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# Estimation and Risk Assessment of Natural Uranium Radioactivity in the Yamuna River Water, DelhiUsing LED Fluorimetry and Biokinetic Modelling

Aditya Mittal[a], Jagjeevan Ram[a], Garima Malik[b], Abhishek[c], Navish Kataria[d,e] & Amanjeet[a*]

[a]Department of Physics, Ramjas College, University, Delhi 110 007, India

[b]Department of Physics, Baba Mastnath University, Rohtak 124 021, India

[c]Department of Energy Management, Technical University, Berlin 106 23 Germany

[d]Department of Environmental Science, J C Bose University of Science & Technology, Faridabad 121006, India

[e]Centre for Herbal Pharmacology and Environmental Sustainability, Chettinad Academy of Research and Education, Kelambakkam, Chengalpattu 603 103, India

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Water is crucial for sustaining life, and its quality directly impacts public health. The existence of radioactive compounds, such as uranium ($^{238}$U) and its decay product, radon ($^{222}$Rn), can render water unsafe for consumption. Therefore, it is crucial to determine the presence and concentration of these elements in water. This study offers a comprehensive analysis of the radioactivity levels in water samples collected from the Yamuna River in Delhi. Uranium concentration is determined using LED fluorimetry technique, and various chemical and radiological risks such as annual effective dose, lifetime average daily dose, hazard quotient, and excess cancer risk, associated with uranium presence are evaluated. The samples average uranium concentration is 28.37 µg/L, which lies within the safe levels set by the U.S. Environmental Protection Agency and the World Health Organization. In order to forecast how uranium will distribute within the body organs, the study also takes into account the age-specific biokinetic framework offered by the International Commission on Radiological Protection (ICRP). While the radiological hazards remain low, higher LADD value in certain samples indicates a potential chemical toxicity concern. It is observed that areas with high fertilizer use and drainage systems close to rivers are associated with increased uranium levels.

**Keywords:** Radioactivity, LED fluorimetry, Uranium biokinetics, Radiological parameters,Chemical toxicity

## 1 Introduction

Radiation exposure is an inherent aspect of human existence. Every person on Earth is exposed to radiation in one way or the other. Radiation refers to the emission and transmission of energy in the form of electromagnetic waves or movement of subatomic particles. Monitoring the radiation levels provides valuable insights into the exposure to the mass population and the potential harm it may cause. There are primarily two sources of radiation: Natural and artificial sources. Natural sources sub-divide into terrestrial and cosmogenic sources. Terrestrial sources consist of radionuclides found in rocks, soil, air, and water. Whereas, cosmogenic radiations are produced by high-energy particles like electrons and protons[1]. Artificial sources of radiation include nuclear waste from power plants and radiation emission from X-ray devices, etc. The amount of ionized radiation absorbed by a substance is known as radiation dose. There are typically three types of radiation dose: absorbed, equivalent, and effective dose. The absorbed dose refers to the breakdown of radiation within human tissues when they are exposed to small quantities of ionizing radiation. Gray (Gy) is the standard measure unit for absorbed dose, which signifies the absorption of radiation energy per kilogram of matter[2]. When ionizing radiation is absorbed by the human tissue, the potentially damaging impacts are described by Equivalent Dose. The radiation weighting factor is an essential component in the determination of equivalent dose[3]. The radiation weighting factor refers to the particleability to induce ionization within the tissue. Sieverts (Sv) is used as the unit of measurement of the equivalent dose.

Equivalent dose = Absorbed dose × Radiation weighting factor(Wr) … (1)

In contrast, the effective dose quantifies the harmful effects of radiation while considering the sensitivity of various organs and tissues. Unlike

*Corresponding author: E-mail: amanjeet@ramjas.du.ac.in

absorbed dose, effective dose evaluates the long-term risks of radiation exposure[3].

Effective dose = Equivalent dose × Tissue weighting factor ($W_t$) … (2)

The tissue weighting factor ($W_t$) refers to the measure of how much a single tissue or organ contributes to the overall health risk associated with radiation exposure. The effective dose of radiation considers the varying sensitivities of different tissues and organs. Everyone on Earth is exposed to background radiation, which comes from the natural radioactivity of various elements. These types of radiation have existed since the Earth formation. Water covers nearly 71% of the Earth surface, but only about 3% of that is freshwater. Out of this freshwater, just 0.3% is available as surface water. All living beings—plants, animals, and humans—depend on this small fraction for survival. Therefore, it is crucial to assess the quality of water, as it has a direct impact on the global population. The excessive levels of radioactive elements like uranium ($^{238}$U) and its decay product radon ($^{222}$Rn) in water can lead to various health problems[4]. Uranium is a naturally occurring, radioactive, long-lived, dense, silver-white and ductile element found in many rocks, soils, and even in oceans and seas. Uranium typically exists as an oxide or complex salt and is more abundant than silver, gold, or mercury. Primarily, there are three isotopes of uranium: Uranium-234 ($^{234}$U), Uranium-235 ($^{235}$U) and Uranium-238 ($^{238}$U), having half-lives of roughly 250,000, 700 million, and 4.5 billion years respectively. The isotope $^{238}$U is the most common, with an average of 2.7 parts per million in the Earth crust, making up 99.27% of uranium by weight[5]. Radioactivity is the spontaneous process by which heavy elements decay into lighter nuclei without external influences like temperature, pressure, or humidity. Since uranium is highly radioactive and unstable, it decays into lighter, more stable nuclei while emitting an alpha particle, which is usually a helium nucleus[6].

