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Radio-Isotopic Contamination and Environmental Health Risks in the Ghaggar River Basin, Northwestern India

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Abstract
The accumulation of radio-isotopes in aquatic and terrestrial ecosystems has emerged as a pressing global concern, particularly in densely populated and industrially active regions. This study investigates the spatial distribution and ecological consequences of radionuclides in soils of the Ghaggar River basin, a trans boundary river system that sustains agriculture and human settlements in north-western India. Soil samples collected from multiple sites were analyzed using high-resolution gamma spectrometry to determine activity concentrations of Uranium-238 (U-238), Thorium-232 (Th-232), Potassium-40 (K-40), and Cesium-137 (Cs-137). Results revealed marked spatial variability, with industrial zones exhibiting elevated concentrations of U-238 and Th-232, while urban settlements showed localized Cs-137 enrichment-indicative of anthropogenic inputs. Potassium-40 remained relatively uniform, reflecting natural lithological control. The findings highlight dual contamination pathways: natural geogenic enrichment and human-induced pollution, including waste mismanagement and potential fallout contributions. The persistence of such isotopes in soils presents long-term health risks through groundwater contamination, crop uptake, and chronic exposure pathways. This research underscores the urgent need for systematic monitoring, public health risk assessments, and policy interventions aimed at sustainable management of the Ghaggar basin.

Keywords: Radio-isotopes, environmental health, gamma spectrometry, Ghaggar River, soil contamination, anthropogenic impact.

1.0 Introduction

Uranium (U) is a radioactive heavy metal extensively distributed in the Earth's crust. It is commonly present in soils, rocks, and natural waters, with its concentration influenced by both geogenic and anthropogenic activities, including phosphate fertilizer usage, mining, and industrial discharges. Uranium exists in multiple oxidation states, with hexavalent uranium (U(VI)) being the most mobile and toxic form in groundwater environments. Chronic uranium exposure, particularly through contaminated drinking water, may result in severe health impacts, including renal dysfunction and skeletal accumulation. Regulatory bodies such as the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have established maximum contaminant levels (MCL) for uranium in drinking water at 30 µg/L. In India, the AERB permits a slightly higher limit of 60 µg/L. This study assesses uranium concentration levels in the Ghaggar River and evaluates their potential implications for public health. Radioactive isotopes, due to their ability to emit ionizing radiation, pose significant ecological and human health challenges. Natural radionuclides such as U-238, Th-232, and K-40 are widely distributed in soils, rocks, and groundwater, but their mobilization and accumulation can be amplified by anthropogenic activities, including mining, fertilizer use, and industrial discharge. Anthropogenic isotopes such as Cs-137-typically associated with nuclear fallout and medical or industrial waste-add another dimension to environmental contamination (IAEA, 2014; Musa, 2019).

The Ghaggar River, originating in the Shivalik Hills and traversing through Himachal Pradesh, Haryana, Punjab, and Rajasthan, serves as a critical freshwater source for agriculture, domestic supply, and industry. However, the basin has witnessed escalating pollution linked to rapid industrialization and unregulated effluent disposal (Thakur *et al.*, 2010). Previous studies have reported uranium

contamination in groundwater of Punjab and adjoining states, raising concerns of nephrotoxicity, skeletal damage, and carcinogenic risks (Patra *et al*., 2013; Ramesh *et al*., 2021). Despite increasing awareness, systematic research on the isotopic composition of Ghaggar basin soils remains limited. The present study addresses this gap by quantifying isotopic concentrations in soils, mapping their spatial distribution, and evaluating implications for public health and agriculture.

1.1 Materials and Methods

1.1.1 Study Area

The research covered selected sites across Haryana and Punjab, focusing on zones near industrial clusters, agricultural fields, and urban settlements. The Ghaggar basin spans diverse geomorphological and climatic settings, with annual rainfall ranging from 200 mm in arid regions to over 1500 mm in sub-humid zones. Sampling sites were selected based on proximity to known pollution hotspots, including industrial estates, urban settlements, and agricultural zones. The Ghaggar River originates in the Shivalik Hills of Himachal Pradesh and flows through the states of Haryana, Punjab, and Rajasthan before dissipating into the Thar Desert. The basin lies between latitudes 30°45′5.93″N to 29°11′49.29″N and longitudes 76°54′36.79″E to 73°13′26.88″E. Key sampling locations include Dugshai, Panchkula, Devigarh, Mandvi, Sardulgarh, and the Ottu Barrage. The region exhibits a diverse climate, with temperature extremes ranging from below 1°C in winter to 47°C in summer. Annual rainfall varies significantly from 200 mm to over 1500 mm across the region.

