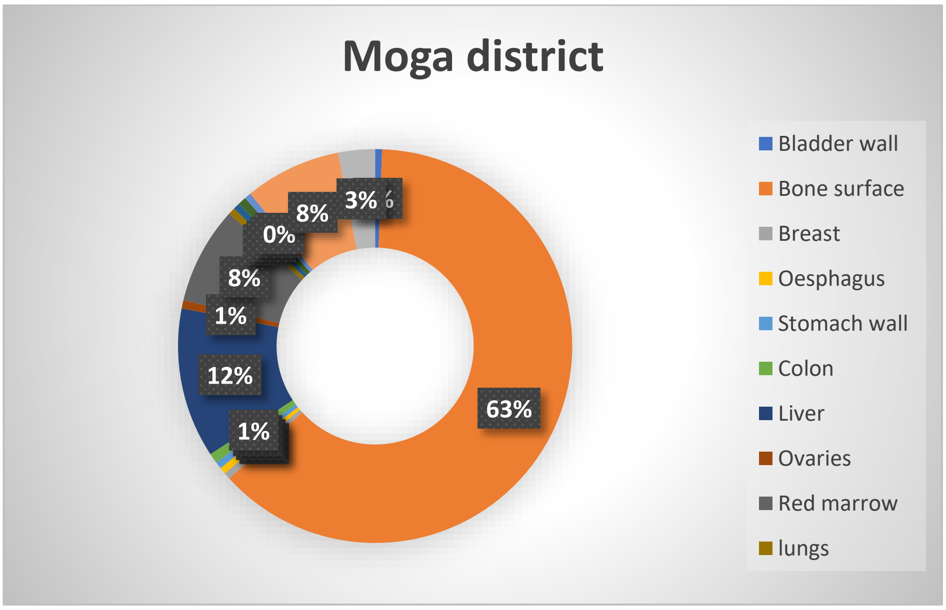


Figure 6.8: Dose percentage to various organs using biokinetic model in Moga district

Hence, Biokinetic models facilitate the absorption, retention and elimination of uranium by the human body. Organ-specific uranium retention and doses enables to identify the target organs/tissues. In Hair Compartment model as the reference as Uranium burden from protracted ingestion of ground water for 60 years is greatest in cortical bone volume followed by soft tissues. Bone surfaces and kidneys are the major recipients of dose due to uranium ingestion. The excretion rates remain fairly constant over the years via urine, hair and feces.

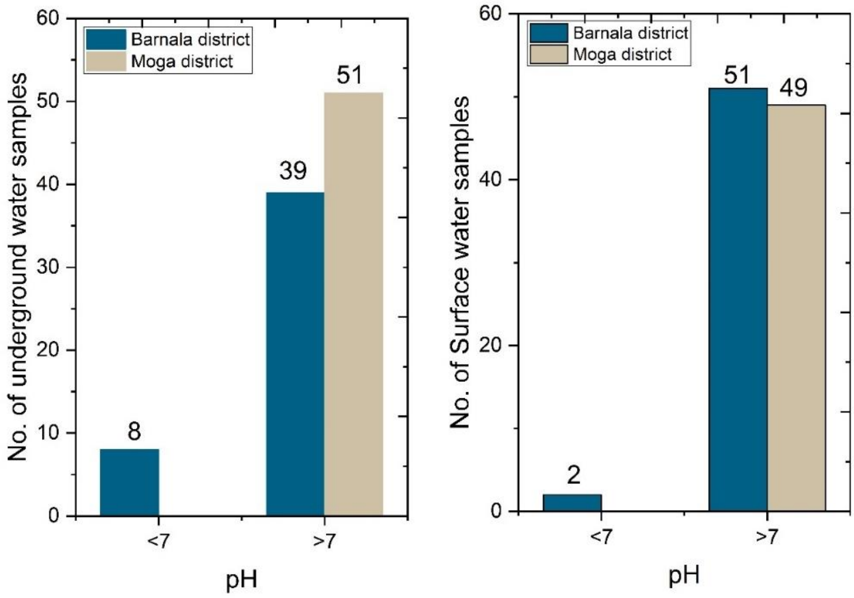
6.4.3 Physicochemical Factors

The data of various physiochemical properties of groundwater and surface water samples in Barnala and Moga districts of Punjab is reported in Table 6.6.

6.4.3.1 pH Value. pH of an aqueous solution is calculated as the negative logarithm of hydrogen ion concentration. It determines the reactive characteristics of water. It is an operational water-quality parameter and is not much of health concern. In all the analysed 200 water samples pH value in a narrow range from 6.6 to 8.1 with an average value of 7.5 and from 7.3 to 8.2 with an average value of 7.8 for Barnala and Moga districts, respectively. The pH values indicated that most of the samples of the studied region were alkaline. The pH value of all the samples lies in permissible range of 6.5-8.5 by Bureau of Indian Standards (BIS, 2012) and WHO, 2011.

For **Barnala district**, the measured pH value of underground water samples lies in the range of 6.6 to 8 with an average value of 7.4 and for surface water samples it lies from 6.7 to 8.1 with an average value of 7.5. It has been observed that the pH value is almost same in underground and surface water samples. Figure 6.9a shows 17% underground water samples have pH less than 7 and 83% samples have pH value greater than 7. Figure 6.9b shows the 4% of the surface water samples have pH value less than 7 and 96% samples have pH value greater than 7.

For **Moga district**, the measured pH value of underground water samples lies in the range of 7.3 to 8.2 with an average value of 7.8 and for surface water samples it lies from 7.5 to 8.2 with an average value of 7.8. It has been observed that the pH value is almost same in underground and surface water samples. Figure 6.9a shows that the 100 % samples have pH value greater than 7. Figure 6.9b shows that 100% surface water samples have pH value greater than 7. Therefore water in most of the studied area is alkaline.



a) b)

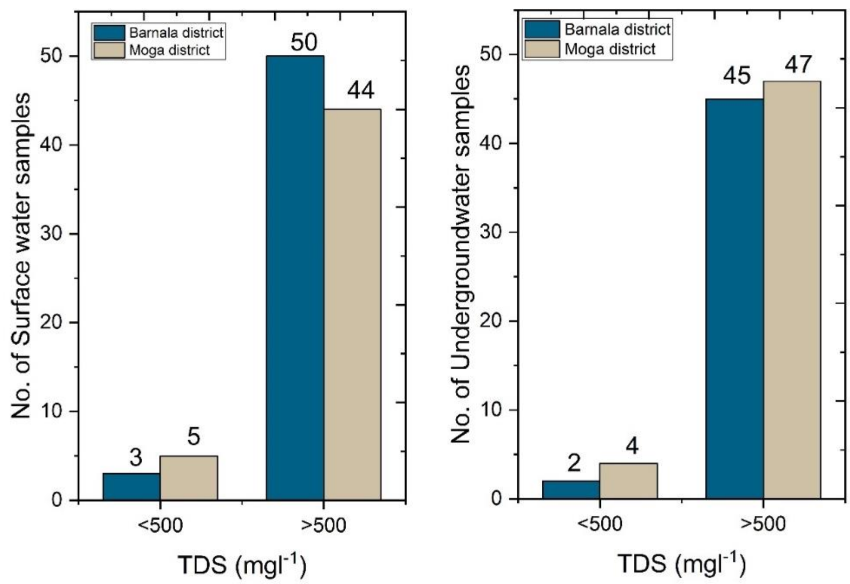
Figure 6.9: Frequency distribution of pH value a) underground water b) surface water

6.4.3.2 Total Dissolved Solids (TDS). TDS comprises all inorganic and organic content in a liquid in molecular, ionized or micro-granular suspended form. Although it is not a primary pollutant, it hints at the aesthetic characteristics of drinking water. It may affect acceptability of drinking water to a significant extent. The overall TDS value fluctuated between 316 to 1963 mgl^{-1} with mean value of 1089 mgl^{-1} and 261 to 1443 mgl^{-1} with an average value of 787 mgl^{-1} for Barnala and Moga districts, respectively. Out of the total 200 samples, 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. Higher TDS value shows that the water may not be fit for drinking.

For **Barnala district**, the measured TDS value of underground water samples lies in the range of 415 to 1963 mgl^{-1} with an average value of 1146.98 mgl^{-1} and for surface water samples it lies from 316 to 1942 mgl^{-1} with an average value of 1037.4 mgl^{-1}. It has been observed that the TDS value in underground water samples have higher values than surface water samples. Figure 6.10a shows the Total Dissolved Solids (TDS) of 6% surface water samples lies in the range of 0-500 mgl^{-1} and 94% samples have higher TDS values than the recommended value of 500 mgl^{-1}. Figure

6.10b shows the 4% of the underground water samples lies in the range of 0-500 mgl^{-1} and 96% samples have higher TDS values than the recommended value of 500 mgl^{-1}.

For **Moga district**, the measured TDS value of underground water samples lies in the range of 454 to 1443 mgl^{-1} with an average value of 864.35 mgl^{-1} and for surface water samples it lies from 261 to 1338 $mgl^{-1}$with an average value of 705.67 mgl^{-1}. It has been observed that the TDS value in underground water samples have higher values than surface water samples. Figure 6.10a shows the TDS of 10% surface water samples lies in the range of 0-500 mgl^{-1} and 90% samples have higher TDS values than the recommended value of 500 mgl^{-1}. Figure 6.10b shows that 100% underground water samples have TDS value higher than the recommended value of 500 mgl^{-1}.



a) b)

Figure 6.10: Frequency distribution of total dissolved solids (TDS)

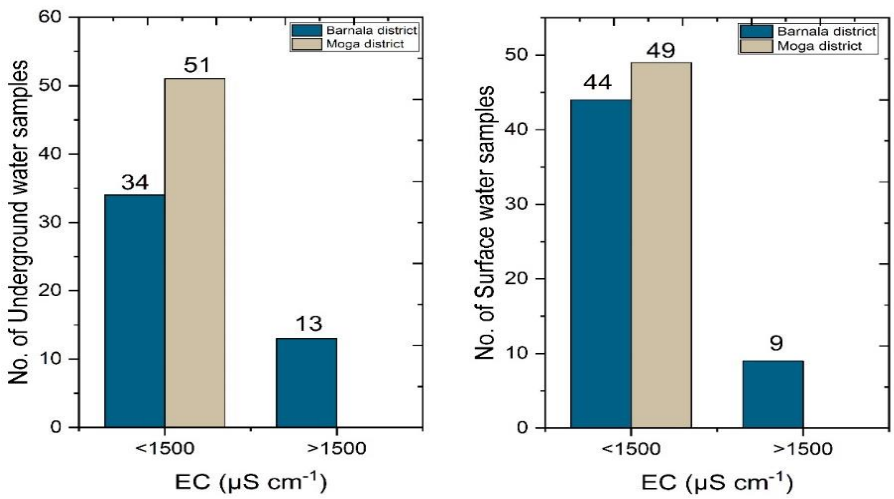
a) surface water b) underground water samples

6.4.3.3 Electrical Conductivity (EC). Electrical conductivity quantifies the concentration of ionizable solutes present in aqueous sample (ISO, 1985). The investigated samples have low mineralization with electrical conductivity varying from 454 to 2068 μScm^{-1} with an arithmetic mean of 1154.3 μScm^{-1} at 35°C temperature and from 410 to 1433 μScm^{-1} with an arithmetic mean of 850.25 μScm^{-1} in the Barnala and Moga districts, respectively. The electrical conductivity of 41.5% samples has higher value than 1000 μScm^{-1} as per regulations on drinking water hygiene in India (Water

Act, 1956) and 22% of samples have higher electrical conductivity than1500 μScm^{-1} as recommended by World Health Organization (WHO, 2004).

For **Barnala district**, the measured electrical conductivity (EC) value of underground water samples lies in the range of 454 to 2068 μScm^{-1} with an average value of 1228.87 μScm^{-1} and for surface water samples it lies from 491 to 1974 μScm^{-1} with an average value of 1088.32 μS cm^{-1}. It has been observed that the electrical conductivity in underground water samples have higher values than surface water samples. Figure 6.11a shows the electrical conductivity (EC) of 72% underground water samples lies in the range of 0-1500 μScm^{-1} and 28% samples have higher electrical conductivity values than the recommended value of 1500 μScm^{-1}. Figure 6.11b shows the 83% of the surface water samples lies in the range of 0-1500 μScm^{-1} and 17% samples have higher electrical conductivity values than the recommended value of 1500 μScm^{-1}.