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{234}_{90}\mathrm{Th} \quad \text{... (3)}$$

$$^{235}_{92}\mathrm{U} \longrightarrow {}^{4}_{2}\mathrm{He} + {}^{231}_{90}\mathrm{Th} \quad \text{... (4)}$$

Uranium is a highly toxic element, and its toxicity can vary based on factors such as solubility, elimination pathways, exposure routes, and duration of contact[7]. Uranium present in the groundwater can accumulate in the soil and is absorbed by the plants. These plants are then consumed by animals and human beings, leading to serious health risks. Inhalation and ingestion are the main methods through which uranium enters the human body. And how uranium moves through the human body is explained by biokinetics. The four main stages of biokinetics - absorption, distribution, metabolism, and excretion, collectively referred to as the ADME process[8]. Uranium primarily enters the body through ingestion as soluble uranyl salts ($UO_2^{2+}$), but only a small fraction is absorbed, typically ranging from less than 0.1% to 6%.[9] The solubility of the uranium compound and the presence of food in the gastrointestinal tract determine the extent of absorption. Once absorbed, uranium enters the bloodstream, where it strongly binds to red blood cells and plasma proteins, forming uranyl-albumin complexes. This uranium is then distributed throughout various organs in the body. Research indicates that approximately 66% of thebody uranium is stored in the bones, 8% in the kidneys, 16% in the liver, and 10% in other tissues[10]. Urine is the body main method of excreting uranium, yet only around 1% of ingested uranium is removed in urine because of the poor rate of absorption[11]. Remaining ingested uranium is expelled from the body through feces. Biokinetic models mathematically depict the processes that radionuclides experience inside the living body[12]. General framework of a biokinetic model comprises of compartments representing organs or tissues connected by transfer rates that predict the radionuclide movement between them[13]. Mass balance, analysis of compartments, and the present knowledge regarding the movement of radionuclides inside the body serve as the foundation for these models[14]. Figure 1 represents a model with three compartments: A depicts intake compartment, B and C represent urinary and feces excretion compartments respectively with $\beta_1$ and $\beta_2$ as transfer rates.

Biokinetic models inform which water sources are of concern. Exposure to uranium can lead to various health issues[15]. Short-term exposure to ionizing radiation can cause acute radiation syndrome, with

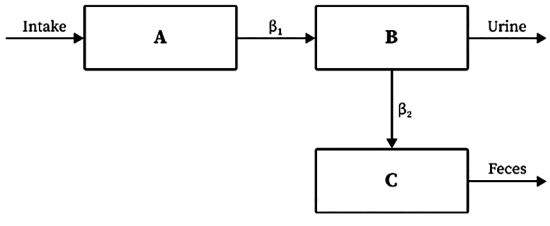


Fig. 1 — Three compartment biokinetic model

symptoms of vomiting, skin burns, and nausea. Prolonged exposure to radiation can result in serious health complications, including cardiovascular diseases due to DNA damage, increased risk of cancer, and genetic mutations[16]. According to WHO, uranium can affect the kidneys' ability to filter blood and eliminate waste from the body by binding with proteins and enzymes and damaging mitochondria. In bones, uranium replaces calcium in the hydroxyapatite (HAp) matrix, which weakens the bone structure over time. The health concerns associated with radiation exposure depend significantly on tissue sensitivity, duration of exposure, and dose of radiation[17]. Radon, with a half-life of 3.82 days, is a decay byproduct of uranium-238 ($^{238}$U) and thorium-232 ($^{232}$Th) series. It is highly radiotoxic substance and the leading cause of lung cancer. Ingestion is a primary route by which uranium enters the human body, making it essential to study its levels in water sources[18]. To effectively regulate the concentration of uranium and its potential radiological and chemical toxicity, organizations like WHO and AERB have set permissible guidelines for uranium levels in water. The guidelines established by U.S. Environmental Protection Agency for tolerable uranium concentration is 30 µg/L, while the AERB allows a higher limit of 60 µg/L. While WHO guidelines consider 30 µg/L as "may be protective"[19]. Additionally, other organizations have established their own guidelines for uranium concentration: the Australian National Health and Medical Research Council guideline sets a limit of 17 µg/L, and Health Canada suggests a limit of 20 µg/L[14]. Estimating the uranium content in water sources is crucial for assessing the potential toxicity that can render the water unsuitable for use. By gathering comprehensive data, authorities can implement necessary measures to reduce uranium levels in these water sources, thereby minimizing the risk of toxicity to the general population. The present study also fills a research gap by providing a comprehensive analysis and estimation of uranium in the Yamuna River in Delhi. Former studies, while evaluating the agricultural, domestic and industrial waste contamination, mainly focus on the pollution caused by the heavy metals such as iron (Fe), copper (Cu), nickel (Ni), lead (Pb) and chromium (Cr) in the Yamuna River, or assess the river's pollution by studying the seasonal variation of pollutants like dissolved oxygen, biochemical oxygen demand, chemical oxygen demand[20,21]. But took the toxicity of uranium into the least account. The estimation of uranium is also a key factor in the examination of the quality of water, as the radioactivity of uranium increases the chemical toxicity of water, and affects both the environment and human health, causing many short-term and long-term health hazards.