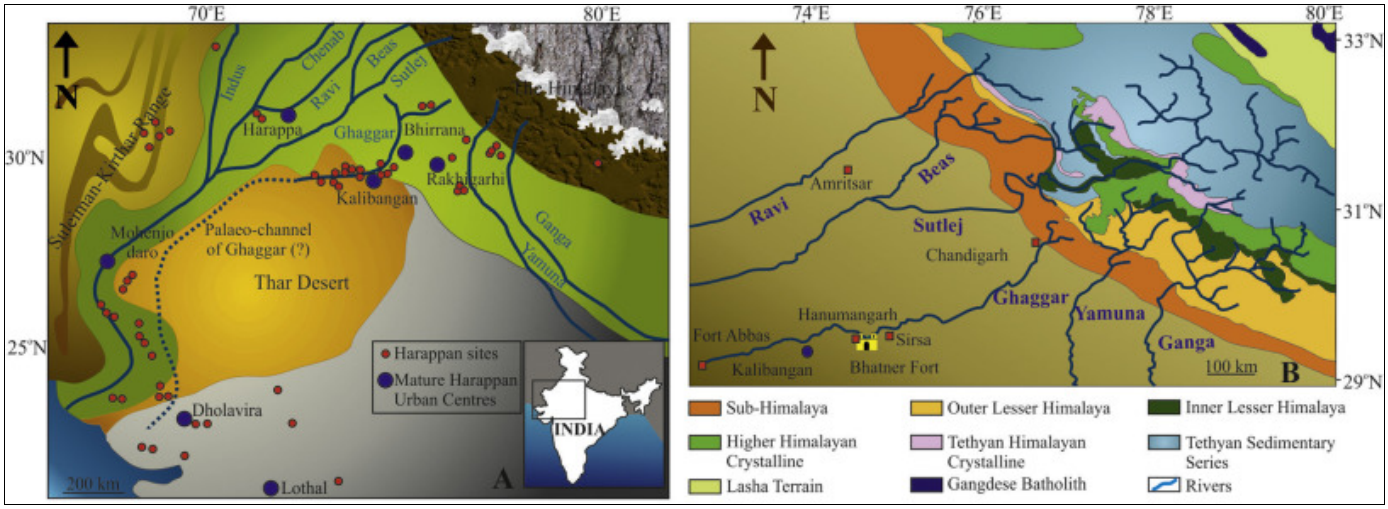

Fig 1: Ghaggar River in Haryana (Chatterjee, A., *et al*. (2018))

1.1.2 Sample Collection

Ten soil samples were collected from distinct locations at a depth of 0-15 cm using a stainless-steel auger to avoid cross-contamination. Samples were air-dried, homogenized, and passed through a 2 mm sieve before analysis. The samples were collected from the surface water of the Ghaggar River in pre-cleaned oxyethylene bottles and geographical picture is given below

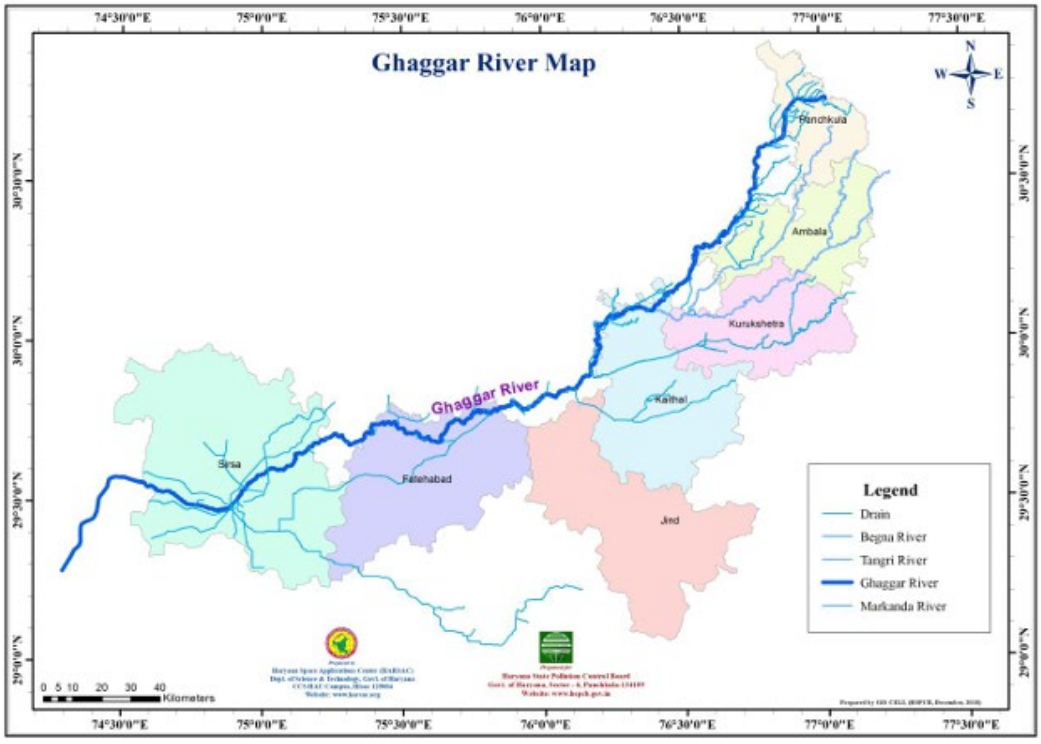

Fig 2: Ghaggar River in Haryana

1.1.3 Analytical Techniques

High-Purity Germanium (HPGe) detectors were employed for gamma spectrometric analysis. Standard Marinelli geometry was used for each sample, with a counting time of 24 hours. Isotopes of interest included U-238, Th-232, K-40, and Cs-137. Activity concentrations were reported in becquerels per kilogram (Bq/kg).