For **Moga district**, the measured EC value of underground water samples lies in the range of 436 to 1433 μScm^{-1} with an average value of 910.35 μScm^{-1} and for surface water samples it lies from 410 to 1216 μScm^{-1} with an average value of 787.69 μScm^{-1}. It has been observed that the electrical conductivity in underground water samples have higher values than surface water samples. Figure 6.11a shows the electrical conductivity (EC) of 100% underground water samples lies in the range of 0-1500 μScm^{-1}. Figure 6.11b shows that the electrical conductivity of 100% surface water samples lies in the range of 0-1500 μScm^{-1}.



a) b)

Figure 6.11: Frequency distribution of electrical conductivity (EC)
a) underground water b) surface water samples

Correlation between Uranium Concentration in Water with Physicochemical Parameters:

In general, the rock porosity and permeability control the behaviour of groundwater. For example, igneous rocks, such as granite, have high permeability, resulting from fractures in the rocks that permit faster flow relative to, for example, shale. The general properties of uranium, thorium, and polonium are metallic while that of radium is alkaline and radon is a gaseous element. Soluble uranium complexes, e.g. uranyl, are readily produced in oxidizing environments, whereas in reducing groundwater environments uranium, and especially the uranyl ion, is readily precipitated or adsorbed on organic compounds. Therefore, in the present investigation, a correlation between uranium concentration and physicochemical parameters like pH, EC and TDS has been established.

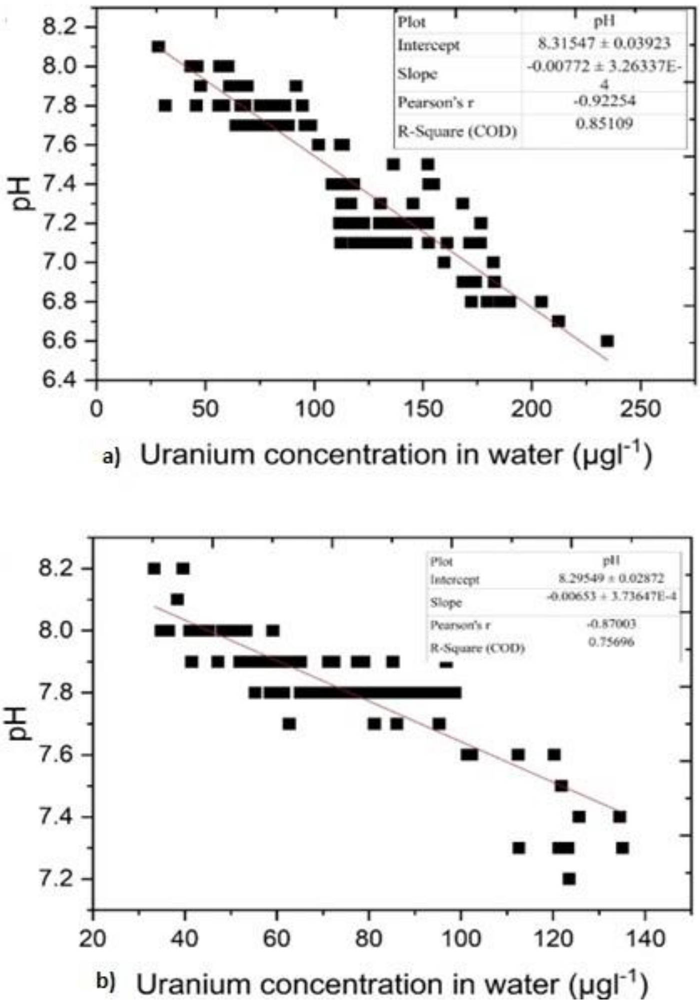


Figure 6.12: Correlation of uranium concentration with pH in water in a) Barnala district b) Moga district

The uranium mobility is controlled by pH and same has been observed in the correlation between uranium and pH of water samples that is r square value of 0.8 for Barnala district and r square value of 0.7 for Moga district, respectively (Figure 6.12). Figure 6.13 shows the positive correlation between uranium concentration and Total Dissolved Solids (TDS) in water with r square value of 0.8 for Barnala district and r square value of 0.9 for Moga district, respectively.

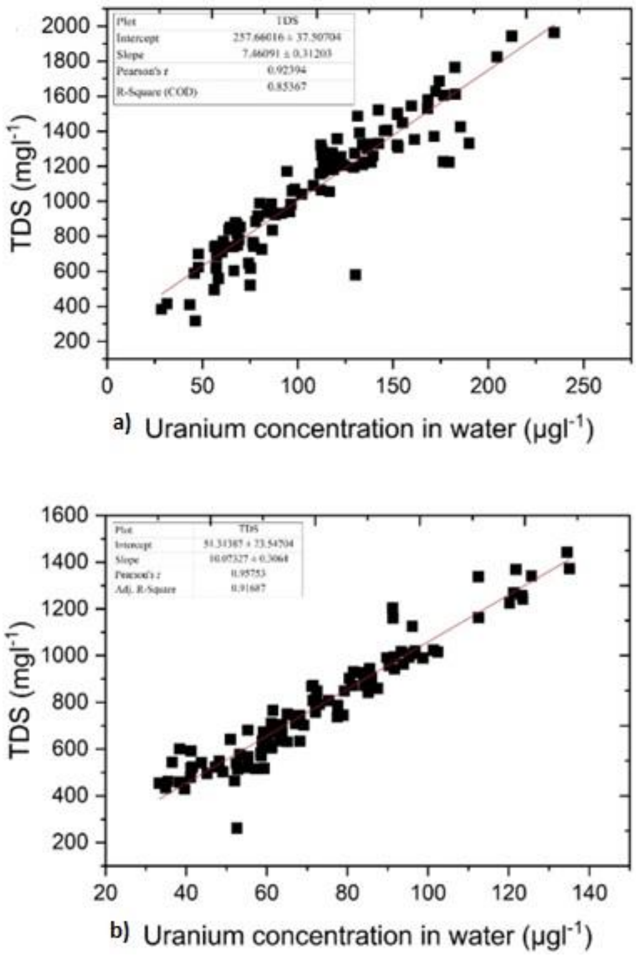


Figure 6.13: Correlation of uranium concentration with total dissolved solids (TDS) in water in a) Barnala district b) Moga district

Figure 6.14 shows the positive correlation between uranium concentration and electrical conductivity (EC) with r square value of 0.9 for both Barnala and Moga districts, respectively.

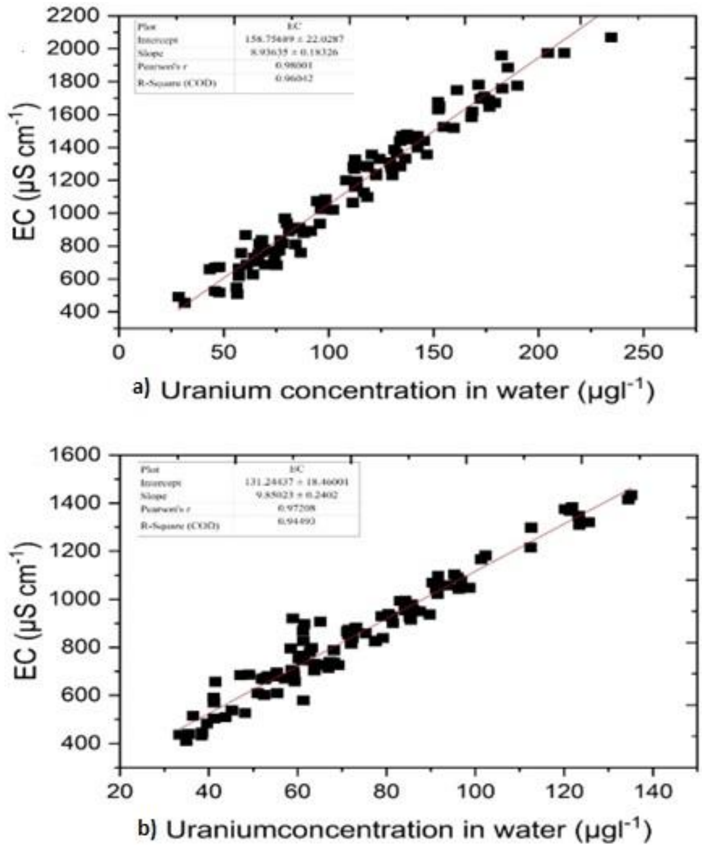


Figure 6.14: Correlation of uranium concentration with electrical conductivity (EC) in water in a) Barnala district b) Moga district

6.5 CONCLUSION

- Out of 200 samples, 99.5% of water samples have higher uranium concentration in water than the safe limit of 30 μgl^{-1} as recommended by WHO (2011), 30 μgl^{-1} by USEPA (2011) and 79% of samples have higher value than 60 μgl^{-1} recommended by AERB (2004).
- Higher uranium concentration may be due to geology, anthropogenic activities and use of phosphate fertilizers in huge quantity for agriculture purposes.
- The calculated hazard quotient in 98% of samples is higher than one hence these areas have increased probability of kidney and lung diseases.
- From the biokinetic modelling, it has been observed that highest dose received to bone surface out of the all organs in the studied area.
- pH value of all the samples lies in permissible range of 6.5-8.5 by Bureau of Indian Standards (BIS, 2012) and WHO, 2011 and the most of the water samples is alkaline.

- Out of 200 samples, 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 and hence may not be fit for drinking.
- The electrical conductivity of 41.5% samples has higher value than 1000 μScm^{-1} as per regulations on drinking water hygiene in India (Water Act, 1956) and 22% of samples have higher electrical conductivity than1500 μScm^{-1} as recommended by World Health Organization (WHO, 2004).
- The total dissolved solids and electrical conductivity have higher values in underground water samples than surface water.
- A positive correlation has been observed between uranium concentration with pH, TDS and EC.
- As concentration of uranium in water is much higher so it may be cause of serious health concern in the studied area and to be explored further.

Table: 6.1 Uranium concentration, cancer morbidity, mortality, lifetime daily average dose, hazard quotient in studied area

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
Barnala district								
1	Dhanola	UG	56.2	1.42	8.18	12.52	1.61	1.61
2		SW	130.4	3.29	18.97	29.05	3.73	3.73
3		UG	171.5	4.32	24.96	38.21	4.90	4.90
4		SW	74.2	1.87	10.80	16.53	2.12	2.12
5	Bhadur	UG	112.3	2.83	16.34	25.02	3.21	3.21
6		UG	95.8	2.41	13.94	21.34	2.74	2.74
7		SW	75.1	1.89	10.93	16.73	2.15	2.15
8		SW	77	1.94	11.20	17.15	2.20	2.20
9	Nainewal	SW	176.5	4.45	25.68	39.32	5.04	5.04
10		UG	81.2	2.05	11.82	18.09	2.32	2.32
11		UG	189.9	4.79	27.63	42.31	5.43	5.43
12		SW	96.4	2.43	14.03	21.48	2.75	2.75
13	Jangiana	SW	161.2	4.06	23.46	35.91	4.61	4.61

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu gkg^{-1}day^{-1}$)	HQ
14		UG	185.5	4.67	26.99	41.32	5.30	5.30
15		UG	112.6	2.84	16.38	25.08	3.22	3.22
16		SW	108.3	2.73	15.76	24.13	3.09	3.09
17	Channa	SW	102.1	2.57	14.86	22.75	2.92	2.92
18		UG	58.4	1.47	8.50	13.01	1.67	1.67
19		UG	136.4	3.44	19.85	30.39	3.90	3.90
20		SW	69.8	1.76	10.16	15.55	1.99	1.99
21	Tapa	SW	64	1.61	9.31	14.26	1.83	1.83
22		UG	152.7	3.85	22.22	34.02	4.36	4.36
23		SW	131.36	3.31	19.11	29.26	3.75	3.75
24		SW	120.6	3.04	17.55	26.87	3.45	3.45
25	Mehta	UG	85.9	2.16	12.50	19.14	2.45	2.45
26		SW	64.8	1.63	9.43	14.44	1.85	1.85
27		UG	31.5	0.79	4.58	7.02	0.90	0.90
28		SW	45.8	1.15	6.66	10.20	1.31	1.31