## 2 Literature Review:

### 2.1Geology of Sampled Region

Delhi, the national capital of India, is situated in the northern part of the country. It lies between the longitudes of 76°50'24" and 77°20'37" East and the latitudes of 28°24'17" and 28°53'00" North. Covering a total area of 1,483 square kilometres, Delhi is bordered by Uttar Pradesh to the east and surrounded by Haryana on three sides: north, west, and south[22]. Located within the Indo-Gangetic plains, Delhi is adjacent to the Aravalli hills to the south. The Yamuna River flows through the city for approximately 22 kilometres, beginning at Palla Village and exiting at Jaitpur.[23] The boundaries of the Yamuna water system are defined to the north by the Himalayas and to the south by the Vindhya Range. To the east, this system is separated from the main Ganga waterway, while to the west, it is distinguished from the Luni and Ghaggar river basins by a ridge[23]. The majority of the water catchment area in Haryana and Uttar Pradesh lies within the Gangetic alluvial plains[22]. The capital region experiences a diverse climate, with an average annual rainfall of 774 mm, predominantly occurring between July and September[22]. The hottest months are April, May, and June, with temperatures soaring between 40 and 45 degrees Celsius. Conversely, winters can be quite chilly, with temperatures dropping to around 4 to 5 degrees Celsius in December and January[23,24].

### 2.2 Comprehensive Geology

The National Capital Territory, which represents a complex geological framework spanning from Archean to Recent periods, is located within one of the Indian subcontinent's most geologically significant locations. The area specifically is a part of the North Delhi Fold Belt (NDFB), one of the Delhi Supergroup's two main structural zones[25]. It has undergone several stages of metamorphism and deformation, with ages estimated to be between 1.8 and 0.96 Ga[26]. The primary rock type found in Delhi is quartzite, which showcases mineralogical features that include 85-95% quartz, present in both monocrystalline and polycrystalline forms[26]. While minerals such as

biotite, muscovite, and feldspars constitute 5-15% of the composition. The high quartz content, characterised by a light grey colouration, lends the formations resistance to erosion, thereby helping them maintain their status as prominent topographic ridges[27]. The Delhi Supergroup displays a variety of metamorphic mineral assemblages, including quartz-mica schist, garnet-bearing mica schist, calc-silicate assemblages, mafic assemblages, and chlorite schist. The occurrence and distribution of groundwater in Delhi are greatly influenced by the geological framework through aquifer systems[25]. The main aquifer system is provided by alluvial cover from Quaternary sediments, fractured zones offer enhanced permeability along structural discontinuities, and quartzite formations typically form poor aquifers due to low porosity and permeability[27]. Moreover, Delhi's geological structure contains a variety of mineral resources, featuring base metal mineralisation with copper found in calc-silicate rocks and dolomitic marble[27]. Lead-zinc deposits are linked with metasedimentary formations, while sulfide minerals such as chalcopyrite, pyrite, pyrrhotite, and arsenopyrite are also present. Additionally, construction materials like quartzite are extensively mined for building purposes, alongside decorative stones from different metamorphic rocks used in architectural designs[25,27].

