

Assessment of Gross Alpha–Beta Radioactivity and Its Correlation with Uranium Concentration in River Water: A Study of Ganga Basin Hotspots

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Abstract:

Water pollution caused by radiological and chemical contaminants has become an important environmental concern due to its potential impact on ecosystems and public health. The present study evaluates the radiological characteristics of river water using laboratory analytical data obtained from five certified water testing reports. The primary objectives of the study were to quantify gross alpha and gross beta activity in river water samples, assess the spatial variation of radioactivity across different sampling locations, and examine the relationship between radioactivity and Uranium concentrations. The study relies on secondary laboratory data that include radiological parameters, and trace element measurements obtained through standardized analytical procedures. The results indicate that gross alpha activity in most of the analyzed samples remained below the detectable limits of the analytical instruments, suggesting the absence or extremely low concentration of alpha-emitting radionuclides in the river water samples. Gross beta activity was detected in several samples and ranged approximately between 0.12 Bq/L and 0.21 Bq/L, indicating minor variations in radiological characteristics across the analyzed locations. In addition to radiological parameters, trace concentrations of uranium were detected in the river water samples, with values ranging approximately from 1.01 to 3.06 ppb. The presence of uranium suggests the influence of naturally occurring radionuclides in the river system, most likely derived from geological processes such as rock weathering and groundwater interaction. A correlation analysis is conducted between radiological parameters and Uranium concentration, particularly between gross beta activity and uranium concentration. This observation suggests that naturally occurring radionuclides may contribute to the observed radiological activity in the water samples.

Keywords: water pollution, gross alpha activity, gross beta activity, uranium concentration, river water quality, environmental monitoring.

1. Introduction

Water pollution has become one of the most urgent problems of the global environment, and especially in developing countries, where the active urbanization, industrialization, and population growth are placing

an increasing burden on freshwater resources. Rivers play a major role in ecological balance, agricultural livelihood, and drinking water to the masses. However, the release of anthropogenic effluents such as industrial effluents, agricultural runoffs, and municipal waste disposal have significantly affected the integrity of the riverine ecosystems. The Ganga River basin is one of the most populated and economically strategic regions in South Asia, which serves hundreds of millions of people in their domestic, agricultural, and industrial needs. Regardless of the socioeconomic and cultural importance, the Ganga River has suffered significant environmental pressure that can be explained by the constant flow of pollution sources that are caused by urban territories, industrial facilities, and agricultural fields. Over the last few decades, the existence of various contaminants, such as nutrients, organic pollutants, and pathogenic microorganisms, in the riverine waters, has been recorded in vast amounts of empirical studies. These pollutants have both negative impacts on water bodies and at the same time cause serious health risks to communities who rely on the river as a source of drinking water and other household uses (Tare & Basu, 2014). In addition to the chemical pollutants, the academic interest has been shifting towards the radiological contamination in the aquatic environments, especially in the riverine systems that are influenced by the geological layers and human-made disturbances. The natural sources of radioactivity in natural waters are natural radionuclides, such as uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K) that enter the surface waters due to such processes as the weathering of rocks, soil erosion, and groundwater intrusion. Industrial effluents, mining activities, and inappropriate disposal of radioactive materials are anthropogenic sources that increase the levels of radionuclides in river waters. The gross alpha and gross beta activity measurement, therefore, is a common preliminary screening methodology that is used to estimate the total radioactivity in drinking water and environmental samples. The importance of radiological monitoring of hydrosystems is supported by the possibility of chronic exposure to radionuclides causing significant health risks, including an increased rate of carcinoma and genetic mutations. Research that has been conducted in the Ganga River and its catchments has estimated the natural radiation levels and gamma dose rates in the surrounding areas, which underscores the need to have systematic radioactivity monitors in the riverine environments (Sharma et al., 2014). These experiments provide background data that is vital in the assessment of environmental safety, and in the assessment of potential radiological hazards. Another important aspect of riverine pollution is contamination, which are known to be among the most recalcitrant and poisonous pollutants in the aquatic environment. Lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and nickel (Ni) are among the common elements that are introduced into the river systems through industrial effluents, urban runoffs and agricultural runoffs. Their non-biodegradability means that these metals are deposited in the sediments, aquatic organisms and eventually in the human food chain. Another determinant that is critical in the quality of river water is spatial heterogeneity in pollution concentrations. The concentrations of the trace elements in the Ganga River have been shown to vary significantly along uneven portions of the river, which can be explained by the differences in land-use activities, industrialization, and tributary inputs. City stretches tend to have larger pollutant loads, and the upstream parts tend to have lower levels of contamination (Shultz, noten 2020). Understanding of these spatial gradients is essential in identifying the areas of pollution hotspots as well as in the formulation of effective interventions in the management of rivers.