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
29	Diwana	UG	122.7	3.09	17.85	27.33	3.51	3.51
30		UG	146.9	3.70	21.38	32.73	4.20	4.20
31		SW	168.2	4.24	24.48	37.47	4.81	4.81
32		SW	113.4	2.86	16.50	25.26	3.24	3.24
33	Dhurkot	SW	75.2	1.90	10.94	16.75	2.15	2.15
34		SW	137.3	3.46	19.98	30.59	3.92	3.92
35		UG	145.5	3.67	21.17	32.41	4.16	4.16
36		UG	111.6	2.81	16.24	24.86	3.19	3.19
37	Draj	UG	122.7	3.09	17.85	27.33	3.51	3.51
38		SW	113.2	2.85	16.47	25.22	3.23	3.23
39		SW	68.1	1.72	9.91	15.17	1.95	1.95
40		UG	77.9	1.96	11.34	17.35	2.23	2.23
41	Handiya	SW	129.9	3.27	18.90	28.94	3.71	3.71
42		UG	142.3	3.59	20.71	31.70	4.07	4.07
43		SW	76.5	1.93	11.13	17.04	2.19	2.19

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
44		UG	84.2	2.12	12.25	18.76	2.41	2.41
45	Mehal kalan	SW	152.5	3.84	22.19	33.97	4.36	4.36
46		SW	68.3	1.72	9.94	15.22	1.95	1.95
47		UG	79.2	2.00	11.52	17.64	2.26	2.26
48		UG	179.4	4.52	26.10	39.97	5.13	5.13
49	Sanghere	UG	66.3	1.67	9.65	14.77	1.89	1.89
50		SW	172.4	4.34	25.09	38.41	4.93	4.93
51		SW	94.5	2.38	13.75	21.05	2.70	2.70
52		UG	112.7	2.84	16.40	25.11	3.22	3.22
53	Wajid ke	SW	86.2	2.17	12.54	19.20	2.46	2.46
54		SW	142.5	3.59	20.74	31.75	4.07	4.07
55		UG	88.2	2.22	12.83	19.65	2.52	2.52
56		UG	168.5	4.25	24.52	37.54	4.81	4.81
57	Chuhan ke	SW	159.7	4.02	23.24	35.58	4.56	4.56
58		UG	174.2	4.39	25.35	38.81	4.98	4.98

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
59		UG	118.4	2.98	17.23	26.38	3.38	3.38
60		SW	97.1	2.45	14.13	21.63	2.77	2.77
61	Bhadalwad	UG	234.7	5.91	34.15	52.29	6.71	6.71
62		SW	212.3	5.35	30.89	47.30	6.07	6.07
63		UG	116.8	2.94	17.00	26.02	3.34	3.34
64		SW	134.9	3.40	19.63	30.05	3.85	3.85
65	Sehjra	SW	118.7	2.99	17.27	26.44	3.39	3.39
66		UG	139.6	3.52	20.31	31.10	3.99	3.99
67		SW	98.4	2.48	14.32	21.92	2.81	2.81
68		UG	134.2	3.38	19.53	29.90	3.83	3.83
69	Barnala	SW	118.2	2.98	17.20	26.33	3.38	3.38
70		UG	182.4	4.60	26.54	40.63	5.21	5.21
71		SW	28.5	0.72	4.15	6.35	0.81	0.81
72		UG	47.9	1.21	6.97	10.67	1.37	1.37
73	Dangarh	UG	138.5	3.49	20.15	30.85	3.96	3.96

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
74		SW	129.4	3.26	18.83	28.83	3.70	3.70
75		SW	47.9	1.21	6.97	10.67	1.37	1.37
76		UG	57.3	1.44	8.34	12.77	1.64	1.64
77	Harigarh	SW	68.1	1.72	9.91	15.17	1.95	1.95
78		UG	69.2	1.74	10.07	15.42	1.98	1.98
79		SW	57.4	1.45	8.35	12.79	1.64	1.64
80		SW	67.2	1.69	9.78	14.97	1.92	1.92
81	Aspal Kalan	SW	60.4	1.52	8.79	13.46	1.73	1.73
82		SW	61.1	1.54	8.89	13.61	1.75	1.75
83		SW	43.4	1.09	6.32	9.67	1.24	1.24
84		UG	66.5	1.68	9.68	14.81	1.90	1.90
85	Bheni Jassa	UG	152.3	3.84	22.16	33.93	4.35	4.35
86		SW	134.1	3.38	19.51	29.87	3.83	3.83
87		SW	46.2	1.16	6.72	10.29	1.32	1.32
88		UG	80.2	2.02	11.67	17.87	2.29	2.29

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD (μg$kg^{-1}day^{-1}$)	HQ
89	Kattu	UG	182.8	4.61	26.60	40.72	5.22	5.22
90		SW	152.4	3.84	22.18	33.95	4.35	4.35
91		SW	112.1	2.82	16.31	24.97	3.20	3.20
92		UG	132.5	3.34	19.28	29.52	3.79	3.79
93	Attar Singhwala	UG	91.6	2.31	13.33	20.41	2.62	2.62
94		SW	86.7	2.18	12.62	19.31	2.48	2.48
95		SW	57.24	1.44	8.33	12.75	1.64	1.64
96		UG	56.57	1.43	8.23	12.60	1.62	1.62
97	Kurar	UG	204.5	5.15	29.76	45.56	5.84	5.84
98		SW	176.7	4.45	25.71	39.36	5.05	5.05
99		SW	124.2	3.13	18.07	27.67	3.55	3.55
100		UG	155	3.91	22.55	34.53	4.43	4.43
Minimum			28.5	0.72	4.15	6.35	0.81	0.81
Maximum			234.7	5.91	34.15	52.29	6.71	6.71
Average			111.4127	2.81	16.21	24.82	3.18	3.18

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
Standard Deviation			45.3465	1.14	6.60	10.10	1.30	1.30
P5			47.815	1.20	6.95	10.65	1.36	1.36
P25			73.1	1.84	10.637	16.28	2.08	2.08
P50			112.45	2.83	16.3629	25.05	3.21	3.21
P75			142.35	3.58	20.7137	31.71	4.06	4.06
P95			182.935	4.60	26.6193	40.75	5.22	5.22
Moga district								
101	Moga	SW	71.5	1.80	10.40	15.93	2.04	2.04
102		UG	61.2	1.54	8.91	13.63	1.75	1.75
103		SW	55.2	1.39	8.03	12.30	1.58	1.58
104		UG	93.9	2.37	13.66	20.92	2.68	2.68
105	Marhi	SW	101.4	2.56	14.75	22.59	2.90	2.90
106		UG	80.5	2.03	11.71	17.93	2.30	2.30
107		SW	58.6	1.48	8.53	13.05	1.67	1.67
108		UG	61.3	1.54	8.92	13.66	1.75	1.75

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
109	Rode	UG	91.6	2.31	13.33	20.41	2.62	2.62
110		SW	63.8	1.61	9.28	14.21	1.82	1.82
111		SW	57.2	1.44	8.32	12.74	1.63	1.63
112		UG	61.5	1.55	8.95	13.70	1.76	1.76
113	khokhrana	UG	73.1	1.84	10.64	16.28	2.09	2.09
114		SW	61.3	1.54	8.92	13.66	1.75	1.75
115		SW	49.1	1.24	7.14	10.94	1.40	1.40
116		UG	55.4	1.40	8.06	12.34	1.58	1.58
117	Nathuwala	UG	102.4	2.58	14.90	22.81	2.93	2.93
118		SW	78.9	1.99	11.48	17.58	2.25	2.25
119		SW	61.3	1.54	8.92	13.66	1.75	1.75
120		UG	52.8	1.33	7.68	11.76	1.51	1.51
121	Smalsar	UG	98.7	2.49	14.36	21.99	2.82	2.82
122		SW	77.5	1.95	11.28	17.27	2.21	2.21
123		SW	63.2	1.59	9.20	14.08	1.81	1.81

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) × 10^{-5}	ECR (Cancer morbidity) × 10^{-5}	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
124		UG	65.1	1.64	9.47	14.50	1.86	1.86
125	Charik	UG	120.2	3.03	17.49	26.78	3.43	3.43
126		SW	112.5	2.84	16.37	25.06	3.21	3.21
127		SW	75.3	1.90	10.96	16.77	2.15	2.15
128		UG	77.6	1.96	11.29	17.29	2.22	2.22
129	Smadh Bhai	UG	91.7	2.31	13.34	20.43	2.62	2.62
130		SW	85.2	2.15	12.40	18.98	2.43	2.43
131		SW	41.5	1.05	6.04	9.25	1.19	1.19
132		UG	35.5	0.89	5.17	7.91	1.01	1.01
133	Nihal Singhwala	UG	121.8	3.07	17.72	27.13	3.48	3.48
134		SW	95.3	2.40	13.87	21.23	2.72	2.72
135		SW	58.5	1.47	8.51	13.03	1.67	1.67
136		UG	72.1	1.82	10.49	16.06	2.06	2.06
137	Himatpura	SW	84.2	2.12	12.25	18.76	2.41	2.41
138		UG	125.6	3.17	18.28	27.98	3.59	3.59

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu gkg^{-1}day^{-1}$)	HQ
139		SW	69.2	1.74	10.07	15.42	1.98	1.98
140		UG	72.1	1.82	10.49	16.06	2.06	2.06
141	Dharmkot	UG	79.2	2.00	11.52	17.64	2.26	2.26
142		SW	53.3	1.34	7.76	11.87	1.52	1.52
143		SW	41.2	1.04	6.00	9.18	1.18	1.18
144		UG	33.4	0.84	4.86	7.44	0.95	0.95
145	Chottain kalan	SW	96.3	2.43	14.01	21.45	2.75	2.75
146		UG	134.5	3.39	19.57	29.96	3.84	3.84
147		SW	61.5	1.55	8.95	13.70	1.76	1.76
148		UG	59.2	1.49	8.61	13.19	1.69	1.69
149	Badhni	SW	87.5	2.21	12.73	19.49	2.50	2.50
150		UG	135.1	3.40	19.66	30.10	3.86	3.86
151		SW	68.2	1.72	9.92	15.19	1.95	1.95
152		UG	71.2	1.79	10.36	15.86	2.03	2.03
153	Moga	UG	91.3	2.30	13.29	20.34	2.61	2.61

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu gkg^{-1}day^{-1}$)	HQ
154		SW	59.1	1.49	8.60	13.17	1.69	1.69
155		UG	38.44	0.97	5.59	8.56	1.10	1.10
156		SW	34.94	0.88	5.08	7.78	1.00	1.00
157	Buttar	UG	84.1	2.12	12.24	18.74	2.40	2.40
158		SW	67.2	1.69	9.78	14.97	1.92	1.92
159		UG	47.2	1.19	6.87	10.52	1.35	1.35
160		SW	41.1	1.04	5.98	9.16	1.17	1.17
161	Baddowal	UG	96.8	2.44	14.09	21.56	2.77	2.77
162		SW	83.1	2.09	12.09	18.51	2.37	2.37
163		SW	52	1.31	7.57	11.58	1.49	1.49
164		UG	59.4	1.50	8.64	13.23	1.70	1.70
165	Gill	UG	89.8	2.26	13.07	20.01	2.57	2.57
166		SW	72.4	1.82	10.54	16.13	2.07	2.07
167		SW	48.2	1.21	7.01	10.74	1.38	1.38
168		UG	60.3	1.52	8.77	13.43	1.72	1.72

S. No.	Sample location	Sources of water	Uranium concentration in water (µg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
169	Mehna	UG	123.3	3.11	17.94	27.47	3.52	3.52
170		UG	91.2	2.30	13.27	20.32	2.61	2.61
171		SW	61.2	1.54	8.91	13.63	1.75	1.75
172		UG	81.5	2.05	11.86	18.16	2.33	2.33
173	Ajitwal	SW	96.1	2.42	13.98	21.41	2.75	2.75
174		UG	121.3	3.06	17.65	27.02	3.47	3.47
175		UG	45.2	1.14	6.58	10.07	1.29	1.29
176		SW	38.4	0.97	5.59	8.55	1.10	1.10
177	Dina	UG	85.5	2.15	12.44	19.05	2.44	2.44
178		SW	72.3	1.82	10.52	16.11	2.07	2.07
179		SW	52.5	1.32	7.64	11.70	1.50	1.50
180		UG	63.8	1.61	9.28	14.21	1.82	1.82
181	Rajaina	UG	90.4	2.28	13.15	20.14	2.58	2.58
182		SW	71.5	1.80	10.40	15.93	2.04	2.04
183		SW	39.6	1.00	5.76	8.82	1.13	1.13