## 3 Method

Water samples are collected at consistent intervals, roughly every two kilometres, along the Yamuna River in Delhi. The sampled locations are plotted and presented in Fig. 2. Water samples are obtained directly from the river as well as from other water sources. The samples are collected in sterilized plastic bottles, with around 50 ml of water taken from each sampling location. The collected samples are evaluated at the Department of Environmental Sciences at J.C. Bose University of Science and Technology, Haryana. Before the evaluation, the samples undergo a double filtration process using filter paper to remove impurities. These impurities can cause unwanted fluorescence or absorb light, which may impact the measurement signal[28]. Uranium levels in water can be measured using various methods, including laser fluorimetry, LED fluorimetry, fusion track registration, neutron activation analysis, and anodic stripping voltammetry[13]. Among these, LED fluorimetry stands out due to its rapid processing capabilities, making it an excellent choice compared to other methods[28]. Additionally, the LED (Light Emitting Diode) in the fluorimeter offers a consistent light source for an extended period. The LED fluorimetry method operates on the principle that the fluorescence intensity emitted by uranium complexes in an aqueous solution indicates the concentration of uranium[29]. Fluorescence occurs when compounds absorb light at specific wavelengths, typically in the ultraviolet and visible ranges, and then re-emit energy as they transition to higher electronic states. In the present study, a wavelength range of 370 to 410 nm is used ensuring peak absorption and excitation of uranium compounds, causing them to fluoresce. The uranium levels in the collected samples are evaluated using a Quantalase LED fluorimeter is shown in Fig. 3 capable of detecting uranium levels of up to 1000 µg/L[30]. To assess uranium levels, a sodium pyrophosphate solution is prepared by mixing five grams of sodium pyrophosphate with hundred millilitres of double distilled water. Then, orthophosphoric acid is slowly incorporated into the solution in small amounts to adjust the pH to 7. Maintaining the pH of the sample is crucial for accurate uranium detection, as fluorescence intensity is highly sensitive to pH levels. In a clean cuvette, five millilitres of sample water is combined with 0.5 ml of the sodium pyrophosphate solution with the help of a pipette. To minimize errors, a micropipette is used for the precise transfer of solutions, as fluorescence intensity is directly proportional to lower concentrations[13]. The cuvette is then placed in in a precisely calibrated LED fluorimeter analyser chamber for accurate fluorescence measurement. When the LED light is activated, it excites uranium complexes, causing them to emit green fluorescence, captured by a Photomultiplier Tube (PMT), which signals the uranium presence in the water. The variation in the light intensity detected by PMT, directly correlates with the uranium levels present in the water[28,31]. Hence, by measuring the intensity, we can easily measure the uranium levels present in the sampled water.

### 3.1 Radiological Hazards Evaluation

LED fluorimeter quantitatively measures the concentration of uranium in micrograms per litre (µg/L). This measurement can be converted to becquerels per litre (Bq/L) for the calculation of activity concentration using rate of conversion of 0.02528 Bq/L[30,32].

$U_{conc}$ (Bq/L) = Measured Conc. (in µg/L) × Conversion rate (0.02528 Bq $L^{-1}$) … (5)

Risk associated with radiation exposure is calculated by multiplying the daily dose of radionuclides by the carcinogenic slope or risk factor, which quantifies the harmful effects of radiation[18].

Fig. 2 — Sampling locations in the study map

Cancer Excess Risk = $U_{conc}$ (Bq/L) × Risk factor… (6)

The risk factor determines the relationship between radiation exposure and subsequent damage.

Risk facto r= Coefficient of risk ($Bq^{-1}$) × Exposure duration (days) × rate of ingestion (L $day^{-1}$) … (7)

Based on the dose received during external exposure or the intake of radionuclides for internal exposure, risk coefficients can predict the mortality or morbidity linked to radiogenic cancer. The number of people who have died from cancer per 100,000 is known as cancer mortality. The risk coefficient varies for different uranium isotopes. Cancer morbidity involves the presence of a disease or its symptoms, along with the frequency of the disease within a population[32,33]. The coefficients for cancer mortality for $^{238}U$, $^{235}U$, and $^{234}U$ are $7.5\times10^{-11}$, $6.2\times10^{-11}$, and $6.1\times10^{-11}$, respectively. For cancer morbidity, the coefficients for $^{238}U$, $^{235}U$, and $^{234}U$ are $1.2\times10^{-10}$, $9.8\times10^{-11}$, and $9.5\times10^{-11}$, respectively. The ingestion rate is 4.05 litres per day for an adult. The total duration of exposure is considered to be 25509 days. The maximum acceptable limit for cancer risk is


Fig. 3 — LED Fluorimeter (Quantalase LF-2a)

$10^{-32,\ 15}$. The risk of illness increases due to food contamination from excessive fertilizer use and water pollution caused by industrial waste. This increases the risk of radiogenic cancer in the populations consuming contaminated food or water.

### 3.2 Chemical Toxicity Evaluation

The chemical toxicity of a compound is determined by its lifetime average daily dose (LADD). LADD denotes the mean daily exposure to a radioactive agent over the course of an individual lifetime, which is calculated using

$$\text{LADD (µg/ kg-day)} = (\text{MV} \times \text{IR} \times \text{F} \times \text{L}) / (\text{W} \times \text{TE}) \quad \ldots (8)$$

Here, MV depicts measured value in µg/L, IR depicts rate of ingestion, that is taken as 4.05 L/day, F signifies frequency of exposure, which is set at 365 days per year. L refers to the life expectancy, taken 69.89 years, W represents an adult body weight taken as 70 kilograms, and TE accounts for the total duration of exposure, which is 25509 days[33].

The reference value ($R_f$) set by WHO (for LADD) = 1.2 µg/ kg-day

Hazard Quotient (HQ) serves as a standard metric for assessment of chemical toxicity. HQ is simply the ratio of LADD to its reference value ($R_f$)[16].

$$\text{Hazard Quotient (HQ)} = \text{LADD} / R_f \quad \ldots (9)$$

### 3.3 Annual Effective Dose

The effective dose with which a person is exposed annually is calculated using

$$\text{AED (µSv/Y)} = U_{conc} \times \text{ED} \times I_{annual} \quad \ldots (10)$$

Here $U_{conc}$ refers to the activity uranium concentration in Bq/L, ED represents the effective dose per unit intake, taken as $4.5 \times 10^{-8}$ µSv $Y^{-1}$ $Bq^{-1}$ $L^{-1}$. The term $I_{annual}$ refers to the yearly ingestion amount, calculated as 1480 litres (365 × 4.05)[16].