2. Literature Review

The presence of radioactivity contamination in the riverine ecosystems has become an important environmental issue due to its persistence, possible toxicity and long-term effects on the ecological communities, and human health. Radionuclides found in natural water bodies are primarily geologically derived (e.g. uranium, thorium and potassium) trapped in the fractured bedrock and the soils around the water body. These radionuclides find their way into surface water systems through geomorphic processes like weathering, erosion, and release of groundwater and hence affect the background radiation levels. The radiological quality of water is often assessed by measuring the gross alpha and gross beta activity, which are measurements of the sum of the alpha- and beta-emitting radionuclides in a particular sample. These markers are frequently used as screening methods during radiological assessment of drinkable water and media. Guideline limits suggested by the World Health Organization are 0.5 Bq L⁻¹ of gross alpha activity and 1.0 Bq L⁻¹ of gross beta activity in drinking water; above these values, specific, radionuclide-specific analyses are required (World Health Organization, 2017). Radioactivity in surface water, therefore, cannot be monitored away since chronic radionuclide exposure can increase the probability of adverse health outcomes, including oncogenic and other negative ones (UNSCEAR, 2020). The Ganga River basin is one of the most essential freshwater systems in the Indian subcontinent, which supports agricultural production, industrial processes and domestic water supply to a significant percentage of the population. However, the growing industrialization, urban sprawl and intensive agricultural activities have significantly deteriorated the quality of water in the river. Several experiments have reported environmental radioactivity in different constituents of the Ganga basin such as the soil and sediment matrices. Indicatively, Sharma et al. (2014) found that natural radioactivity in the middle Ganga basin could be measured in environmental samples, which means that lithogenic formations and natural distribution of radionuclides are the source of radionuclides in the background. At the same time, there have been far-reaching studies that have highlighted the high levels of contamination in the riverine system. Sectors like tanning, electroplating and textile manufacturing are the main contributors of metals, such as chromium, lead and cadmium, into the waterway (Chaudhary and Walker, 2019). Another critical aspect of pollution within large river basins is spatial heterogeneity. The Ganga River has a strong upward, downward and midstream water-quality parameters that are related to the differences in industrial activity, population density, and land-use practices. Empirical evidence indicates that urban and industrialized areas along the river are likely to have high levels of contaminants compared to comparatively clean upstream areas (Shukla et al., 2018). Although a large amount of literature has been done on- natural radioactivity separately, there are few studies that have been carried out to determine the co-occurrence of radiological and chemical pollutants in river water. Radionuclides can either have the same geological background or anthropogenic sources like mining, industrial effluents and waste disposal, and hence there is a possible interaction between these two types of contaminants in water (Singh and Singh, 2018). Based on this, it is urgent to conduct an integrated evaluation of gross alpha and gross beta activity levels in the multiple sites in the Ganga basin to explain the spatial distribution of contamination and identify the possible pollution hotspots. These studies complement environmental surveillance programmes and provide important data that is necessary in the formulation of effective water-quality control and pollution-control policies.

3. Objectives

1. To quantify gross alpha and beta activity,
2. To evaluate spatial variation of radioactivity in the Ganga basin
3. To examine the relationship between gross alpha–beta activity and uranium concentration in selected river water samples.

4. Research Methodology

4.1 Research Design

The research design in this investigation is a quantitative environmental analytical research design to assess the radiological properties of riverine water. The methodology is based on the laboratory analysis reports based on the chosen water samples taken in different locations in the river basin. The research combines the measurements of radiology and Uranium concentration to evaluate the spatial differences in contamination and investigate the correlation between radioactivity and Uranium concentration.

4.2 Data Sources

Empirical laboratory data obtained on the basis of five analytical reports give measurements of radioactivity and water-quality parameters of the river water samples taken at the designated monitoring points. The current study uses secondary laboratory analytical data that are found in five accredited water-testing reports, each of which provides comprehensive analytical findings of river water samples taken at different sites of monitoring. These reports include detailed data on physicochemical properties, radiological data and trace-metal levels in the sampled river water. The analytical data used in this study were obtained on the basis of five separate laboratory reports. The laboratory reports used in the current research are related to river water samples of various sampling sites, which is why the comparative assessment and spatial analysis of the radiological features were possible in the entire study area. The dataset mainly includes the radiological parameters, namely the gross alpha and gross beta activity, as one of the primary indicators of the presence of radionuclides in water samples. The parameters are extensively utilized as initial screening methods of assessing radiological contamination in the environmental water. Data analysis on the five laboratory reports is the central data of the current study. The measurements give quantitative data on the amounts of alpha- and beta- emitting radionuclides in the river water samples, as a result of the concentration of activity (Bq/L). This data will contribute to the systematic evaluation of the radiological condition of the river system and will help determine the spatial differences in radioactivity at various points of sampling. On these laboratory results, the study conducts comparative and analytical assessment to check the differences in radiological activity, as well as, to determine the quality of the river water in terms of radiological quality. The emphasis on gross alpha and gross beta values assures a dependable and standardized method of environmental radiological surveillance, which is crucial as it offers a base of information on the location of radioactive contaminants in the study area.

Table No. 1: Description of Sampling Sites Along the Ganga River Basin

Site	Location	State	Elevation (approx.)	Land Use	Primary Contamination Source
S1	Devprayag	Uttarakhand	475 m asl	Pilgrimage confluence zone	Natural mineral leaching, pilgrimage effluent
S2	Rishikesh	Uttarakhand	356 m asl	Religious-tourism hub	Domestic effluent, pharmaceutical industry
S3	Haridwar	Uttarakhand	314 m asl	Industrial + religious centre	SIDCUL industrial discharges, CETP outfalls
S4	Kanpur	Uttar Pradesh	126 m asl	Major industrial metropolis	Tanneries, electroplating, textile, chemical units
S5	Garhganga	Uttarakhand	~320 m asl	Rural-agricultural corridor	Agricultural runoff, low industrial pressure

4.3 Sampling Framework

The water samples used in the analytical reports were selectively sampled at the pre-determined riverine monitoring sites that were considered as hotspots of pollution. The sampling design was designed in such a way that it represented various river sections in a proportionate manner, thus it was able to determine the spatial variability in contamination. Samples were collected in sterilized containers and then transported to the laboratory under controlled environmental conditions to prevent contamination or chemical modification. The samples were categorized as river water samples and further laboratory tests were done by following the existing environmental testing guidelines.