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu gkg^{-1}day^{-1}$)	HQ
184		UG	43.8	1.10	6.37	9.76	1.25	1.25
185	Kokri kokri	SW	85.8	2.16	12.48	19.11	2.45	2.45
186		UG	112.6	2.84	16.38	25.08	3.22	3.22
187		UG	66.9	1.69	9.73	14.90	1.91	1.91
188		SW	52.6	1.33	7.65	11.72	1.50	1.50
189	karyal	UG	123.5	3.11	17.97	27.51	3.53	3.53
190		SW	86.1	2.17	12.53	19.18	2.46	2.46
191		UG	65.1	1.64	9.47	14.50	1.86	1.86
192		SW	58.9	1.48	8.57	13.12	1.68	1.68
193	Babiha Bhaike	UG	62.7	1.58	9.12	13.97	1.79	1.79
194		SW	55.3	1.39	8.05	12.32	1.58	1.58
195		SW	36.5	0.92	5.31	8.13	1.04	1.04
196		UG	41.2	1.04	6.00	9.18	1.18	1.18
197	Ludhaike	UG	93.4	2.35	13.59	20.81	2.67	2.67
198		SW	81.2	2.05	11.82	18.09	2.32	2.32

S. No.	Sample location	Sources of water	Uranium concentration in water (μg l^{-1})	Activity of uranium concentration (Bql^{-1})	ECR (Cancer mortality) $\times 10^{-5}$	ECR (Cancer morbidity) $\times 10^{-5}$	LADD ($\mu g kg^{-1} day^{-1}$)	HQ
199		UG	68.2	1.72	9.92	15.19	1.95	1.95
200		SW	51	1.29	7.42	11.36	1.46	1.46
Minimum			33.4	0.84	4.86	7.44	0.95	0.95
Maximum			135.1	3.40	19.66	30.10	3.86	3.86
Average			72.99	1.84	10.62	16.26	2.09	2.09
Standard Deviation			24.16	0.61	3.52	5.38	0.69	0.69
P5			38.43	0.96	5.59	8.5	1.09	1.09
P25			56.75	1.43	8.25	12.64	1.6	1.62
P50			68.7	1.73	9.9	15.3	1.9	1.9
P75			88.07	2.21	12.03	19.62	2.5	2.5
P95			121.87	3.07	17.73	27.15	3.4	3.48

Table 6.2 Annual effective ingestion dose due to uranium concentration in water in various age groups of studied area

District	Life stage group	Age group	Daily water Intake (IGW)	Dose conversion Factor (DCF)	Minimum (μSvy^{-1})	Maximum (μSvy^{-1})	MEAN (μSvy^{-1})
Barnala District	Infants	0-6 months	0.7	3.4×10^{-7}	62.55	513.40	243.24
		7-12 months	0.8	3.4×10^{-7}	71.48	586.74	277.98
	Children	1-3year	1.3	1.2×10^{-7}	41.00	336.52	159.43
		4-8 year	1.7	8×10^{-8}	35.74	293.37	138.99
	Males	9-13 year	2.4	6.8×10^{-8}	42.89	2112.28	166.79
		14-18 year	3.3	6.7×10^{-8}	58.11	476.95	225.96
		Adults	3.7	4.5×10^{-8}	43.76	359.17	170.16
	Females	9-13 year	2.1	6.8×10^{-8}	37.53	308.04	145.94
		14-18 year	2.3	6.7×10^{-8}	40.50	332.42	157.49
		Adults	2.7	4.5×10^{-8}	31.93	262.09	124.17
	Pregnancy	14-18 year	3	6.7×10^{-8}	52.82	433.59	205.42
		19-50 year	3	4.5×10^{-8}	35.48	291.22	137.97
	Lactation	14-18 year	3.8	6.7×10^{-8}	66.91	549.21	260.20
		19-50 year	3.8	4.5×10^{-8}	44.94	368.87	174.76
Moga District	Infants	0-6 months	0.7	3.4×10^{-7}	70.36	295.36	158.97
		7-12 months	0.8	3.4×10^{-7}	80.42	337.55	181.68

District	Life stage group	Age group	Daily water Intake (IGW)	Dose conversion Factor (DCF)	Minimum (μSvy^{-1})	Maximum (μSvy^{-1})	MEAN (μSvy^{-1})
	Children	1-3year	1.3	1.2×10^{-7}	56.94	193.60	104.20
		4-8 year	1.7	8×10^{-8}	40.21	168.78	90.84
	Males	9-13 year	2.4	6.8×10^{-8}	48.25	202.53	109.01
		14-18 year	3.3	6.7×10^{-8}	65.37	274.39	147.68
		Adults	3.7	4.5×10^{-8}	49.23	206.63	111.21
	Females	9-13 year	2.1	6.8×10^{-8}	42.22	177.21	95.38
		14-18 year	2.3	6.7×10^{-8}	45.56	191.24	102.93
		Adults	2.7	4.5×10^{-8}	35.92	150.78	81.16
	Pregnancy	14-18 year	3	6.7×10^{-8}	59.43	249.44	134.26
		19-50 year	3	4.5×10^{-8}	39.91	167.54	90.17
	Lactation	14-18 year	3.8	6.7×10^{-8}	75.27	315.96	170.06
		19-50 year	3.8	4.5×10^{-8}	50.56	212.21	114.22

Table 6.3 Literature survey of uranium distribution in groundwater samples of different regions of India

State	District/ City	Uranium concentration	Mean	References
Punjab	Bathinda, Mansa, Ferozpur, Faridkot	0.5- 571.7	73.5	Bajwa et al., 2017
	Faridkot	16-350		Pant et al., 2020
	Sangrur district	2.47-119.95		Virk et al., 2017
	Amritsar district	0.6-65.3		Sharma et al., 2019
	Jalandhar district	1.53-50.2	17.66	Kumar et al., 2017
	Bathinda and Mansa districts	0.13- 676		Saini et al., 2018
	Malwa	5.4-43.4		Mehra et al., 2018
Jammu & Kashmir	Sri Nagar City	0.10- 15.28	2.63	Nazir et al., 2020
Kerala	Palakkad, Thrissur, Kottayam, Idukki, Enrakulam	<0.5 -12.54 pre-monsoon <0.5-5.93 post-monsoon		Shrlumon et al., 2021
Andhra Pradesh	Tummalapalle Uranium mining area, Kadapa district	0-2	0.4	Kumar et al., 2020
Arunachal Pradesh	Nalbari district	0.3-7.1 pre-monsoon 0.6-10.3 post-monsoon	2.15 2.75	Salkia et al., 2021
Bihar	273 districts	<1-80	2.08	Richards et al., 2020
Chattisgarh	Balod district	0.56-23.42		Sar et al., 2017
Gujrat	Dahod, Ahmedabad, Vadodra and Patna districts	31.9-56.7		Govt. of India, 2020

State	District/ City	Uranium concentration	Mean	References
Haryana	Around Sohna Fault Line	0.10- 223.16	22.09	Chahal et al., 2019
Himachal Pradesh	Kulu	0.3-2.5		Rohit et al., 2018
Jharkhand	Jadugada, Uranium mining area	0.03-11.6		Patra et al., 2013
Karnatka	Kolar district	0.3-14442.9		Babu et al., 2008
Madhya Pradesh		0.0-233.91		Govt. of India, 2020
Maharastra	Arunagabad district	0.01-16.6	2.75	Kale et al., 2018
Rajasthan	Northern Rajasthan	2.5-171		Duggal et al., 2016
Tamil Nadu	Trivannamalai	0.2-25.8	5.4	Thivya et al., 2014
Telangana	Peddagattu and Seripally, Nalgo		3.03	Ganesh et al., 2020
Punjab	Barnala District	28.5 – 234.7	111.43	**Present Study**
	Moga District	33.4 – 135.1	73	

Table 6.4 Biokinetic data of ingested uranium through drinking water

S No	Sample location	Uranium concentration in water (μg l^{-1})	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (μg)	C kidneys (μg g^{-1})	Plasma (μg)	Liver1+liver2 (μg)	ST+SI+ULI+LLI (μg)	Urinary Bladder (μg)	Urine (μg d^{-1})	Hair (μg d^{-1})	Faeces (μg d^{-1})	Cortical bone surface (μg)	Cortical bone volume (μg)	Trabecular bone surface (μg)	Trabecular bone volume non-ex) (μg)
Barnala district															
1	Dhanola	56.2	0.968	0.00312	0.0373	32.651	137.97	0.1369	0.164	0.3027	78.21	0.412	73.31	0.518	19.69
2		130.4	2.246	0.00724	0.0867	75.759	320.1387	0.0317	0.381	0.70238	181.47	0.956	170.1	1.196	45.69
3		171.5	2.9548	0.00953	0.114	99.63	421.0414	0.0412	0.5015	0.9237	238.66	1.2577	223.722	1.5741	60.103
4		74.2	1.278	0.00412	0.04935	43.10867	182.164	0.01808	0.21697	0.3996	103.26	0.544	96.794	0.68104	26.003
5	Bhadur	112.3	1.934	0.00624	0.0747	65.243	275.7023	0.027366	0.328	0.6048	156.28	0.82359	146.49	1.0307	39.356
6		95.8	1.6505	0.00532	0.0637	55.65	235.194	0.02334	0.28	0.516	133.31	0.7025	124.97	0.879	33.573
7		75.1	1.2939	0.00417	0.0499	43.631	184.374	0.0183	0.219	0.4045	104.51	0.5507	97.968	0.689	26.31
8		77	1.3266	0.00428	0.0512	44.735	189.039	0.018764	0.2251	0.41475	107.156	0.5647	100.446	0.70674	26.985
9	Nainewal	176.5	3.041	0.00981	0.1174	102.5429	433.31	0.043	0.5161	0.95070	245.625	1.2944	230.244	1.62	61.855
10		81.2	1.399	0.00451	0.054	47.175	199.35	0.01978	0.2374	0.43629	113.001	0.5955	105.92	0.745	28.457
11		189.9	3.271	0.01055	0.1263	110.328	466.2143	0.046276	0.555	1.02287	264.27	1.392	247.72	1.743	66.55
12		96.4	1.6609	0.00535	0.06412	56.0064	236.667	0.023491	0.28189	0.5192	134.154	0.7069	125.75	0.8848	33.78
13	Jangiana	161.2	2.777	0.0089	0.107	93.653	395.754	0.0392	0.4713	0.86828	224.33	1.479	56.493	1.479	56.49
14		185.5	3.196	0.0103	0.1233	107.77	455.412	0.0452	0.54244	0.9991	258.15	1.36	241.98	1.702	65.009
15		112.6	1.94	0.00625	0.0748	65.418	276.4388	0.27439	0.3292	0.6065	156.699	0.8257	146.887	1.033	39.461
16		108.3	1.865	0.006	0.072	62.92007	265.88	0.0263	0.3166	0.58334	150.71	0.7942	141.277	0.994	37.95
17	Channa	102.1	1.759	0.00567	0.0679	59.318	250.66	0.0248	0.2985	0.5499	142.087	0.787	133.189	0.937	35.78153
18		58.4	1.00276	0.00323	0.03871	33.813	142.884	0.014182	0.17018	0.31348	80.9938	0.42683	75.922	0.53419	20.395
19		136.4	2.35011	0.00758	0.09073	79.245	334.8691	0.033239	0.3988	0.7347	189.82	1	177.934	1.25195	47.80216
20		69.8	1.2026	0.00387	0.0464	40.5523	171.3626	0.017009	0.20411	0.37597	97.137	0.5119	91.054	0.64066	24.4618
21		64	1.10269	0.00355	0.04257	37.182	157.1233	0.015596	0.1871	0.34473	89.0654	0.46936	83.4881	0.587427	22.42917