According to WHO, the threshold limit for annual effective dose = 0.1 mSv/Y.

### 3.4 Evaluation using Biokinetic Models

Biokinetic models are sophisticated tools for evaluating radioactive element retention analytically and potentially, as well as to compute tissue and organ dose following the ingestion[9]. These models predict translocation, retention, and elimination of radioactive elements within the body by accounting for elements such as the material absorption with the entry, uptake, and the time it stays in different tissues and organs, along with chemical and physical factors such as solubility, particle size distribution, and clearance kinetics from the body[12,13]. As a result, they are essential for understanding related toxicity and predicting the biological impacts of intakes. Various factors like age, nutrition, physical activities, drugs, physiological traits, and environmental factors like temperature, humidity, and precipitation affect the uranium biokinetics[11].The most importanteffect of uranium ingestion is chemical nephrotoxicity. Even moderate absorbed doses damage the tubular cells, affects bone metabolism and mineralization. Using ICRP methodology, the retention of uranium is calculated for the various tissues and body organs like

Table 1 — Measured uranium concentration in the respective study location (March, 2024)

| Sample Code | Location | Latitude & Longitude | Water Source | Measured Uranium Conc. (µg/L) |
|---|---|---|---|---|
| RCY 01 | Ladakh Budh Vihar Colony, Civil Lines | 28.674967N; 77.231501E | River | 18.63 |
| RCY 02 | Metro Vihar, Shastri Park, Shahdara | 28.669676N; 77.238899E | River | 41.36 |
| RCY 03 | Mahatma Gandhi Rd, Raj Ghat | 28.652274N; 77.25183E | Handpump | 24.89 |
| RCY 04 | Yamuna River | 28.644591N; 77.257652E | River | 32.76 |
| RCY 05 | Kanyakumari Hwy, RPS Complex, Raj Ghat | 28.646267N; 77.2565E | Tubewell | 39.53 |
| RCY 06 | IG Indoor Stadium, ITO, Vikram Nagar | 28.628942N; 77.253302E | River | 17.80 |
| RCY 07 | Bank Enclave, Laxmi Nagar | 28.642377N; 77.268352E | River | 23.59 |
| Min | | | | 17.80 |
| Average | | | | 28.37 |
| Max | | | | 41.36 |

Table 2 — Radiological and chemical toxicity in the study region (March, 2024)

| Sample Code | Measured Uranium Conc (µg/L) | Uranium Concentration(Bq $L^{-1}$) | LADD (µg $kg^{-1}$ $day^{-1}$) | Annual Effective Dose (µSv $Y^{-1}$) | HQ |
|---|---|---|---|---|---|
| RCY 01 | 18.63 | 0.47 | 1.08 | 3.14E-05 | 0.90 |
| RCY 02 | 41.36 | 1.05 | 2.39 | 6.96E-05 | 1.99 |
| RCY 03 | 24.89 | 0.63 | 1.44 | 4.19E-05 | 1.20 |
| RCY 04 | 32.76 | 0.83 | 1.90 | 5.52E-05 | 1.58 |
| RCY 05 | 39.53 | 1.00 | 2.29 | 6.65E-05 | 1.91 |
| RCY 06 | 17.80 | 0.45 | 1.03 | 3.00E-05 | 0.86 |
| RCY 07 | 23.59 | 0.60 | 1.37 | 3.97E-05 | 1.14 |
| Min | 17.80 | 0.45 | 1.03 | 3.00E-05 | 0.86 |
| Average | 28.37 | 0.72 | 1.64 | 4.78E-05 | 1.37 |
| Max | 41.36 | 1.05 | 2.39 | 6.96E-05 | 1.99 |

soft tissues, liver, bones, kidney, and gastrointestinal tract (GIT). Consider a two-compartment system with compartments 'i' and 'j', rate of activity transfer from 'j' to 'i' is denoted by $\beta_{ji}$ and vice versa. And, $\beta_R$ represents the radioactive decay constant. Consider the nuclide number at any instant of time 't' be $N_i(t)$ and $N_j(t)$, respectively.[10,12]

$$\frac{dN_i}{dt} = \sum_{j=1,j\#i}^{n} \beta_{ji} N_j(t) - \sum_{i=1,i\#j}^{n} \beta_{ij} N_i(t) - \beta_R N_i \quad \ldots (11)$$

When radioactive elements are likely to build up in bones, they typically start on the bone surfaces, such as the cortical and trabecular areas[14]. During the uranium retention estimation, some parameters are taken constant, breathing rate is taken as 0.633 $m^3$/h, food intake rate and water consumption rate is taken as 0.253 kg/d and 4.05 L/d respectively. Average body weight, kidney mass, and urine volume is taken as 66.83 kg, 310 g, and 1.38 L/d respectively[8].