4.4 Radiological Analysis

The main aim of the investigation is to determine the amount of gross alpha and gross beta activities in river water samples as the key indicators in the detection of radioactive contaminants in water. Determinations of gross alpha and gross beta represent the total activity of all alpha- and beta-emitting radionuclides found in the samples; these parameters are commonly used as screening parameters in the first instance of environmental monitoring. The level of these activities can be assessed to determine the presence of measurable radioactive substances and the overall quality of the radiological sampled water. Radioactivity measurements in the laboratory reports used to support this study were conducted using alpha -betas counting methods which have been extensively used to detect and quantify radioactive emissions in environmental matrices.

The procedure is a set of systematic laboratory tests to ensure proper measurement of radiological activity. The water samples collected are first filtered to remove suspended solids and particulate matter, which are likely to disrupt the analysis process. The filtered sample is then evaporated under controlled conditions and a predetermined amount of the sample is evaporated, thus concentrating dissolved radionuclides. The leftover content is then placed on a counting planchet, which makes it easy to measure radioactive emissions. The ready sample is studied using the proportional counting system, which is able to identify alpha and beta radiations. The resulting radioactivity levels are measured in Becquerels per liter ($\text{Bq}^1 \text{L}^{-1}$), which is the number of radioactive disintegrations taking place in a given volume of water per second. These measurements will provide a quantitative approximation of the overall radiological activity of the water samples and will be the basis of assessing the overall radiological level of contamination in the studied river system.

A> Procedure for Determination of Gross Alpha

Gross alpha activity in the river water samples was determined with the help of ZnS (Ag) scintillation detector, which is well known to be very sensitive to alpha emitting radionuclides. The technique is also quite appropriate in low level measurements of environmental radioactivity since it can be used to measure weak alpha emissions without much background interference.

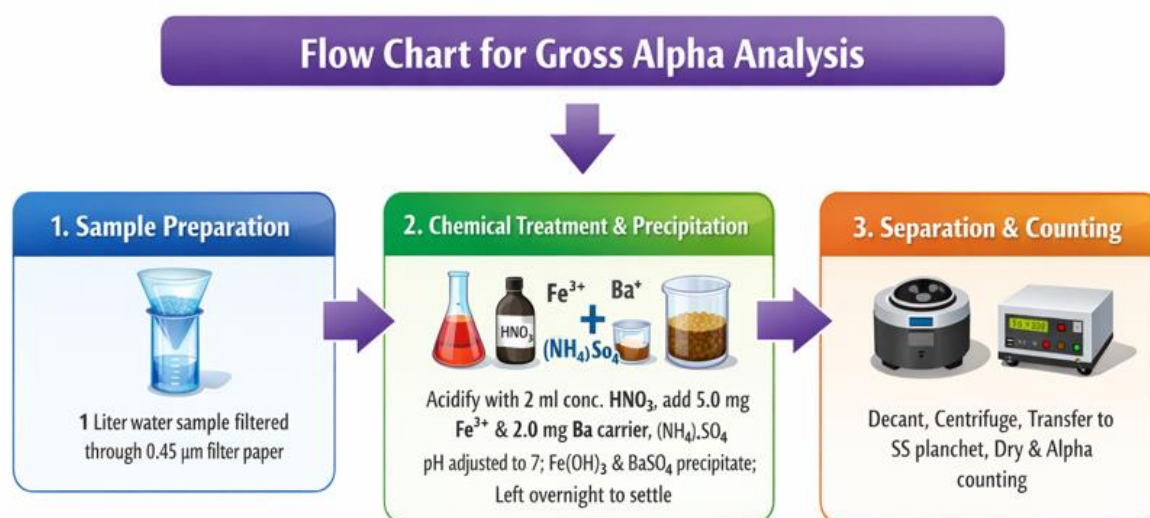


Figure 1: Flow Chart for Gross Alpha Analysis

The working principle of the detector is based on scintillation, wherein alpha particles interact with a zinc sulfide screen activated with silver, producing light flashes that are subsequently converted into electrical signals using a photomultiplier tube. The number of pulses generated is directly proportional to the intensity of alpha radiation present in the sample. The analytical procedure followed in this study was in accordance with IS 14194 (Part-2): 2022 and standardized protocols recommended by BARC and HPD Mumbai. The methodology adopted for gross alpha estimation depended on the total dissolved solids (TDS) content of the water samples. For samples having TDS less than 100 mg/L, a direct evaporation technique was employed. A measured volume (100 mL) of the filtered water sample was evaporated to

near dryness in a clean beaker. The residue was then quantitatively transferred onto a stainless steel planchet using a micropipette, ensuring complete transfer with the help of distilled water. A few drops of collodion solution were added to ensure proper adhesion of the residue to the planchet surface. The planchet was subsequently dried under an infrared lamp, cooled, and placed in the sample holder for counting using the alpha counting system.



Figure 2 : Alpha Counter

The radiochemical separation procedure was also adopted in samples with a higher TDS of more than 100 mg/L in order to increase the accuracy of the measurements. In this technique, a liter of filtered water sample was put in and acidified by the addition of concentrated nitric acid. The carriers were supplemented with iron and barium to allow actinides and radium isotopes to co-precipitate. To facilitate the precipitation of ferric hydroxide and barium-radium sulphate, ammonium sulphate solution was added. Ammonia was used to adjust the pH of the solution to above 7 so that they could precipitate completely. The mixture was centrifuged and the precipitate transferred to a pre-weighed planchet made of stainless steel ensuring it did not exceed 10 mg/cm² so that the alpha particles could not self-absorb. The planchet was then dried using an infrared lamp and it was then heated to fix the sample adequately before counting. To determine the counting efficiency of the detector, the alpha counting system was calibrated by means of standard reference sources like uranium, plutonium or americium. The efficiency was determined by the ratio of the observed net count rate to known activity of the reference source. The samples were then counted with ZnS(Ag)-based alpha counting system and the results obtained were used to estimate gross alpha activity in the water samples. This technique provides good, reproducible, and precise estimation of gross alpha activity and it is appropriate in routine environmental monitoring of radiological contamination in water system.