S No	Sample location	Uranium concentration in water ($\mu g\ l^{-1}$)	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (µg)	C kidneys ($\mu g\ g^{-1}$)	Plasma (µg)	Liver1+liver2 (µg)	ST+SI+ULI+LLI (µg)	Urinary Bladder (µg)	Urine ($\mu g\ d^{-1}$)	Hair ($\mu g\ d^{-1}$)	Faeces ($\mu g\ d^{-1}$)	Cortical bone surface (µg)	Cortical bone volume (µg)	Trabecular bone surface (µg)	Trabecular bone volume non-ex) (µg)
22	Tapa	152.7	2.63095	0.00848	0.1015	88.71	374.88	0.037	0.44652	0.82250	212.504	1.1198	199.197	1.401565	53.51459
23		131.36	2.26	0.0073	0.0873	76.31	322.4956	0.032	0.3841	0.707	182.8	0.963	171.35	1.205	40.035
24		120.6	2.077	0.0067	0.08022	70.066	296.079	0.029	0.352	0.649	167.83	0.884	157.32	1.106	42.26
25	Mehta	85.9	1.48	0.0047	210.889	49.9	210.88	0.02	0.251	0.462	119.54	0.629	112.05	0.788	30.1
26		64.8	1.116	0.003	0.0431	37.64	159.08	0.0157	0.189	0.349	90.178	0.4753	84.53	0.5947	22.7
27		31.5	0.54	0.0017	0.0209	18.3	77.33	0.0076	0.092	0.169	43.83	0.231	41.09	0.289	11.039
28		45.8	0.789	0.00254	0.03	26.6	112.44	0.01116	0.1339	0.2466	63.73	0.335	59.74	0.42	16.05
29	Diwana	122.7	2.11	0.0068	0.081	71.28	301.23	0.029	0.358	0.66	170.75	0.899	160.06	1.126	43
30		146.9	2.53	0.0081	0.0977	85.34	360.64	0.035	0.429	0.791	204.43	1.077	191.63	1.348	51.48
31		168.2	2.89	0.0093	0.1118	97.7	412.93	0.04	0.491	0.905	234.07	1.233	219.41	1.54	58.94
32		113.4	1.95	0.0063	0.0754	65.88	278.4	0.027	0.331	0.61	157.81	0.831	147.93	1.0408	39.741
33	Dhurkot	75.2	1.295	0.00418	0.05	43.689	184.619	0.01832	0.2199	0.405	104.651	0.5515	98.09	0.6902	26.354
34		137.3	2.365	0.00763	0.09132	79.768	337.0786	0.03345	0.4014	0.73955	191.073	1.0069	179.108	1.2602	48.117
35		145.5	2.5069	0.008	0.09678	84.532	357.21	0.03545	0.4254	0.78372	202.484	1.067	189.8	1.33547	50.991
36		111.6	1.922	0.0062	0.07423	64.837	273.983	0.027195	0.3263	0.6011	155.307	0.818	145.58	1.0243	39.11
37	Draj	122.7	2.114	0.00682	0.0816	71.286	301.234	0.0299	0.3588	0.6609	170.755	0.8998	160.0625	1.1262	43.0009
38		113.2	1.95	0.0062	0.07529	65.766	277.91	0.02758	0.331	0.6097	157.53	0.8301	147.669	1.039	39.671
39		68.1	1.173	0.00378	0.0452	39.564	167.189	0.0165	0.1991	0.3668	94.771	0.4994	88.836	0.625	23.866
40		77.9	1.3421	0.00433	0.0518	45.258	191.248	0.01898	0.2277	0.4196	108.409	0.5713	101.62	0.715	27.3
41	Handiya	129.9	2.238	0.00722	0.0864	75.46	318.91	0.03165	0.3798	0.6996	180.77	0.9526	169.454	1.192	45.52
42		142.3	2.451	0.0079	0.09465	82.673	349.35	0.0346	0.416	0.766	198.031	1.0436	185.63	1.3061	49.865
43		76.5	1.318	0.00425	0.50886	44.44	187.81	0.0186	0.2237	0.412	106.46	0.561	99.794	0.7021	26.809
44		84.2	1.45	0.00468	0.056	48.91	206.71	0.0205	0.246	0.453	117.17	0.617	109.839	0.7728	29.508
45		152.5	2.627	0.00847	0.101	88.59	374.39	0.0371	0.445	0.8214	212.22	1.118	198.93	1.399	53.44

S No	Sample location	Uranium concentration in water ($\mu g\ l^{-1}$)	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (μg)	C kidneys ($\mu g\ g^{-1}$)	Plasma (μg)	Liver1+liver2 (μg)	ST+SI+ULI+LLI (μg)	Urinary Bladder (μg)	Urine ($\mu g\ d^{-1}$)	Hair ($\mu g\ d^{-1}$)	Faeces ($\mu g\ d^{-1}$)	Cortical bone surface (μg)	Cortical bone volume (μg)	Trabecular bone surface (μg)	Trabecular bone volume non-ex) (μg)
46	Mehal kalan	68.3	1.176	0.0037	0.0454	39.68	167.68	0.0166	0.1997	0.3678	95.049	0.05009	89.097	0.626	23.93
47		79.2	1.364	0.0044	0.05268	46.01	194.44	0.0193	0.23159	0.4266	110.218	0.58	103.316	0.7269	27.756
48		179.4	3.09	0.0099	0.1193	104.2277	440.436	0.0437	0.5246	0.96632	249.66	1.3156	234.027	1.646	62.871
49	Sanghere	66.3	1.142	0.0036	0.0441	38.518	162.769	0.01615	0.1938	0.357	92.26	0.4862	86.488	0.6085	23.235
50		172.4	2.97	0.00958	0.1146	100.16	423.2509	0.042	0.504	0.9286	239.92	1.264	224.89	1.582	60.418
51		94.5	1.628	0.00525	0.0628	54.9	232.0024	0.02302	0.276	0.509	131.51	0.693	123.275	0.867	33.118
52		112.7	1.941	0.00626	0.0749	65.476	276.68	0.02746	0.329	0.607	156.83	0.8265	147.017	1.0344	34.49
53	Wajid ke	86.2	1.485	0.00479	0.0573	50.08	211.625	0.021	0.252	0.4643	119.96	0.6321	112.448	0.7911	30.209
54		142.5	2.455	0.0079	0.0947	82.78	349.84	0.0347	0.4167	0.7675	198.3	1.045	185.89	1.307	49.93
55		88.2	1.519	0.0049	0.0586	51.24	216.53	0.0214	0.2579	0.475	122.74	0.646	115.05	0.809	30.912
56		168.5	2.903	0.0093	0.112	97.89	413.676	0.041	0.492	0.907	234.49	1.235	219.8	1.546	59.05
57	Chuhan ke	159.7	2.751	0.0088	0.1062	92.78	392.071	0.0389	0.466	0.8602	222.24	1.171	208.32	1.4658	55.967
58		174.2	3.001	0.0096	0.115	101.206	427.67	0.0424	0.509	0.9383	242.42	1.277	227.244	1.598	61.049
59		118.4	2.039	0.0065	0.0785	68.789	290.678	0.0288	0.346	0.6377	164.77	0.868	154.45	1.086	41.493
60		97.1	1.672	0.0053	0.064	56.413	238.38	0.02366	0.283	0.523	135.12	0.712	126.66	0.891	34.02
61	Bhadalwad	234.7	4.043	0.013	0.156	136.35	576.2	0.0571	0.686	1.264	326.61	1.721	306.166	2.154	82.251
62		212.3	3.57	0.0117	0.1412	123.34	521.207	0.0517	1.6208	1.143	295.44	1.556	276.94	1.948	74.4
63		116.8	2.012	0.00649	0.0776	67.85	286.75	0.0284	0.341	0.629	162.54	0.856	152.36	1.072	40.933
64		134.9	2.324	0.00749	0.0897	78.37	331.185	0.0328	0.394	0.7266	187.3	0.989	175.37	1.238	47.276
65	Sehjra	118.7	2.045	0.0065	0.0789	68.96	291.41	0.0289	0.347	0.639	165.18	0.87	154.84	1.089	41.599
66		139.6	2.405	0.0077	0.0928	81.104	342.72	0.034	0.408	0.751	194.27	1.023	182.1	1.281	48.92
67		98.4	1.695	0.0054	0.0654	57.168	241.577	0.0239	0.287	0.53	136.93	0.7216	128.36	0.903	34.48
68		134.2	2.312	0.00745	0.0892	77.96	329.467	0.0327	0.392	0.7228	186.759	0.9842	175.064	1.217	47.03
69	Barnala	118.2	2.036	0.00656	0.0786	68.671	290.187	0.0288	0.345	0.636	164.492	0.8668	154.192	1.084	41.423

S No	Sample location	Uranium concentration in water ($\mu g\ l^{-1}$)	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (μg)	C kidneys ($\mu g\ g^{-1}$)	Plasma (μg)	Liver1+liver2 (μg)	ST+SI+ULI+LLI (μg)	Urinary Bladder (μg)	Urine ($\mu g\ d^{-1}$)	Hair ($\mu g\ d^{-1}$)	Faeces ($\mu g\ d^{-1}$)	Cortical bone surface (μg)	Cortical bone volume (μg)	Trabecular bone surface (μg)	Trabecular bone volume non-ex) (μg)
70		182.4	3.142	0.01013	0.1213	105.97	447..801	0.0444	0.533	0.9824	253.883	1.337	237.94	1.674	63.92
71		28.5	0.491	0.0015	0.0189	16.557	69.96	0.00694	0.0833	0.1535	39.661	0.209	37.178	0.261	9.987
72		47.9	0.825	0.00266	0.0318	27.828	117.59	0.0116	0.14	0.258	66.659	0.3512	62.485	0.439	16.78
73	Dangarh	138.5	2.386	0.00769	0.0921	80.465	340.024	0.0337	0.405	0.746	192.74	1.0157	180.673	1.271	48.538
74		129.4	2.229	0.00719	0.086	75.178	317.68	0.03153	0.378	0.697	180.079	0.948	168.8	1.187	45.34
75		47.9	0.825	0.00266	0.0318	27.828	117.59	0.0116	0.14	0.258	66.659	0.3512	62.485	0.439	16.78
76		57.3	0.987	0.00318	0.0381	33.29	140.67	0.0139	0.1675	0.3086	79.74	0.4202	74.748	0.5259	20.081
77	Harigarh	68.1	1.173	0.00378	0.0452	39.564	167.189	0.0165	0.1991	0.3668	94.771	0.4994	88.836	0.625	23.866
78		69.2	1.192	0.00384	0.046	40.203	169.88	0.0168	0.202	0.3727	9630	0.507	90.271	0.635	24.25
79		57.4	0.988	0.0031	0.0381	33.348	140.92	0.01398	0.1678	0.309	79.88	0.4209	74.878	0.526	20.116
80		67.2	1.157	0.0037	0.0447	39.041	164.97	0.0163	0.196	0.361	93.51	0.492	87.66	0.616	25.55
81	Aspal Kalan	60.4	1.04	0.00335	0.401	35.09	148.28	0.0147	0.176	0.325	84.055	0.442	78.79	0.554	21.167
82		61.1	1.052	0.0033	0.0406	35.49	150.003	0.01488	0.178	0.329	85.02	0.448	79.705	0.56	21.41
83		43.4	0.747	0.0024	0.0288	25.21	106.54	0.0105	0.126	0.233	60.397	0.318	56.615	0.398	15.209
84		66.5	1.145	0.0036	0.0442	38.63	163.26	0.0162	0.194	0.358	92.544	0.4877	86.749	0.6103	23.305
85	Bheni Jassa	152.3	2.624	0.00846	0.1013	88.48	373.9	0.037	0.445	0.8203	211.94	1.116	198.67	1.397	53.37
86		134.1	2.31	0.0074	0.089	77.9	329.22	0.0326	0.392	0.722	186.61	0.983	174.93	1.23	46.99
87		46.2	0.796	0.00256	0.0307	26.84	113.42	0.0112	0.135	0.248	64.29	0.338	60.26	0.424	16.19
88		80.2	1.38	0.004	0.053	46.59	196.89	0.0195	0.234	0.431	111.61	0.588	104.6	0.736	28.106
89	Kattu	182.8	3.14	0.0101	0.121	106.2	448.78	0.044	0.534	0.984	254.39	1.34	238.46	1.67	64.06
90		152.4	2.62	0.0084	0.1013	88.54	374.14	0.037	0.445	0.82	212.08	1.117	198.8	1.398	53.4
91		112.1	1.931	0.0062	0.0745	65.12	275.21	0.0273	0.327	0.603	156.003	0.822	146.23	1.028	39.28
92		132.5	2.28	0.007	0.088	76.97	325.29	0.0322	0.387	0.713	184.39	0.971	172.84	1.216	46.435
93		91.6	1.57	0.00509	0.0609	53.21	224.88	0.022	0.267	0.493	127.47	0.671	119.49	0.84	32.101