## 4 Results

Seven water samples are collected and their sampling locations and water sources are tabulated in Table 1 along with the values of measured uranium concentration. There are various toxicity risks associated with the uranium content present in water. The risks are evaluated and summarized in Table 2.

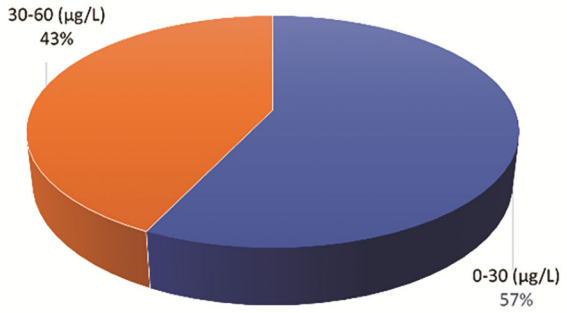


Fig. 4 — Percentage of samples across uranium concentration ranges

These risks include radiological and chemical toxicity health hazards, making it vital for regular monitoring of water sources. Figure 4 represents the percentage distribution of samples across the two concentration ranges; 0-30 µg/L and 30-60 µg/L. The mean of the daily dose over a lifetime appears to be precisely proportional to the amount of uranium in water, as observed in Fig. 5. Therefore, we can imply that higher uranium concentration in water lead to increased chemical toxicity.

Different uranium isotopes involve different risk factors causing cancer risk.Table 3 represents the values of cancer mortality and morbidity rate for different isotopes of Table 1 − Uranium retention in different bodily organs (March, 2024) uranium. The

risk of cancer increases directly with uranium activity concentration. As the activity concentration rises, so do the risks of cancer and other chemical and biological hazards. Figure 6 demonstrates a direct relationship between cancer morbidity and mortality: as cancer cases in the sampled region increase because of high uranium concentrations, the number of cancer-related deaths also rise. However, Fig. 7 shows with increase in uranium concentration in water, the rate of cancer cases rises more significantly than the mortality rate associated with cancer caused by elevated uranium levels. Table 4 depicts the uranium retention (µg/L) using biokinetic models. It aims to predict the measure of uranium presence and the way it is retained within the living body. Uranium enters the body through GI tract. The uranium in the tract gets absorbed in the blood and migrates to various organs and tissues segments like small intestine, large intestine, stomach, and gastrointestinal tract.

## 5 Discussion

Looking at Table 1, it is observed that 5 out of 7 samples (approx. 71%) are collected directly from the river. Only in the areas where the river access is restricted, the samples are collected from the water source nearest to the river. The measured uranium concentrations range from 17.80 µg/L to 41.36 µg/L, having an average 28.37 µg/L. Notably, three out of the seven samples (roughly 43%) represent concentration that exceeds the permissible limit set by WHO, while all the values remain under the AERB prescribed limit[17]. However, the average concentration of uranium i.e. 28.37 µg/L, is under the

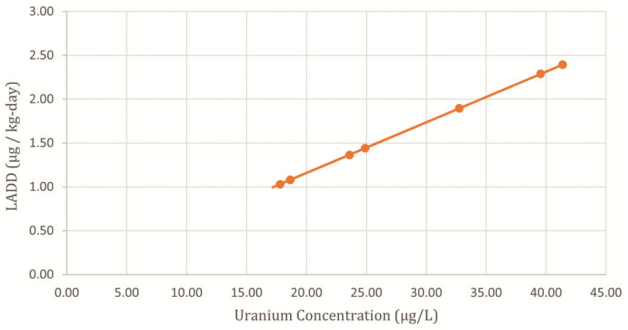


Fig. 5 — Relationship between LADD and Measured concentration

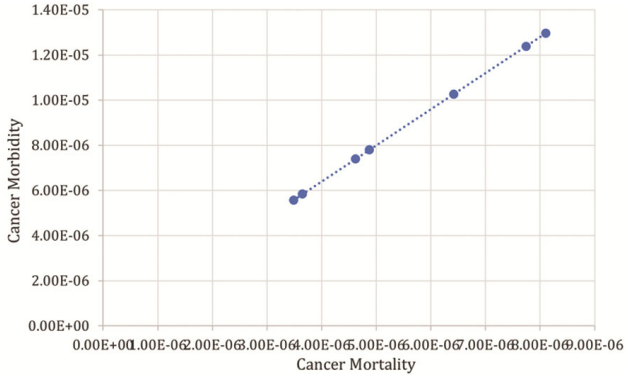


Fig. 6 — Relationship between cancer mortality and morbidity

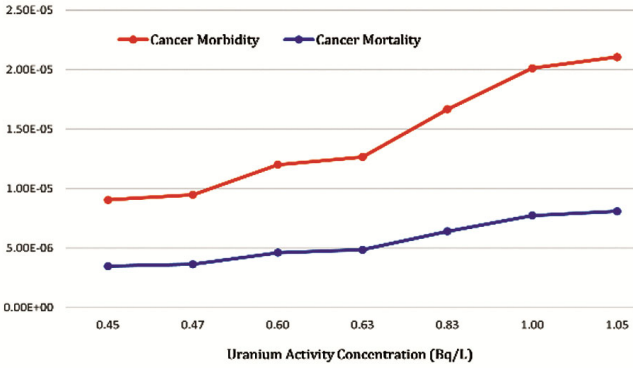


Fig. 7 — Variation of cancer risks with activity concentration

Table 3 — Cancer Excess Risk for different uranium isotopes (March, 2024)