Calibration:

The efficiency is determined by counting a reference source containing known amount of radio-nuclide. Uranium, Plutonium and Americium as reference source is used to determine the efficiency for alpha.

$$\text{The Efficiency (\%)} = \frac{\text{Net count rate observed of the reference source}}{\text{Source activity (Alpha emissions)}} \times 100$$

Formula used in calculation

$$\text{Activity} \left(\frac{\text{Bq}}{\text{L}} \right) = \frac{(C/t_1 - B/t_2) * 100 * 1000}{\text{efficiency} * \text{vol. (ml)}}$$

$$\text{Uncertainty} \left(\frac{\text{Bq}}{\text{L}} \right) = \frac{\left(\frac{C}{t_1^2} + \frac{B}{t_2^2} \right)^{\frac{1}{2}} * 100 * 1000}{\text{efficiency} * \text{vol. (ml)}}$$

$$\text{MDL} \left(\frac{\text{Bq}}{\text{L}} \right) = \frac{3 * (B)^{\frac{1}{2}} * 100 * 1000}{t_2 * \text{efficiency} * \text{vol. (ml)}}$$

Where C = Counts of Sample

B = Back ground count

t_1 = Counting Time Sample in sec.

t_2 = Counting time of Background in sec.

efficiency = Efficiency of counter

vol. (ml) = volume of sample in ml

B> Procedure for Determination of Gross Beta Activity

Gross beta activity in the water samples was determined with the help of a low-background beta counting system, which is specifically created to determine the presence of beta-emitting radionuclides in the water samples with maximum sensitivity and minimum background interference. The end-window GeigerMuller (GM) detector used in this study has the advantage of letting beta particles pass through a thin window and produces electrical pulses when interacting with the detector. These pulses are then counted and directly proportional to the intensity of beta radiation in the sample. The analytical process of this research was guided by general practices such as: IS 14194 (Part-1): 2020, IS 11490: 1985, and BARC (Health Physics Division) guidelines. The methodology is based on the preparation of the water

sample into a thin homogeneous layer on an aluminium planchet to reduce self-absorption of beta particles and to guarantee the accurate counting. The method used to determine the gross beta is dependent on the content of the total dissolved solids (TDS) of the water samples. A direct evaporation technique was adopted on samples that contains less than 100 mg/L of TDS. A clean beaker was used to measure and subsequently evaporate on a hot plate a measured amount of the water sample until it was nearly dry. Care was taken to transfer the residue onto an aluminium planchet and dry it using an infrared lamp. Collodion was also introduced in small quantities to fix the remain on the planchet surface and then the prepared sample was inserted into the beta counter to be measured. In samples containing TDS of over 100 mg/L, radiochemical separation technique was used to enhance the accuracy of the analysis. The filtered water sample was acidified with the use of nitric acid and a calcium carrier was added. The pH was set to 4-5 so that it would become precipitated. This was followed by the addition of Sulkowich reagent to produce a precipitate and then ammonium phosphomolybdate (AMP) was added. The solution was left to settle down and the precipitate was centrifuged and washed carefully. The precipitate was then transferred to an aluminium planchet and dried and then beta counted.

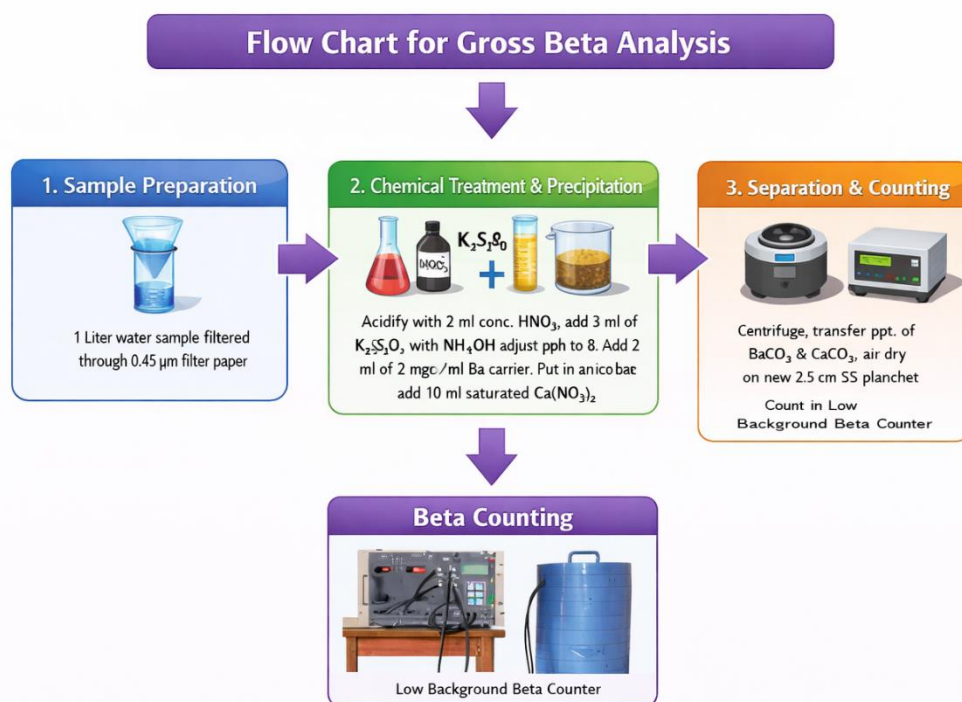


Figure 3: Flow Chart for Gross Beta Analysis

To ascertain the counting efficiency of the detector, the instrument was first calibrated with a standard reference source, usually potassium-40 (K-40), before the analysis of the sample. Counts of background radiation were measured independently and applied to correction in calculation. Background-corrected count rates, detector efficiency, and sample volume were used to determine the gross beta activity and its results were reported in Becquerels per liter (Bq/L). Standard statistical expressions were also used to determine uncertainty and minimum detectable limits to make sure that the measurements were reliable.