S No	Sample location	Uranium concentration in water (μg l^{-1})	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (μg)	C kidneys (μg g^{-1})	Plasma (μg)	Liver1+liver2 (μg)	ST+SI+ULI+LLI (μg)	Urinary Bladder (μg)	Urine (μg d^{-1})	Hair (μg d^{-1})	Faeces (μg d^{-1})	Cortical bone surface (μg)	Cortical bone volume (μg)	Trabecular bone surface (μg)	Trabecular bone volume non-ex) (μg)
94	Attar Singhwala	86.7	1.49	0.004	0.0576	50.37	212.85	0.02112	0.253	0.467	120.65	0.635	113.1	0.795	30.38
95		57.24	0.986	0.00318	0.038	33.25	140.527	0.0139	0.167	0.308	79.65	0.419	74.66	0.525	20.06
96		56.57	0.974	0.00314	0.037	32.86	138.88	0.0137	0.165	0.304	78.72	0.414	73.79	0.519	19.82
97	Kurar	204.5	3.52	0.0113	0.136	118.81	502.08	0.049	0.598	1.101	284.59	1.499	266.77	1.877	71.66
98		176.7	3.04	0.0098	0.117	102.65	433.8	0.043	0.516	0.951	245.9	1.29	230.5	1.62	61.92
99		124.2	2.139	0.0069	0.0826	72.15	304.991	0.0302	0.363	0.668	172.84	0.9108	162.01	1.139	43.52
100		155	2.67	0.0086	0.103	90.05	380.53	0.037	0.453	0.834	215.705	1.136	202.19	1.422	54.32
Minimum		28.500	0.491	0.002	0.019	16.557	69.960	0.007	0.083	0.154	39.661	0.050	37.178	0.261	9.987
Maximum		234.700	4.043	0.013	210.889	136.350	576.200	0.274	1.621	1.264	326.610	1.721	306.166	2.154	82.251
Average		111.413	1.918	0.006	2.191	64.724	271.757	0.031	0.336	0.600	155.000	0.816	143.789	1.022	38.952
Moga district															
101	Moga	71.5	1.23	0.0039	0.0475	41.54	175.53	0.0174	0.209	0.385	99.5	0.5224	93.27	0.656	25.05
102		61.2	1.05	0.003	0.04	35.55	150.24	0.0149	0.178	0.329	85.16	0.448	79.83	0.561	21.44
103		55.2	0.951	0.003	0.0367	32.07	135.51	0.0134	0.161	0.297	76.81	0.404	72.008	0.506	19.34
104		93.9	1.617	0.0052	0.062	54.5	230.52	0.022	0.274	0.505	130.67	0.688	122.49	0.861	32.9
105	Marhi	101.4	1.74	0.005	0.0674	58.91	248.94	0.0247	0.296	0.546	141.11	0.743	132.27	0.93	35.53
106		80.5	1.38	0.004	0.0535	46.76	197.63	0.0196	0.235	0.433	112.02	0.59	105.012	0.738	28.21
107		58.6	1.009	0.0032	0.0389	34.04	143.86	0.0142	0.171	0.315	81.55	0.429	76.44	0.537	20.53
108		61.3	1.056	0.003	0.0407	35.61	150.49	0.0149	0.179	0.33	85.3	0.449	79.96	0.562	21.48
109	Rode	91.6	1.57	0.00509	0.0609	53.21	224.88	0.022	0.267	0.493	127.47	0.671	119.49	0.84	32.101
110		63.8	1.099	0.0035	0.042	37.06	156.63	0.0155	0.186	0.343	88.78	0.467	83.22	0.58	22.35
111		57.2	0.98	0.003	0.038	33.23	140.42	0.0139	0.167	0.308	79.6	0.419	74.61	0.525	20.046
112		61.5	1.05	0.003	0.451	35.73	150.98	0.014	0.179	0.33	85.58	0.451	80.22	0.56	21.55
113	khokhrana	73.1	1.259	0.004	0.0486	42.46	179.46	0.0178	0.213	0.393	101.72	0.536	95.35	0.67	25.61

S No	Sample location	Uranium concentration in water (µg l^{-1})	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (µg)	C kidneys (µg g^{-1})	Plasma (µg)	Liver1+liver2 (µg)	ST+SI+ULI+LLI (µg)	Urinary Bladder (µg)	Urine (µg d^{-1})	Hair (µg d^{-1})	Faeces (µg d^{-1})	Cortical bone surface (µg)	Cortical bone volume (µg)	Trabecular bone surface (µg)	Trabecular bone volume non-ex) (µg)
114		61.3	1.056	0.003	0.0407	35.61	150.49	0.0149	0.179	0.33	85.3	0.449	79.96	0.562	21.48
115		49.1	0.845	0.0027	0.0326	28.52	120.54	0.0119	0.143	0.264	68.32	0.36	64.05	0.45	17.2
116		55.4	0.954	0.003	0.0368	32.18	136	0.013	0.162	0.298	77.09	0.406	72.26	0.508	19.415
117		102.4	1.76	0.0056	0.068	59.49	251.39	0.0249	0.299	0.551	142.5	0.75	133.58	0.939	35.88
118	Nathuwala	78.9	1.35	0.004	0.052	45.83	193.7	0.019	0.23	0.424	109.8	0.578	102.92	0.724	27.65
119		61.3	1.056	0.003	0.0407	35.61	150.49	0.0149	0.179	0.33	85.3	0.449	79.96	0.562	21.48
120		52.8	0.9	0.0029	0.035	30.67	129.62	0.0128	0.154	0.284	73.47	0.38	68.87	0.484	18.5
121		98.7	1.7	0.0054	0.065	57.34	242.31	0.024	0.288	0.531	137.35	0.723	128.75	0.905	34.589
122	Smalsar	77.5	1.335	0.0043	0.0515	45.02	190.266	0.0188	0.226	0.417	107.85	0.568	101.09	0.711	27.16
123		63.2	1.088	0.0035	0.042	36.71	155.15	0.0154	0.184	0.34	87.95	0.463	82.44	0.58	22.14
124		65.1	1.21	0.0036	0.0433	37.82	159.82	0.0158	0.19	0.3506	90.59	0.477	84.92	0.597	22.81
125		120.2	2.07	0.0066	0.0799	69.83	295.09	0.029	0.351	0.647	167.27	0.881	156.8	1.103	42.12
126	Charik	112.5	1.938	0.0062	0.0748	65.36	276.19	0.0274	0.328	0.605	156.56	0.825	146.75	1.032	39.426
127		75.3	1.297	0.004	0.05	43.74	184.86	0.0183	0.2201	0.405	104.79	0.552	98.22	0.691	26.38
128		77.6	1.33	0.0043	0.0516	45.084	190.51	0.01189	0.226	0.417	107.99	0.569	101.22	0.712	27.19
129		91.7	1.579	0.00509	0.0609	53.27	225.128	0.0223	0.268	0.493	127.61	0.672	119.62	0.841	32.13
130	Smadh	85.2	1.467	0.00473	0.0566	49.49	209.17	0.02076	0.249	0.4589	118.56	0.624	111.143	0.782	29.85
131	Bhai	41.5	0.715	0.0023	0.0276	24.11	101.884	0.0101	0.1213	0.2235	57.753	0.304	54.136	0.3809	14.54
132		35.5	0.6116	0.00197	0.0236	20.624	87.154	0.00865	0.1038	0.1912	49.403	0.2603	46.309	0.3258	12.44
133		121.8	2.098	0.00677	0.081	70.763	299.025	0.00865	0.356	0.656	169.5	0.893	158.88	1.117	42.68
134	Nihal	95.3	1.641	0.00529	0.0633	55.367	233.966	0.02322	0.278	0.5133	136.624	0.698	124.31	0.874	33.398
135	Singhwala	58.5	1.007	0.00325	0.0389	33.98	143.62	0.0142	0.171	0.315	81.411	0.429	76.31	0.536	20.501
136		72.1	1.242	0.004	0.0479	41.888	177.009	0.01757	0.2108	0.3883	100.337	0.528	94.054	0.6617	25.267
137	Himatpura	84.2	1.45	0.00468	0.056	48.91	206.71	0.0205	0.246	0.453	117.17	0.617	109.839	0.7728	29.508

S No	Sample location	Uranium concentration in water (μg l^{-1})	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (μg)	C kidneys (μg g^{-1})	Plasma (μg)	Liver1+liver2 (μg)	ST+SI+ULI+LLI (μg)	Urinary Bladder (μg)	Urine (μg d^{-1})	Hair (μg d^{-1})	Faeces (μg d^{-1})	Cortical bone surface (μg)	Cortical bone volume (μg)	Trabecular bone surface (μg)	Trabecular bone volume non-ex) (μg)
138		125.6	2.164	0.00698	0.0835	72.97	308.354	0.0306	0.367	0.676	174.79	0.921	163.845	1.152	44.017
139		69.2	1.192	0.00384	0.046	40.203	169.88	0.0168	0.202	0.3727	9630	0.507	90.271	0.635	24.25
140		72.1	1.242	0.004	0.0479	41.888	177.009	0.01757	0.2108	0.3883	100.337	0.528	94.054	0.6617	25.267
141	Dharmkot	79.2	1.364	0.0044	0.05268	46.01	194.44	0.0193	0.23159	0.4266	110.218	0.58	103.316	0.7269	27.756
142		53.3	0.918	0.00296	0.0354	30.96	130.854	0.0129	0.155	0.287	74.174	0.39	69.53	0.489	18.679
143		41.2	0.709	0.00229	0.0274	23.936	101.148	0.01	0.1204	0.221	57.33	0.302	53.745	0.378	14.438
144		33.4	0.575	0.00185	0.022	19.404	81.998	0.00813	0.0976	0.179	46.481	0.244	43.57	0.306	11.705
145	Chottain kalan	96.3	1.659	0.00535	0.064	55.948	236.421	0.0234	0.281	0.518	134.015	0.706	125.62	0.883	33.748
146		134.5	2.317	0.00747	0.0894	78.14	330.204	0.0327	0.393	0.7244	187.17	0.986	175.45	1.234	47.136
147		61.5	1.05	0.003	0.451	35.73	150.98	0.014	0.179	0.33	85.58	0.451	80.22	0.56	21.55
148		59.2	1.0199	0.00329	0.0393	34.39	145.33	0.01442	1.731	0.3188	82.385	0.434	77.226	0.543	20.74
149	Badhni	87.5	1.507	0.00486	0.0582	50.835	214.817	0.0213	0.2558	0.4713	121.769	0.641	114.144	0.8031	30.664
150		135.1	2.327	0.0075	0.0898	78.49	331.677	0.0329	0.395	0.727	188.011	0.9908	176.238	1.24	47.346
151		68.2	1.175	0.00379	0.0453	39.622	167.43	0.0166	0.1994	0.367	94.91	0.5	88.967	0.625	23.901
152		71.2	1.226	0.0039	0.0473	41.365	174.79	0.01735	0.208	0.383	99.085	0.522	92.88	0.653	24.952
153	Moga	91.3	1.573	0.00507	0.0607	53.04	224.146	0.0222	0.2669	0.4917	127.05	0.669	119.1	0.838	31.996
154		59.1	1.018	0.00338	0.0393	34.33	145.093	0.0144	0.1728	0.318	82.246	0.433	77.096	0.54	20.7
155		38.44	0.661	0.00213	0.0255	22.309	94.273	0.0093	0.112	0.206	53.43	0.281	50.09	0.352	13.457
156		34.94	0.601	0.0019	0.0232	20.276	85.681	0.0085	0.102	0.1879	48.568	0.255	45.52	0.32	12.23
157	Buttar	84.1	1.44	0.00467	0.0559	48.86	206.469	0.0204	0.245	0.452	117.037	0.616	109.708	0.771	29.4733
158		67.2	1.157	0.0037	0.0447	39.041	164.97	0.0163	0.196	0.361	93.51	0.492	87.66	0.616	25.55
159		47.2	0.813	0.0026	0.0313	27.42	115.878	0.0115	0.138	0.254	65.685	0.346	61.57	0.433	16.541
160		41.1	0.708	0.0022	0.027	23.878	100.902	0.01005	0.1201	0.221	57.196	0.3014	53.61	0.3772	14.403
161	Baddowal	96.8	1.667	0.00538	0.0643	56.23	237.64	0.02358	0.283	0.521	134.71	0.709	126.27	0.888	33.92