| Sample Code | Uranium Activity Conc. (Bq/L) | CANCER MORTALITY | | | CANCER MORBIDITY | | |
|---|---|---|---|---|---|---|---|
| | | $^{238}U$ | $^{235}U$ | $^{234}U$ | $^{238}U$ | $^{235}U$ | $^{234}U$ |
| RCY 01 | 0.47 | 3.65E-06 | 3.02E-06 | 2.97E-06 | 5.84E-06 | 4.77E-06 | 4.62E-06 |
| RCY 02 | 1.05 | 8.10E-06 | 6.70E-06 | 6.59E-06 | 1.30E-05 | 1.06E-05 | 1.03E-05 |
| RCY 03 | 0.63 | 4.87E-06 | 4.03E-06 | 3.96E-06 | 7.80E-06 | 6.37E-06 | 6.17E-06 |
| RCY 04 | 0.83 | 6.42E-06 | 5.30E-06 | 5.22E-06 | 1.03E-05 | 8.38E-06 | 8.13E-06 |
| RCY 05 | 1.00 | 7.74E-06 | 6.40E-06 | 6.30E-06 | 1.24E-05 | 1.01E-05 | 9.81E-06 |
| RCY 06 | 0.45 | 3.49E-06 | 2.88E-06 | 2.84E-06 | 5.58E-06 | 4.56E-06 | 4.42E-06 |
| RCY 07 | 0.60 | 4.62E-06 | 3.82E-06 | 3.76E-06 | 7.39E-06 | 6.04E-06 | 5.85E-06 |
| Min | 0.45 | 3.49E-06 | 2.88E-06 | 2.84E-06 | 5.58E-06 | 4.56E-06 | 4.42E-06 |
| Average | 0.68 | 5.30E-06 | 4.38E-06 | 4.31E-06 | 8.48E-06 | 6.92E-06 | 6.71E-06 |
| Max | 1.05 | 8.10E-06 | 6.70E-06 | 6.59E-06 | 1.30E-05 | 1.06E-05 | 1.03E-05 |

Table 4 − Uranium retention in different bodily organs (March, 2024)

| Sample code | Uranium conc. (μg/L) | Blood (μg/L) | Skeleton (μg/L) | | | | Kidney (μg/L) | | Liver (μg/L) | OST (μg/L) | Gastrointestinal (GI) Tract (μg/L) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | c_bone_s | c_bone_v | t_bone_s | t_bone_v | retention | concentration | | | st_conc | si_conc | uli_conc | lli_conc |
| RCY 01 | 18.63 | 0.011 | 0.13 | 24.29 | 0.17 | 6.52 | 0.32 | 0.001 | 0.99 | 9.82 | 1.08 | 4.30 | 14.40 | 25.91 |
| RCY 02 | 41.36 | 0.025 | 0.30 | 53.93 | 0.37 | 14.48 | 0.70 | 0.002 | 2.19 | 21.80 | 2.40 | 9.55 | 31.97 | 57.53 |
| RCY 03 | 24.89 | 0.015 | 0.18 | 32.46 | 0.22 | 8.71 | 0.42 | 0.001 | 1.32 | 13.12 | 1.44 | 5.75 | 19.24 | 34.62 |
| RCY 04 | 32.76 | 0.020 | 0.24 | 42.72 | 0.29 | 11.47 | 0.56 | 0.002 | 1.74 | 17.26 | 1.90 | 7.57 | 25.32 | 45.57 |
| RCY 05 | 39.53 | 0.024 | 0.28 | 51.55 | 0.36 | 13.84 | 0.67 | 0.002 | 2.10 | 20.83 | 2.29 | 9.13 | 30.56 | 54.99 |
| RCY 06 | 17.80 | 0.011 | 0.13 | 23.21 | 0.16 | 6.23 | 0.30 | 0.001 | 0.94 | 9.38 | 1.03 | 4.11 | 13.76 | 24.76 |
| RCY 07 | 23.59 | 0.014 | 0.17 | 30.76 | 0.21 | 8.26 | 0.40 | 0.001 | 1.25 | 12.43 | 1.37 | 5.45 | 18.24 | 32.81 |
| Average | 28.37 | 0.017 | 0.20 | 36.99 | 0.26 | 9.93 | 0.48 | 0.002 | 1.50 | 14.95 | 1.65 | 6.55 | 21.93 | 39.46 |