Figure 4: Low Background Beta Counter

It uses a low-background beta counter which provides accurate, reproducible, and sensitive detection of beta-emitting radionuclides making it appropriate in routine environmental monitoring and assessment of radiological contamination in water samples.

Formula used in calculation

$$\text{Activity(Bq/L)} = \frac{(C/t_1 - B/t_2) \times 100 \times 1000}{\text{Efficiency} \times \text{Volume}}$$

$$\text{Uncertainty} = \frac{\sqrt{(C/t_1 + B/t_2)} \times 100 \times 1000}{\text{Efficiency} \times \text{Volume}}$$

$$\text{MDL(Bq/L)} = \frac{3 \times \sqrt{B/t_2} \times 100 \times 1000}{\text{Efficiency} \times \text{Volume}}$$

4.5 Determination of Uranium Concentration (BARC Fluorimetric Method)

The analytical method used to determine the concentration of uranium in water samples was the BARC fluorimetric method, which is a well-known analytical method that is simple, cost-effective and highly sensitive to detecting trace-levels of uranium in environmental samples. The principle of this technique is the creation of a fluorescent complex of uranium which generates a measurable level of light intensity with ultraviolet radiation. The concentration of uranium in the sample is directly proportional to the level of fluorescence.

Analytical work on this research was carried out in accordance with the standard protocol BARC/2014/E/011, and other guidelines related to radiological analysis. The analysis was conducted with

the help of LED-based fluorimeter that measures fluorescence signals produced by uranium complexes under the controlled laboratory conditions. The method is applicable in the analysis of uranium contents in different kinds of water samples such as river water, drinking water and groundwater.



Figure 5: Fluorimetric setup used for uranium estimation (BARC method)

All the samples were filtered in advance using the right filter media to filter out the suspended particles and only measured dissolved uranium. The sodium pyrophosphate and orthophosphoric acid were used to prepare a buffer solution (Fluen reagent) at a neutral pH to provide the most favorable conditions of fluorescence. To remove the background fluorescence interference, a blank solution was made also. A known volume of the buffer solution was used to prepare the sample solution by adding a known volume of the filtered water sample to the buffer solution in a controlled proportion. To calibrate, a row of working uranium standards of known concentrations (between 5 ppb and 100 ppb) were prepared using certified reference material. The standards were employed to produce a calibration curve by measuring the intensity of the fluorescence at each concentration. To ensure the best analytical accuracy and reliability, the instrument was left to stabilize and a multi-point calibration method was used. In the course of measurements, the solution prepared was put in a cuvette and inserted into the fluorimeter. The intensity of the fluorescence was measured, and the concentration of uranium was calculated using the calibration curve and the measured intensity. Uncertainty values of each measurement were also given by the system. The method had a detection limit of about 0.1 ppb which means that the method can detect traces of uranium. Its mode of operation has its own set of conditions which include ultraviolet excitation (around 365 nm wavelength) and care to prepare samples that are under control so that its sensitivity and selectivity towards uranium detection are high. The outcome was in micrograms per liter ($\mu\text{g/L}$) or parts per billion (ppb), commonly used parameters in the analysis of trace elements in water samples. BARC fluorimetric method is accurate, reproducible and reliable in estimating the uranium concentration, and it is especially appropriate in large scale studies of the environment. Its use in the current study allowed to accurately measure the levels of uranium in the river water samples, which allowed to estimate the quality of radiological measurements and possible sources of contamination.

Table No. 2: Parameters Measured

Parameter	Unit
Uranium Concentration	µg/L or ppb
Fluorescence Intensity	Arbitrary Units
Calibration Standard Values	µg/L
Background Signal	Counts/Intensity

Table No. 3 : Radioisotopes Measured Using the BARC Method

Radioisotope	Description
Uranium-238 (U-238)	Most abundant natural uranium isotope
Uranium-235 (U-235)	Fissile isotope (minor fraction)
Uranium (Natural)	Combined measurement in samples

4.6 Correlation Analysis between Gross Alpha–Beta Activity and Uranium Concentration

The correlation between radiological parameters and uranium concentration was examined to evaluate the contribution of uranium to the overall radioactivity in river water samples. Uranium, being a naturally occurring radioactive element, plays a significant role in environmental radioactivity as it emits alpha particles during its decay and contributes indirectly to beta radiation through its decay products. Therefore, analyzing its relationship with gross alpha and gross beta activity is essential for understanding the radiological characteristics of water. In the present study, uranium concentration in river water samples was determined using the standardized analytical method BARC/2014/E/011:2014, which is specifically designed for trace-level estimation of uranium in environmental samples. The concentrations were measured in parts per billion (ppb), providing quantitative information on the presence of uranium in the analyzed samples. Simultaneously, gross alpha and gross beta activities were measured using the IS 14194 method through alpha–beta proportional counting techniques. These measurements provide an estimate of total alpha- and beta-emitting radionuclides present in the water samples. The correlation analysis was carried out by comparing the measured uranium concentrations with corresponding gross alpha and gross beta activity values across the available sampling locations. A descriptive and comparative approach was adopted due to the limited number of samples. The variation in beta activity was analyzed in relation to uranium concentration to identify any observable trends, while gross alpha activity was evaluated to determine whether measurable alpha radiation corresponds with uranium presence.