S No	Sample location	Uranium concentration in water ($\mu g\ l^{-1}$)	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (µg)	C kidneys ($\mu g\ g^{-1}$)	Plasma (µg)	Liver1+liver2 (µg)	ST+SI+ULI+LLI (µg)	Urinary Bladder (µg)	Urine ($\mu g\ d^{-1}$)	Hair ($\mu g\ d^{-1}$)	Faeces ($\mu g\ d^{-1}$)	Cortical bone surface (µg)	Cortical bone volume (µg)	Trabecular bone surface (µg)	Trabecular bone volume non-ex) (µg)
162		83.1	1.431	0.00461	0.055	48.279	204.014	0.0202	0.243	0.447	115.64	0.609	108.4	0.762	29.122
163		52	0.895	0.0028	0.034	30.21	127.66	0.0126	0.152	0.28	72.365	0.381	67.83	0.477	18.223
164		59.4	1.023	0.0033	0.039	34.51	145.83	0.0144	0.173	0.319	82.66	0.435	77.48	0.545	20.81
165	Gill	89.8	1.547	0.00499	0.0597	52.17	220.463	0.0218	0.262	0.483	124.97	0.658	117.144	0.824	31.47
166		72.4	1.247	0.004	0.048	42.062	177.74	0.0176	0.211	0.389	100.75	0.53	94.44	0.664	25.37
167		48.2	0.83	0.0026	0.032	28	118.33	0.0117	0.14	0.259	67.077	0.353	62.87	0.442	16.89
168		60.3	1.038	0.0033	0.04	35.03	148.03	0.0146	0.176	0.324	83.91	0.442	78.66	0.553	21.132
169	Mehna	123.3	2.12	0.0068	0.082	71.63	302.7	0.03	0.36	0.664	171.59	0.904	160.84	1.131	43.211
170		91.2	1.571	0.005	0.0605	52.98	223.9	0.022	0.266	0.491	126.91	0.668	118.97	0.837	31.96
171		61.2	1.05	0.003	0.04	35.55	150.24	0.0149	0.178	0.329	85.16	0.448	79.83	0.561	21.44
172		81.5	1.404	0.0045	0.0542	47.34	200.086	0.0198	0.238	0.438	113.41	0.597	106.31	0.748	28.56
173	Ajitwal	96.1	1.655	0.0053	0.0639	55.832	235.93	0.023	0.281	0.517	133.73	0.704	125.36	0.882	33.67
174		121.3	2.08	0.006	0.0806	70.47	297.79	0.0295	0.3547	0.6533	169	0.889	158.23	1.113	42.51
175		45.2	0.778	0.00251	0.03	26.26	110.96	0.011	0.132	0.243	62.902	0.331	58.96	0.414	15.84
176		38.4	0.661	0.0021	0.0255	22.3	94.273	0.0093	0.112	0.2068	53.43	0.28	50.092	0.352	13.457
177	Dina	85.5	1.473	0.0047	0.0568	49.673	209.906	0.0208	0.25	0.46	118.98	0.627	111.53	0.784	29.96
178		72.3	1.24	0.004	0.048	42.004	177.5002	0.0176	0.211	0.389	100.61	0.53	94.31	0.663	25.33
179		52.5	0.904	0.0029	0.0349	30.5	128.89	0.0127	0.153	0.282	73.06	0.38	68.48	0.481	18.398
180		63.8	1.099	0.0035	0.042	37.06	156.63	0.0155	0.186	0.343	88.78	0.467	83.22	0.58	22.35
181	Rajaina	90.4	1.55	0.005	0.0601	52.52	221.93	0.022	0.264	0.486	125.804	0.662	117.92	0.829	31.68
182		71.5	1.23	0.0039	0.0475	41.54	175.53	0.0174	0.209	0.385	99.5	0.5224	93.27	0.656	25.05
183		39.6	0.682	0.0022	0,026	23.006	97.22	0.00965	0.115	0.213	55.109	0.29	51.65	0.363	13.87
184		43.8	0.752	0.002	0.029	25.44	107.53	0.0106	0.128	0.235	60.95	0.321	57.137	0.402	15.349
185	Kokri kokri	85.8	1.478	0.00476	0.057	49.84	210.64	0.0209	0.25	0.462	119.4	0.629	111.92	0.787	30.06

S No	Sample location	Uranium concentration in water (µg l⁻¹)	Kidneys		Blood	Liver	GI Tract	Bladder	Excretion			Skelton			
			R Kidneys (µg)	C kidneys ($\mu g\ g^{-1}$)	Plasma (µg)	Liver1+liver2 (µg)	ST+SI+ULI+LLI (µg)	Urinary Bladder (µg)	Urine ($\mu g\ d^{-1}$)	Hair ($\mu g\ d^{-1}$)	Faeces ($\mu g\ d^{-1}$)	Cortical bone surface (µg)	Cortical bone volume (µg)	Trabecular bone surface (µg)	Trabecular bone volume non-ex) (µg)
186		112.6	1.94	0.00625	0.0748	65.418	276.4388	0.27439	0.3292	0.6065	156.699	0.8257	146.887	1.033	39.461
187		66.9	1.152	0.0037	0.044	38.86	164.24	0.016	0.195	0.36	93.101	0.49	87.27	0.614	23.44
188		52.6	0.906	0.0029	0.0349	30.559	129.135	0.0128	0.153	0.283	73.2	0.3857	68.61	0.482	18.43
189	karyal	123.5	2.127	0.00686	0.0821	71.75	303.198	0.03	0.361	0.665	171.86	0.905	161.106	1.133	43.281
190		86.1	1.483	0.0047	0.057	50.02	211.38	0.0209	0.251	0.463	119.82	0.631	112.317	0.79	30.174
191		65.1	1.21	0.0036	0.0433	37.82	159.82	0.0158	0.19	0.3506	90.59	0.477	84.92	0.597	22.81
192		58.9	1.014	0.0032	0.0391	34.21	0.014	144.6	0.172	0.317	81.96	0.431	76.83	0.54	20.64
193	Babiha Bhaike	62.7	1.08	0.00348	0.0417	36.42	153.93	0.0152	0.183	0.337	87.256	0.459	81.79	0.575	21.973
194		55.3	0.952	0.003	0.0367	32.128	135.76	0.0134	0.161	0.297	76.958	0.405	72.139	0.507	19.38
195		36.5	0.628	0.00202	0.0242	21.205	89.6	0.008894	0.106	0.1966	50.79	0.267	47.61	0.335	12.79
196		41.2	0.709	0.00229	0.0274	23.936	101.148	0.01	0.1204	0.221	57.33	0.302	53.745	0.378	14.438
197	Ludhaike	93.4	1.609	0.0051	0.062	54.263	229.3	0.022	0.273	0.503	129.97	0.684	121.84	0.857	32.732
198		81.2	1.399	0.00451	0.054	47.175	199.35	0.01978	0.2374	0.43629	113.001	0.5955	105.92	0.745	28.457
199		68.2	1.175	0.00379	0.0453	39.622	167.43	0.0166	0.1994	0.367	94.91	0.5	88.967	0.625	23.901
200		51	0.947	0.00305	0.0365	31.95	135.027	0.0134	0.16	0.296	76.54	0.403	71.74	0.504	19.27
Minimum		33.400	0.575	0.002	0.022	19.404	0.014	0.008	0.098	0.179	46.481	0.244	43.570	0.306	11.705
Maximum		135.100	2.327	0.008	0.451	78.490	331.677	144.600	1.731	0.727	188.100	0.991	176.238	1.240	47.346
Average		72.994	1.258	0.004	0.057	42.427	177.851	1.466	0.229	0.393	101.000	0.535	95.268	0.670	25.612

R=Retention, C= Concentration, ST = Stomach, SI = Small intestine, ULI= Upper Large Intestine, LLI= Lower Large Intestine

Table 6.5: Dose received to various organs using biokinetic modelling

	Uranium concentration (μg l^{-1})	Bladder wall	Bone Surface	Breast	Oesphagus	Stomach Wall	Colon	Liver	Ovaries	Red Marrow	Lungs	Skin	Testes	Thyroid	Remainder	Effective dose
Barnala District																
Minimum	28.500	168.2 nSv	18.83 μSv	167.2 nSv	167.2 nSv	170.2 nSv	246.2 nSv	3.314 μSv	205 nSv	2.401 μSv	167.9 nSv	167.2 nSv	204.6 nSv	167.2 nSv	2.38 μSv	904.8 nSv
Maximum	234.700	1.38 μSv	155 μSv	1.377 μSv	1.377 μSv	1.402 μSv	2.028 μSv	27.29 μSv	1.688 μSv	19.77 μSv	1.382 μSv	1.377 μSv	1.685 μSv	1.377 μSv	19.58 μSv	7.451 μSv
Average.	111.413	657.9 nSv	73.62 μSv	653.7 nSv	653.7 nSv	665.6 nSv	962.8 nSv	12.95 μSv	801.5 nSv	9.389 μSv	656.4 nSv	653.7 nSv	800 nSv	653.7 nSv	9.298 μSv	3.537 μSv
Moga District																
Minimum	33.400	197.2 nSv	22.07 μSv	195.9 nSv	195.9 nSv	199.5 nSv	288.6 nSv	3.884 μSv	240.2 nSv	2.814 μSv	196.8 nSv	195.9 nSv	239.8 nSv	195.9 nSv	2.787 μSv	1.06 μSv
Maximum	135.100	797.8 nSv	89.27 μSv	729.6 nSv	792.6 nSv	807.1 nSv	1.167 μSv	15.71 μSv	971.9 μSv	11.38 μSv	796 nSv	792.6 nSv	970.1 nSv	792.6 nSv	11.27 μSv	4.289 μSv
Average	72.994	431 nSv	48.23 μSv	428.2 nSv	428.2 nSv	436.1 nSv	630.8 nSv	8.489 μSv	525.1 nSv	6.151 μSv	430 nSv	428.2 nSv	524.1 nSv	428.2 nSv	6.091 μSv	2.317 μSv

Table 6.6: Measurement of pH, TDS and EC in studied area

Sr. No	Sample location	Source of water	Uranium concentration (µg l^{-1})	TDS (mg l^{-1})	EC (µScm^{-1})	pH
Barnala district						
1	Dhanola	UG	56.2	495	548	7.8
2		SW	130.4	580	1231	7.3
3		UG	171.5	1370	1781	7.1
4		SW	74.2	646	733	7.7
5	Bhadur	UG	112.3	1063	1269	7.1
6		UG	95.8	940	936	7.7
7		SW	75.1	521	768	7.7
8		SW	77	743	835	7.7
9	Nainewal	SW	176.5	1227	1688	7.1
10		UG	81.2	726	890	7.7
11		UG	189.9	1331	1776	6.8
12		SW	96.4	982	1023	7.7
13	Jangiana	SW	161.2	1352	1747	7.1
14		UG	185.5	1425	1885	6.8
15		UG	112.6	1296	1325	7.4
16		SW	108.3	1089	1199	7.4
17	Channa	SW	102.1	1040	1020	7.6
18		UG	58.4	558	758	7.8
19		UG	136.4	1300	1332	7.5
20		SW	69.8	853	686	7.7
21	Tapa	SW	64	838	627	7.7
22		UG	152.7	1307	1650	7.4
23		SW	131.36	1486	1387	7.1
24		SW	120.6	1356	1356	7.1
25	Mehta	UG	85.9	952	912	7.7
26		SW	64.8	851	730	7.7
27		UG	31.5	415	454	7.8

Sr. No	Sample location	Source of water	Uranium concentration (µg l^{-1})	TDS (mg l^{-1})	EC (µScm^{-1})	pH
28		SW	45.8	588	527	7.8
29	Diwana	UG	122.7	1255	1238	7.1
30		UG	146.9	1404	1356	7.2
31		SW	168.2	1529	1584	7.3
32		SW	113.4	1228	1181	7.6
33	Dhurkot	SW	75.2	617	683	7.8
34		SW	137.3	1326	1477	7.2
35		UG	145.5	1402	1439	7.3
36		UG	111.6	1158	1064	7.2
37	Draj	UG	122.7	1251	1230	7.2
38		SW	113.2	1168	1195	7.2
39		SW	68.1	869	770	7.8
40		UG	77.9	885	816	7.8
41	Handiya	SW	129.9	1274	1279	7.2
42		UG	142.3	1521	1468	7.1
43		SW	76.5	765	773	7.8
44		UG	84.2	936	810	7.8
45	Mehal kalan	SW	152.5	1504	1642	7.1
46		SW	68.3	748	836	7.8
47		UG	79.2	916	969	7.8
48		UG	179.4	1223	1671	6.8
49	Sanghere	UG	66.3	739	706	7.8
50		SW	172.4	1628	1695	6.8
51		SW	94.5	1170	1072	7.8
52		UG	112.7	1264	1160	7.3
53	Wajid ke	SW	86.2	985	905	7.8
54		SW	142.5	1330	1399	7.2
55		UG	88.2	923	880	7.7
56		UG	168.5	1578	1619	6.9