threshold limit of 30 μg/L for WHO and USEPA [15,16]. It is observed that higher uranium levels are detected in areas near the drainage systems and regions with extensive use of phosphate fertilizers for flower plantation, which contribute to the increased uranium concentration. With reference to Table 2, only 2 out of 7 (approx. 28%) LADD values fall below the reference limit ($R_f$) set by WHO. Furthermore, the average LADD (1.64 μg $kg^{-1}$ $day^{-1}$) and the maximum LADD (2.39 μg $kg^{-1}$ $day^{-1}$) levels exceed the reference limit ($R_f$) by 36.6% and 99.1% respectively. The high LADD values indicate a potential impact on residents regarding the chemical toxicity of uranium[17]. The annual effective dose ranges from $3 \times 10^{-5}$ to $6.96 \times 10^{-5}$ μSv/Y, having a mean value of $4.78 \times 10^{-5}$ μSv/Y, which remains under WHO threshold limit of 100 μSv/Y. Since the hazard quotient is the ratio of LADD to its reference value, both LADD and HQ show a comparable relationship throughout the sampled area. Average value for HQ is 1.37, exceeding the threshold value established by AERB[17]. However, WHO indicates that the HQ can range from 0.07 to 2.48. While the HQ for each sample falls beneath WHO thresholds, only 2 of the 7 samples recorded an HQ value below one. According to Table 3, the cancer mortality values for $^{238}U$ range from $3.49 \times 10^{-6}$ to $8.10 \times 10^{-6}$, with an average of $5.30 \times 10^{-6}$ [17]. In terms of cancer morbidity for the same isotope, the values range from $5.58 \times 10^{-6}$ to $1.30 \times 10^{-5}$, averaging at $8.48 \times 10^{-6}$. Importantly, both cancer mortality and morbidity values for the sampled areas are of the order $10^{-5}$ - $10^{-6}$ and are well below the threshold limit recommended by USEPA, which is $10^{-3}$ indicating the low radiologicalrisks[14]. We can imply that; the risk of death and the likelihood of symptoms associated with the ingestion of water collected from these regions are significantly lower. The uranium values in the gastrointestinal tract (GIT), presented in Table 4 range from 1.03 μg/L to 57.53 μg/L. The mean values of migrated uranium in stomach, small intestine, upper large intestine and lower large intestine are 1.65 μg/L, 6.55 μg/L, 21.93 μg/L, and 39.46 μg/L respectively. Uranyl ions in bloodstream binds strongly with RBCs (Red Blood Cells) and plasma proteins before it distributes to various body organs. The concentration in the bloodstream ranges from 0.011 μg/L to 0.025 μg/L, averaging 0.017 μg/L. Uranium through the bloodstream enters the bones and the uranyl ions ($UO_2^{2+}$) form phosphate crystals generating oxidative stress in the bone cells. The evaluated uranium mean values for surface and volume of cortical bone are 0.20 μg/L and 36.99 μg/L respectively. And for trabecular bone the surface value is 0.26 μg/L and the volume value is 9.93 μg/L. According to the hair compartmental biokinetic model, uranium is taken up by Liver 1 from the blood, transported by plasma as uranium complexes, and then transferred to Liver 2[13]. Before the ingestion uranium is transported to different organs, it accumulates in the surrounding tissues. The tissues act as a primary site for accumulation, thus exhibiting higher concentrations[10]. The mean values of uranium retained in liver and tissues are 1.50 μg/L and 14.95 μg/L respectively. In kidneys, uranium accumulates as insoluble materials or as organo-mineral composites. The uranium retention in kidneys is recorded with a mean of 0.48 μg/L. There is no further safe limit for organs, as the WHO determined limit (30 μg/L), applies to all tissues and organs[30]. The average value and 5 out of 7 values of lower large intestine (roughly 71%) is beyond the established WHO limit[14]. A similar trend can be observed for volume of cortical bone.

## 6 Conclusion

Water samples are collected from the Yamuna River in Delhi and are analysed using LED fluorimetry technique. The concentration of uranium in collected samples is determined, along with various radiological and chemical risks. The measured uranium levels in samples range from 17.80 μg/L to 41.36 μg/L, having an average of 28.37 μg/L. This

average value is under established guideline of WHO, USEPA and AERB. However, it falls beyond the guidelines of Health Canada (20 µg/L) and Australian National Health and Medical Research Council (17 µg/L), However, approx. 43% of samples exceed the guideline value of 30 µg/L. While the lifetime cancer excess risks are not significant since the measured values are below permissible limits, most values for LADD (typically 72%) exceed the permissible value of WHO, indicating that the residents in the sampled region may experience non-carcinogenic risks because of the chemical toxicity associated with uranium, with carcinogenic risks remaining insignificant. It is also observed that approx. 71% values of lower large intestine and surface cortical bone are beyond the recommended limit of 30 µg/L. Biokinetic models represent significant retention insoft tissues, cortical volume, and lower large intestine, with intestine values being highest. Fortunately, the annual effective dose due to uranium ingestion remains within the recommended limits. Therefore, we can conclude that while radiological risks are insignificant, chemical toxicity varies across the sampled region.

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