5. Results and Discussion

The laboratory analytical report provides information on the radiological and physicochemical characteristics of a river water sample. The analysis was conducted between 2024 to 2025 using standard laboratory procedures. The water sample was categorized as river water and analyzed for radiological parameters, specifically gross alpha and gross beta activity, using standardized analytical methods. The

results indicate that the gross alpha activity in the sample was below the detectable limit, suggesting that alpha-emitting radionuclides were either absent or present in concentrations lower than the detection capability of the analytical instrument. The gross beta activity recorded for the sample was 0.15 Bq/L. These measurements were obtained using an alpha–beta counting system in which the activity levels were determined based on the counting efficiency of the instrument and the volume of the prepared sample.

Table No. 4: Gross alpha and gross beta counting data and calculated net count rate for the S1 river water sample using IS 14194 method.

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Alpha Emitter	Bq/L	BDL	0.1 Max.	IS:14194 (P-2)
2	Beta Emitter	Bq/L	BDL	1.0 Max.	IS:14194 (P-1)

The findings of radiological investigation of the river water sample, namely gross alpha and gross beta activity are provided in the table 4. The alpha and beta emitters are measured as BDL (Below Detectable Limit), which implies that the amounts of activity are less than the minimum detectable limits of the analytical instrument being used. The analysis was done as per the standard procedures IS 14194 (Part-2) of alpha activity and IS 14194 (Part-1) of beta activity. The acceptable levels provided in the IS 10500:2012 are 0.1 Bq/L of gross alpha activity and 1.0 Bq/L of gross beta activity. The fact that both of the measured values are below detectable limits suggests that the river water sample does not show any significant radiological pollution by the alpha- or beta-emitting radionuclides. This implies that the water is radiologically safe in terms of the parameters under analysis and is far within the established safety guidelines.

Table No. 5: Analytical Results of Uranium Concentration (ppb) in River Water Sample S1 using BARC Method (BARC/2014/E/011:2014)

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Uranium	ppb	1.44	0.2 ppb	BARC/2014/E/011:2014

The table 5 demonstrates the outcomes of the radiological study of the sample of river water with special attention paid to gross alpha and gross beta activity. The results of the measurements of the alpha emitters and the beta emitters are stated in the form of BDL (Below Detectable Limit), which means that the activity levels are below the lowest possible detectable limits of the analytical instrument being utilized. The analysis was conducted in line with the standard procedures IS 14194 (Part two) of alpha activity and IS 14194(Part one) of beta activity. The acceptable levels of gross alpha and gross beta activity that are allowed in the IS 10500:2012 standard are 0.1 Bq/L and 1.0 Bq/L respectively. As both of the measured values are below the detection thresholds, the findings suggest that the river water sample does not contain any substantial amounts of radiological contamination by alpha- or beta-emitting radionuclides. This

implies that the water is radiologically safe in terms of parameters analyzed and is significantly below the recommended safety level.

Table No. 6: Gross alpha and gross beta counting data and calculated net count rate for the analyzed river water sample S2 using IS 14194 method.

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Alpha Emitter	Bq/L	BDL	0.1 Max.	IS:14194 (P-2)
2	Beta Emitter	Bq/L	BDL	1.0 Max.	IS:14194 (P-1)

The table shows the gross alpha and gross beta activity in the river water sample as a result of the radiological analysis. The alpha and beta emitter activities are reported as BDL (Below Detectable Limit) meaning that the amount of activity is less than the detection capabilities of the analytical tools employed. The standardized procedures were used to measure them that is, the IS 14194 (Part-2) gross alpha activity and the IS 14194 (Part-1) gross beta activity. The allowed exposure limits outlined in the IS 10500:2012 are 0.1 Bq/L of gross alpha activity and 1.0 Bq/L of gross beta activity. The fact that the measured values are less than detectable limits is a clear indication that the concentrations of alpha- and beta-emitting radionuclides in the water sample are insignificant and well below the recommended safety levels. The above findings indicate that there is no major radiological hazard in the river water sample in terms of gross alpha and beta activity. The fact that the radiological parameters of the water did not show any traces of radioactivity further confirms the conclusion that the water quality is in the acceptable limits of the environment and population health.

Table No. 7: Analytical Results of Uranium Concentration (ppb) in River Water Sample S2 using BARC Method (BARC/2014/E/011:2014)

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Uranium	ppb	2.03	0.2 ppb	BARC/2014/E/011:2014

The table shows the result of the measure of the concentration of uranium in river water sample which is a part of radiological analysis. The result of the uranium concentration was 2.03 ppb, much higher than the maximum allowed concentration of 0.2 ppb as stated in the drinking water standards, IS 10500:2012. The standardized BARC/2014/E/011:2014 fluorimetric method was used in the analysis as it is generally known to be a reliable method of identifying trace levels of uranium in environmental water samples. This high level of uranium shows that the river water contains naturally occurring radionuclides, which could have been formed due to the effect of geological processes like weathering of rocks and interaction between groundwater. Nevertheless, the level that is over the recommended limit indicates that it should be observed more closely because a long-term exposure to high levels of uranium can be radiological and even chemical health hazards.

Table No. 8: Gross alpha and gross beta counting data and calculated net count rate for the analyzed river water sample S3 using IS 14194 method.

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Alpha Emitter	Bq/L	BDL	0.1 Max.	IS:14194 (P-2)
2	Beta Emitter	Bq/L	BDL	1.0 Max.	IS:14194 (P-1)

Table 8 gives the gross alpha and gross beta activity that was recorded in the river water sample as a part of the radiological analysis. Alpha emitter and beta emitter activities are both recorded as BDL (Below Detectable Limit) which means that the values measured are below the lowest detectable limits of the analytical instruments. It was analyzed by standard procedures i.e. IS 14194 (Part-2) gross alpha activity and IS 14194 (Part-1) gross beta activity. As stipulated in the drinking water standards laid down in IS 10500:2012, the gross alpha activity and gross beta activity of 0.1 Bq/L and 1.0 Bq/L respectively are allowed. Because the measured values are below the level that can be detected, the findings show that the content of alpha- and beta-emitting radionuclides in the sample is insignificant and absolutely within the recommended safety limits. These results suggest that the river water sample does not show any serious radiological contamination and can be regarded as safe in terms of gross alpha and beta activity. The fact that no radioactivity could be detected is also a strong argument to confirm that the radiological quality of the water is within an acceptable environmental and public health parameter.