Sr. No	Sample location	Source of water	Uranium concentration (µg l^{-1})	TDS (mg l^{-1})	EC (µScm^{-1})	pH
57	Chuhan ke	SW	159.7	1545	1518	7
58		UG	174.2	1687	1709	6.9
59		UG	118.4	1236	1098	7.1
60		SW	97.1	1059	1063	7.7
61	Bhadalwad	UG	234.7	1963	2068	6.6
62		SW	212.3	1942	1974	6.7
63		UG	116.8	1055	1126	7.3
64		SW	134.9	1222	1469	7.2
65	Sehjra	SW	118.7	1180	1279	7.2
66		UG	139.6	1260	1449	7.2
67		SW	98.4	1070	1084	7.7
68		UG	134.2	1208	1439	7.2
69	Barnala	SW	118.2	1278	1287	7.4
70		UG	182.4	1765	1959	7
71		SW	28.5	384	491	8.1
72		UG	47.9	623	672	7.9
73	Dangarh	UG	138.5	1222	1468	7.1
74		SW	129.4	1194	1309	7.1
75		SW	47.9	699	518	7.9
76		UG	57.3	619	663	8
77	Harigarh	SW	68.1	814	763	7.8
78		UG	69.2	781	779	7.9
79		SW	57.4	687	633	8
80		RW	67.2	878	814	7.8
81	Aspal Kalan	SW	60.4	709	867	8
82		SW	61.1	772	688	7.9
83		SW	43.4	410	659	8
84		UG	66.5	603	751	7.9
85	Bheni Jassa	UG	152.3	1320	1677	7.2

Sr. No	Sample location	Source of water	Uranium concentration (μg l^{-1})	TDS (mg l^{-1})	EC (μScm^{-1})	pH
86		SW	134.1	1323	1284	7.1
87		SW	46.2	316	669	8
88		UG	80.2	989	938	7.8
89	Kattu	UG	182.8	1612	1758	6.9
90		SW	152.4	1496	1630	7.5
91		SW	112.1	1322	1282	7.6
92		UG	132.5	1390	1365	7.2
93	Attar Singhwala	UG	91.6	931	891	7.9
94		SW	86.7	835	759	7.8
95		SW	57.24	745	617	8
96		UG	56.57	739	507	8
97	Kurar	UG	204.5	1824	1973	6.8
98		SW	176.7	1605	1646	7.7
99		SW	124.2	1204	1330	7.7
100		UG	155	1448	1525	7.3
Minimum			28.5	316	454	6.6
Maximum			234.7	1963	2068	8.1
Average			111.413	1088.9	1154.38	7.465
Standard Deviation			45.3465	366.177	413.499	0.37883
P5			47.815	519.7	546.95	6.8
P25			73.1	778.75	772.25	7.175
P50			112.45	1163	1170.5	7.55
P75			142.35	1327	1468	7.8
P95			182.935	1630.95	1786.2	8
Moga District						
101	Moga	SW	71.5	808	852	7.8
102		UG	61.2	604	745	7.8
103		SW	55.2	521	680	7.9
104		UG	93.9	964	1057	7.8

Sr. No	Sample location	Source of water	Uranium concentration (µg l^{-1})	TDS (mg l^{-1})	EC (µScm^{-1})	pH
105	Marhi	SW	101.4	1023	1166	7.6
106		UG	80.5	902	939	7.8
107		SW	58.6	571	705	7.9
108		UG	61.3	612	579	7.8
109	Rode	UG	91.6	994	1021	7.8
110		SW	63.8	673	704	7.9
111		SW	57.2	516	670	7.9
112		UG	61.5	679	897	7.9
113	khokhrana	UG	73.1	791	882	7.8
114		SW	61.3	612	826	7.8
115		SW	49.1	502	686	8
116		UG	55.4	568	610	7.9
117	Nathuwala	UG	102.4	1016	1182	7.6
118		SW	78.9	745	930	7.9
119		SW	61.3	674	765	7.9
120		UG	52.8	514	674	8
121	Smalsar	UG	98.7	990	1047	7.8
122		SW	77.5	738	824	7.9
123		SW	63.2	635	797	7.9
124		UG	65.1	631	907	7.9
125	Charik	UG	120.2	1225	1375	7.6
126		SW	112.5	1338	1216	7.6
127		SW	75.3	806	857	7.8
128		UG	77.6	786	828	7.8
129	Smadh Bhai	UG	91.7	942	1097	7.8
130		SW	85.2	842	925	7.9
131		SW	41.5	523	657	7.9
132		UG	35.5	461	440	8
133		UG	121.8	1369	1383	7.5

Sr. No	Sample location	Source of water	Uranium concentration (μg l^{-1})	TDS (mg l^{-1})	EC (μScm^{-1})	pH
134	Nihal Singhwala	SW	95.3	991	1103	7.7
135		SW	58.5	582	795	7.8
136		UG	72.1	758	840	7.8
137	Himatpura	SW	84.2	872	994	7.8
138		UG	125.6	1340	1321	7.4
139		SW	69.2	702	726	7.8
140		UG	72.1	797	815	7.8
141	Dharmkot	UG	79.2	849	839	7.8
142		SW	53.3	576	680	8
143		SW	41.2	517	570	8
144		UG	33.4	454	436	8.2
145	Chottain kalan	SW	96.3	1009	1042	7.8
146		UG	134.5	1443	1415	7.4
147		SW	61.5	766	764	7.8
148		UG	59.2	675	683	7.9
149	Badhni	SW	87.5	860	950	7.8
150		UG	135.1	1372	1433	7.3
151		SW	68.2	633	787	7.8
152		UG	71.2	868	866	7.9
153	Moga	UG	91.3	1160	1063	7.8
154		SW	59.1	629	697	8
155		UG	38.44	458	446	8.1
156		SW	34.94	434	410	8
157	Buttar	UG	84.1	915	954	7.8
158		SW	67.2	709	739	7.8
159		UG	47.2	523	684	7.9
160		SW	41.1	479	591	8
161	Baddowal	UG	96.8	1020	1077	7.9
162		SW	83.1	927	993	7.8

Sr. No	Sample location	Source of water	Uranium concentration (μg l^{-1})	TDS (mg l^{-1})	EC (μScm^{-1})	pH
163		SW	52	463	669	7.9
164		UG	59.4	517	658	7.9
165	Gill	UG	89.8	991	936	7.8
166		SW	72.4	849	839	7.9
167		SW	48.2	549	527	8
168		UG	60.3	655	752	7.9
169	Mehna	UG	123.3	1258	1346	7.3
170		UG	91.2	1203	1042	7.8
171		SW	61.2	711	869	7.9
172		UG	81.5	931	901	7.8
173	Ajitwal	SW	96.1	1126	1090	7.8
174		UG	121.3	1268	1368	7.3
175		UG	45.2	495	537	8
176		SW	38.4	600	433	8.1
177	Dina	UG	85.5	943	915	7.8
178		SW	72.3	815	845	7.8
179		SW	52.5	538	601	7.9
180		UG	63.8	704	731	7.9
181	Rajaina	UG	90.4	957	1069	7.8
182		SW	71.5	871	873	7.8
183		SW	39.6	429	483	8.2
184		UG	43.8	541	510	8
185	Kokri kokri	SW	85.8	873	979	7.8
186		UG	112.6	1163	1297	7.3
187		UG	66.9	743	713	7.8
188		SW	52.6	261	666	7.7
189	karyal	UG	123.5	1241	1310	7.8
190		SW	86.1	909	956	7.7
191		UG	65.1	749	727	7.5

Sr. No	Sample location	Source of water	Uranium concentration (μg l^{-1})	TDS (mg l^{-1})	EC (μScm^{-1})	pH
192		SW	58.9	634	920	7.7
193	Babiha Bhaike	UG	62.7	691	781	7.7
194		SW	55.3	681	695	7.6
195		SW	36.5	543	515	7.7
196		UG	41.2	592	504	7.7
197	Ludhaike	UG	93.4	1017	1058	7.5
198		SW	81.2	872	927	7.6
199		UG	68.2	743	738	7.8
200		SW	51	641	609	7.5
Minimum			33.4	261	410	7.3
Maximum			135.1	1443	1433	8.2
Average			72.99	786.6	850.25	7.801
Standard Deviation			24.16	254.19	244.849	0.19
P5			38.438	460.85	481.15	7.4
P25			56.75	589.5	682.25	7.8
P50			68.7	744	833.5	7.8
P75			88.07	942.25	993.25	7.9
P95			121.87	1271.5	1347.1	8

OVERALL CONCLUSION

The present research work has been carried out to assess the radioactivity levels and associated health effects due to presence of radon/thoron, their progeny and uranium concentration in the environment of studied area.

The results shows that out of 200 dwellings, 32.5% have higher annual average radon concentration than the recommended value and 9% of the dwellings have higher annual average radon progeny concentration (EERC) than the worldwide average value. 100% of the dwellings have higher annual average thoron concentration than the world average value and 96% have higher annual average thoron progeny concentration (EETC) than the world average value which may be due to the use of thorium rich materials used in construction of dwellings of this area. The measured average radon, thoron and their progeny concentration in the studied area have been found higher in winter season as compared to rainy and summer season. Also the poor ventilated houses have more concentration than the well ventilated houses. This may be due to less exchange of gases between the indoor and outdoor environment in winter and poorly ventilated houses. The annual average equilibrium factor between radon and its progeny is 0.37 which is slightly less than world average value and for thoron and its progeny, it is 0.02, which is same as world average value. The total annual effective inhalation dose received to the local population is well below the recommended level.

The radon mass exhalation rates in all soil samples have lower value than the worldwide average value whereas the thoron surface exhalation rates in 98% samples have higher values than worldwide average value. The variation in the exhalation rates may be because of varied geological locations of soil samples, topography, radon emanation factor and soil porosity. The higher thoron surface exhalation rates may be because of higher thorium rich contents in rocks in the Northern portion of India. Weak correlation has been found between average indoor radon/thoron concentration and exhalation rates in samples which may be due to the reason that the, radon/thoron emitted from soil surface underneath the concrete and mud houses would not contribute to indoor radon/thoron concentrations.

The radon concentration in all water samples have been found to be below the recommended limit. The annual effective dose due to ingestion and inhalation for infants has been found to be higher than the dose received by children and adults. Whereas the overall dose received by the residents is well below the recommended limit. The underground water samples have slightly higher values of radon concentration than in surface water samples which may be because the radon easily escape from surfaces while as underground water retains. A weak positive correlation has been observed between radon in underground water with depth.

The uranium concentration in 99.5% of water samples have higher value than the recommended limit. The higher uranium concentration observed may be due to geology, anthropogenic activities and use of phosphate fertilizers in huge quantity for agriculture purposes. The calculated hazard quotient in 98% of samples is higher than one hence these areas may have increased probability of kidney and lung diseases. Biokinetic model has been applied to calculate retention, removal and dose received by various organs of human body due intake of uranium from drinking water. The retention of uranium has been calculated in the organs like GI tract, skeleton, blood, kidney, liver, urinary bladder. The highest retention of ingested uranium has been found in GI tract. The excretion of uranium has been calculated through excretory paths like hair faeces and urine. It has been found that the excretion rate of uranium is much greater through large intestine pathways (faeces) than through urine or hair. The dose received to various organs like bone surfaces, red bone marrow, thyroid, breast, skin, oesophagus, stomach and colon, liver and bladder wall has been calculated. It has been found that highest dose received to bone surface out of the all organs of human body.

Physicochemical parameters like pH, TDS and EC have been also studied in total 200 groundwater and surface water samples. In all the samples, the pH value lies in the recommended permissible range. 5% samples have lower pH value and 95% samples have higher value than 7. Hence, the water in the most of studied area is alkaline. The pH value of all the samples lies in permissible range. The total dissolved solids (TDS) in 7% samples have lesser value and 93% samples have higher TDS value than the recommended contaminant level which shows that the water in most of the area may not be fit for drinking. The electrical conductivity in 48.5% samples have lower value and in 41.5% samples have higher value than the recommended value. It has been observed that the total dissolved solids and electrical conductivity have higher values in underground water samples than surface water. A positive correlation has been observed between uranium concentration with pH, TDS and EC.

The radon concertation in the air and water along with radon mass exhalation rates in soil has been found to be lower than the recommended value, hence it may not pose any significant radiological risk to the residents of studied area. Whereas thoron, thoron surface exhalation rates and uranium in water have higher values than the recommended level, therefore these may be of concern for the local population from the health risk point of view. The data will contribute towards the national pool for mapping and for further studies.

FUTURE SCOPE

As uranium concentration has come out to be higher than safe limit, hence further research may be carried out to understand the cause and associated health effects for the residents of studied area. Although radon concentration has been found to be less but thoron concentration and thoron exhalation rates have been found to be higher, so a detailed study may be carried out for the construction and building materials used in the houses.