1.2 Results

1.2.1 Activity Concentrations

i) U-238: 25–75 Bq/kg (mean: 49.3 Bq/kg)
ii) Th-232: 20–65 Bq/kg (mean: 43.6 Bq/kg)
iii) K-40: 200–600 Bq/kg (mean: 398.4 Bq/kg)
iv) Cs-137: 1–10 Bq/kg (mean: 4.8 Bq/kg)

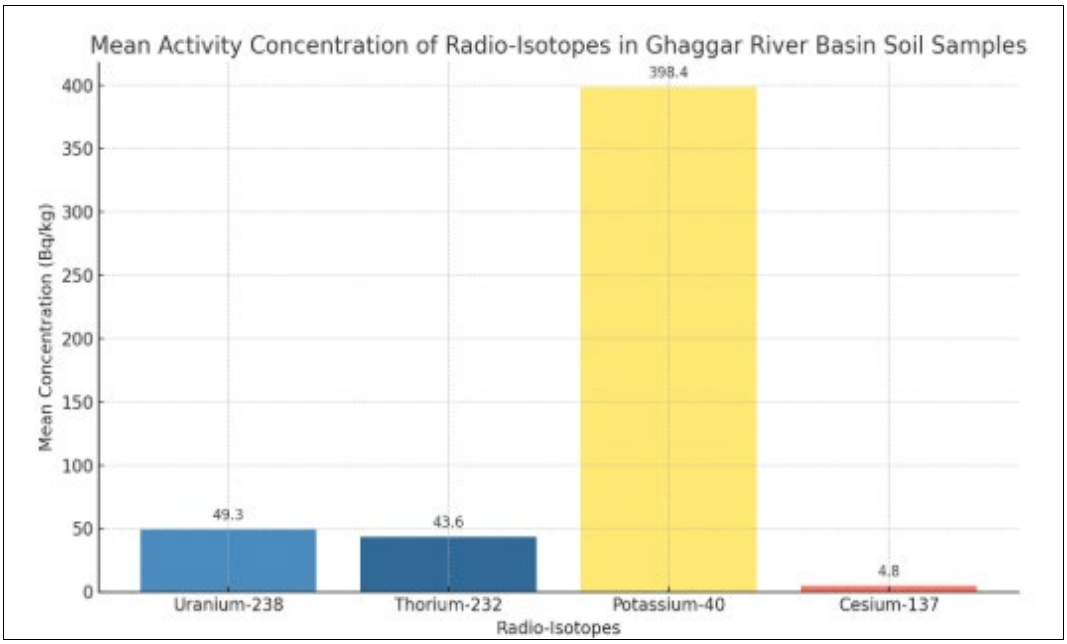

Fig 3: the bar chart showing the mean activity concentration of each radio-isotope in the Ghaggar River basin soil samples

1.2.2 Spatial Distribution

Mapping of data points using GIS tools showed:

i) Industrial zones (Sirsa, Hisar) displayed elevated U-238 and Th-232.
ii) K-40 distribution remained uniform, reflecting mineralogical origins.
iii) Cs-137 hotspots were localized near urban settlements, suggesting anthropogenic sources such as fallout deposition or improper disposal of radioactive waste.

1.3 Discussion

The study confirms dual origins of isotopic contamination:

i) Geogenic enrichment due to regional lithology and natural weathering, and
ii) Anthropogenic pollution arising from waste discharges, fertilizer residues, and possible nuclear fallout.

While naturally occurring isotopes contribute to baseline radioactivity, anthropogenic isotopes such as Cs-137 are of particular concern due to their persistence and bioavailability. Prolonged exposure through groundwater and food chains may contribute to renal toxicity, reproductive disorders, and increased cancer risk (UNSCEAR, 2000; Canton, 2021). Agricultural soils irrigated with contaminated river water further risk bioaccumulation of radionuclides in food crops, exacerbating chronic exposure pathways.

The spatial heterogeneity observed suggests that mitigation strategies must be site-specific, with priority given to industrial and urban hotspots.

Conclusion

This investigation demonstrates that the Ghaggar River basin exhibits significant spatial variation in radio-isotopic contamination, with natural radionuclides (U-238, Th-232, K-40) dominating the baseline and anthropogenic Cs-137 marking localized pollution. The findings call for:

1. **Comprehensive Monitoring:** Routine isotopic surveillance of soils, sediments, and groundwater using GIS-integrated mapping.
2. **Health Risk Assessment:** Longitudinal epidemiological studies on communities exposed to elevated uranium and cesium levels.
3. **Policy Interventions:** Enforcement of industrial discharge regulations and remediation of radioactive hotspots.
4. **Public Engagement:** Awareness programs to educate local populations about radiation risks and safe agricultural practices.
5. **Future Research:** Bioaccumulation studies in staple crops and livestock, alongside modeling of radionuclide transport pathways.

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