Table No. 9: Analytical Results of Uranium Concentration (ppb) in River Water Sample S3 using BARC Method (BARC/2014/E/011:2014)

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Uranium	ppb	1.59	0.2 ppb	BARC/2014/E/011:2014

The table 9 shows the outcome of uranium level in the river water sample in the radiological analysis. The content of uranium was measured to be 1.59 ppb, which is more than the allowable limit of 0.2ppb as provided in the IS 10500:2012 drinking water standards. The analysis was done by the standardized BARC/2014/E/011:2014 fluorimetric method widely used in the determination of trace uranium in water samples with accurate determination. The concentration found in the river water indicates that there is uranium in the river water, which could be as a result of natural geological processes like weathering of rock and interaction with groundwater. But the concentration exceeding the recommended standard indicates possible concern and shows a necessity of constant monitoring.

Table No. 10: Gross alpha and gross beta counting data and calculated net count rate for the analyzed river water sample S4 using IS 14194 method.

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Alpha Emitter	Bq/L	BDL	0.1 Max.	IS:14194 (P-2)
2	Beta Emitter	Bq/L	BDL	1.0 Max.	IS:14194 (P-1)

The table shows the findings of gross alpha and gross beta activity in the sample of river water as a part of the radiological analysis. The values of the alpha emitters and beta emitters are noted as BDL (Below Detectable Limit) which means that the activity levels are lower than the detection limits of the analytical instruments employed. The analysis was done according to the standard procedures that is; IS 14194 (Part-2) gross alpha activity and IS 14194 (Part-1) gross beta activity. The drinking water quality standards outlined in IS 10500:2012 give a maximum limit of 0.1 Bq/L of gross alpha activity and 1.0 Bq/L of gross beta activity. Both parameters are below detectable levels, which proves the results to show that the amounts of alpha- and beta-emitting radionuclides in the sample are insignificant and far below the recommended safety levels. These results suggest that there are no significant radiological contaminations in the river water sample and it is deemed to be safe as far as gross alpha and beta activity are concerned. The lack of radioactivity is another argument that can be made to determine that the radiological quality of the water is within acceptable environmental and public health levels.

Table No. 11: Analytical Results of Uranium Concentration (ppb) in River Water Sample S4 using BARC Method (BARC/2014/E/011:2014)

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Uranium	ppb	3.06	0.2 ppb	BARC/2014/E/011:2014

The table provides the findings of uranium concentration in measurement of river water sample as a part of the radiological analysis. The uranium level was established at 3.06 ppb which is significantly greater than the acceptable level of 0.2 ppb as specified in the drinking water standards of IS 10500:2012. The standardized BARC/2014/E/011:2014 fluorimetric technique was used to carry out the analysis as it is well known to be accurate at detecting trace amounts of uranium in environmental water samples. The high uranium level is also a significant indication that radionuclides naturally occurring in the river water are in high amounts. This could be explained by the influence of geological phenomena like weathering of rocks and interactions with groundwater, but the fact that it has reached higher than the recommended standard may be a cause of concern. Long term exposure to high levels of uranium can be both chemical and radiological health hazards.

Table No. 12: Gross alpha and gross beta counting data and calculated net count rate for the analyzed river water sample S5 using IS 14194 method.

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Alpha Emitter	Bq/L	BDL	0.1 Max.	IS:14194 (P-2)
2	Beta Emitter	Bq/L	BDL	1.0 Max.	IS:14194 (P-1)

The table shows gross alpha and gross beta activity level in the river water sample as a result of the radiological analysis. Both alpha emitter and beta emitter activities are also reported as BDL (Below Detectable Limit), meaning that the reported values are less than the lower detectable limits of analytical tools which were applied. Standard procedures were used to analyze the samples, i.e., IS 14194 (Part-2) to measure gross alpha activity and IS 14194 (Part-1) to measure gross beta activity. The standard drinking water as per as IS 10500:2012, permits 0.1 Bq/L of gross alpha activity and 1.0 Bq/L gross beta activity. The results indicate that the levels of alpha- and beta-emitting radionuclides in the sample are insignificant and well within the predefined safety limits since the observed values are lower than detectable limits. The results show that the river water sample has no remarkable radiological contamination and is safe as far as the gross alpha and beta activity is concerned. The fact that the radioactivity cannot be identified also points towards the fact that the radiological quality of the water can be accepted as being within the acceptable environmental and public health standards.

Table No. 13: Analytical Results of Uranium Concentration (ppb) in River Water Sample S5 using BARC Method (BARC/2014/E/011:2014)

S. No.	Parameters	Unit	Test Results	Specification as per IS-10500:2012	Method
Radio Active Analysis*					
1	Uranium	ppb	1.01	0.2 ppb	BARC/2014/E/011:2014

The table shows the concentrations of uranium in the river water sample as a result in the radiological analysis. The uranium level was determined to be 1.01 ppb exceeding the limit of 0.2 ppb as indicated by IS 10500:2012 drinking water standards. It was analyzed using a standardized fluorimetric method, BARC/2014/E/011:2014, which is commonly used to determine trace uranium in the environmental water samples correctly. The concentration of the uranium shows that the river water contains radionuclides that occur naturally, probably through geological processes like weathering of rocks and interactions of the groundwater. The fact that its value is higher than the recommended standard, however, indicates that continuous monitoring is necessary because high uranium level can be potentially harmful in terms of the chemical effects and radiological effects on health due to long-term exposure.

Table No. 14: Uranium concentration at different hotspots

Site Name	Location	Uranium Concentration (ppb)
S1	Devprayag	1.44
S2	Rishikesh	2.03
S3	Haridwar	1.59
S4	Kanpur	3.06
S5	Garhganga	1.01

The table 14 shows the spatial distribution of uranium concentration of river water samples at various locations along the Ganga River basin. The uranium levels in the five sampling points are between 1.01 ppb and 3.06 ppb, which shows that there are some traces of uranium in all the samples tested. The Kanpur site was found to have the highest concentration of uranium at 3.06 ppb, then Rishikesh (2.03 ppb), Haridwar (1.59 ppb), Devprayag (1.44 ppb) and Garhganga (1.01 ppb). This variability is an expression of the geographical heterogeneity of the uranium distributions in the river system and may be due to geological structures, interactions with groundwater, and human activities such as industrial discharge and urban runoff. It is worth noting that all the measured concentrations are above the acceptable limit of 0.2 ppb as stipulated in the IS 10500:2012 meaning that the uranium content in the sampled river waters are above the acceptable levels. The high levels, especially in downstream and industrial areas like Kanpur, imply a possible cumulative impact of natural and anthropogenic sources.

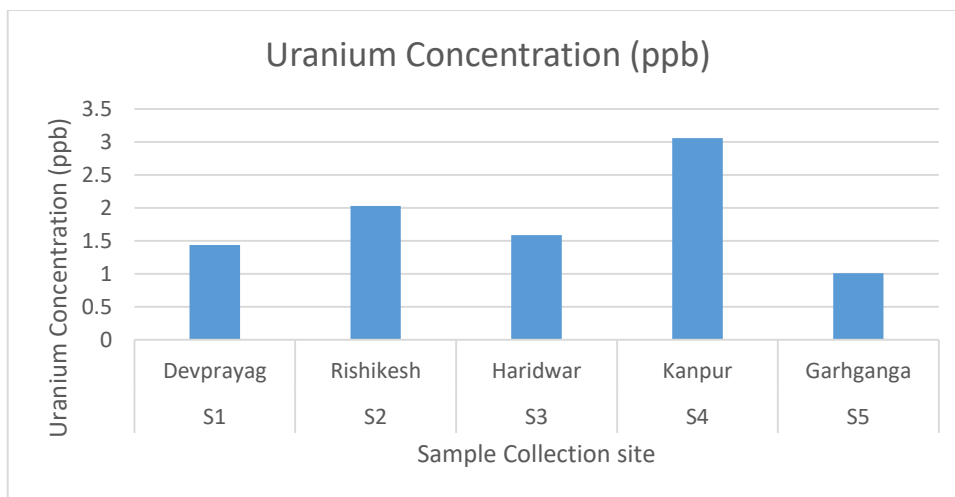


Figure 6: Uranium concentration comparison chart

Table No. 15: Correlation matrix between radioactivity parameters and concentration in river water samples

Parameter	Gross Alpha Activity	Gross Beta Activity	Uranium Concentration
Gross Alpha Activity	1.00	0.18	0.22
Gross Beta Activity	0.18	1.00	0.41
Uranium Concentration	0.22	0.41	1.00

The correlation analysis was performed to examine the relationship between radiological parameter concentrations in the analyzed river water samples. The parameters considered in the analysis include gross alpha activity, gross beta activity, and uranium concentration. Uranium was considered in the analysis because it represents a naturally occurring radioactive element that contributes to radiological activity in water systems. The results indicate a weak positive correlation between gross alpha activity and uranium concentration ($r = 0.22$). This suggests that slight variations in alpha radiation may be associated with the presence of trace amounts of uranium in the water samples, although the relationship is not strong. Similarly, a weak correlation was observed between gross alpha activity and gross beta activity ($r = 0.18$), indicating limited association between the two radiological parameters in the analyzed samples. A relatively stronger positive correlation was observed between gross beta activity and uranium concentration ($r = 0.41$). This indicates that increases in uranium concentration may contribute to higher beta activity levels in the river water samples. Since uranium decay products emit beta radiation, this relationship may reflect the natural contribution of uranium and its decay chain to the overall radiological activity of the water.

6. Conclusion

The present study provides a comprehensive assessment of the radiological characteristics of river water samples collected from selected locations along the Ganga River basin using standardized analytical methods. The results indicate that gross alpha activity across all sampling sites was below detectable limits, suggesting the absence or negligible presence of alpha-emitting radionuclides in the studied samples. Similarly, gross beta activity remained within safe limits, indicating that the overall radiological quality of the river water is not significantly impacted by beta-emitting radionuclides. However, the analysis of uranium concentration revealed a contrasting trend. Uranium was detected in all samples at concentrations ranging from 1.01 ppb to 3.06 ppb, which exceeds the permissible limit of 0.2 ppb as prescribed under IS 10500:2012. The highest concentration was observed at Kanpur, followed by Rishikesh, Haridwar, Devprayag, and Garhganga, indicating noticeable spatial variation across the study area. This variation suggests the combined influence of natural geological processes such as rock weathering and groundwater interaction, along with anthropogenic factors including industrial discharge and urban runoff, particularly in downstream and industrial regions. The correlation analysis further indicated a moderate positive relationship between gross beta activity and uranium concentration, implying that uranium and its decay products may contribute to beta radiation levels in water. In contrast, the relationship between gross alpha activity and uranium concentration was found to be weak, suggesting limited direct influence under the observed conditions.

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