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Bangalorians are Vulnerable to Carcinogenic Cancer Due to Higher ^{222}Rn and ^{238}UConcentrations in Groundwater-A Case Study

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ABSTRACT
The discover presents the results of ^{222}Rn and ^{238}U concentration measurements in the groundwater (bore and open wells) and surface water (lake). The investigations were carried out using Rad-7 detectors and ICPMS. Samples of groundwater from the urban nucleus (Hebbal and Challaghatta) of the of Bangalore city were studied. The results are compared with international recommendations and the values are found to be tremendously higher than the recommended value of 10.3 Bq/l for ^{222}Rn and 15µg/l for ^{238}U. The analysis showed a higher correlation between the concentration of ^{222}Rn and ^{238}U in water and observed difference between the ^{222}Rn and ^{238}U is significant at 5% level. The geogenic origin of the ^{222}Rn and ^{238}U in the water is inferred and consequently Bangalorians at some locations are vulnerable to carcinogenic health risk.

Keywords: Bangalore, Ground and Surface water, Carcinogenic Cancer, Radon and Uranium.

INTRODUCTION

Bangalore, the capital of Karnataka state, spans over a geographical area of 2,174 Km^2 is blessed with uneven landscape with intermingling hills and valleys. The prominent ridges run parallel towards NNE-SSW direction. The particular physiographic setting of gentle slopes and valleys on either side of this ridge hold better prospects of groundwater utilization and harvesting. The low lying areas are marked by a series of tanks and small ponds.

Bangalore city supports a contemporary population density of approximately 20000 per km^2. A significant shift in the land use from agricultural to residential occurred over the 1920's. Coincident with this trend there has been a rise in industrial and commercial/institutional land uses. City experienced rapid industrial growth during the latter half of the 70's. Use of urban groundwater from the open and bore wells declined at the beginning of 80's because of the implementation of river Cauvery drinking water scheme in part of the city. Nevertheless, intensive abstraction of groundwater for both domestic as well as industrial use continued and reached a peak in the early 1990s.

Uranium is the naturally occurring heaviest element and its average concentration is 0.0003% in the earth crust and 3.0 µg/l in sea water (Bleise *et al.,* 2003). On the other hand natural Uranium by mass of isotope proportion is 99.3% for ^{238}U; 0.7% for ^{235}U and 0.005% for ^{234}U. The radioactive ratios for $^{235}U/^{238}U$ and $^{234}U/^{238}U$ are 0.46 and 0.05% with performance specific activities respectively (Table 1) (UNSCEAR, 1982).

Study Area

The Drainage System

The granitic ridge running from NNE to SSE governs the drainage pattern of Bangalore North. Towards east, the drainage is made up of a network of canals generally flowing from west to east with storage tanks along the canals, ultimately feeding the South Pinakini River.

In the west also the drainage pattern includes a network of canals generally flowing westwards with storage tanks, ultimately feeding the Arakavathy River. Also the Bangalore south drain towards east, into the Pinakini basin and to the west into the Arakavathy basin (Jiban Singh *et al.,* 2012). The Vrishabhavathy is a minor river within the city marked with a series of tanks (Fig. 1a).

Geo-Hydrological Nature

Geologically the western portion of Bangalore is composed of gneissic granites belonging to Precambrian age. They are exposed as a continuous chain of mounds raising 90-150m above the ground on the western portion constituting the Bannerghatta groups of hills. Inclusions of quartz and pegmatite also occur here and there (Fig. 1b). Hydro-geologically western portion shows groundwater occurrence under water table in the weathered mantle of the granite gneisses and joints, cracks and crevices of basement rocks (Fig. 1c). Generally, the water table fluctuation in open and bore wells of Challaghatta valley are high around Domlur and Ulsoor Lake respectively, which are the major recharge areas of groundwater. The depth of water table is dependent upon the rate of weathering and topographic factors. Chief source of groundwater is infiltration and recharge by rainwater. Considering the climatic water balance, soil characteristics account for nearly 70% allowing only 20% rainfall being added to groundwater pool. Percolation and recharges in the groundwater account for 10% discharge through wells (Jiban Singh *et al.,* 2012).

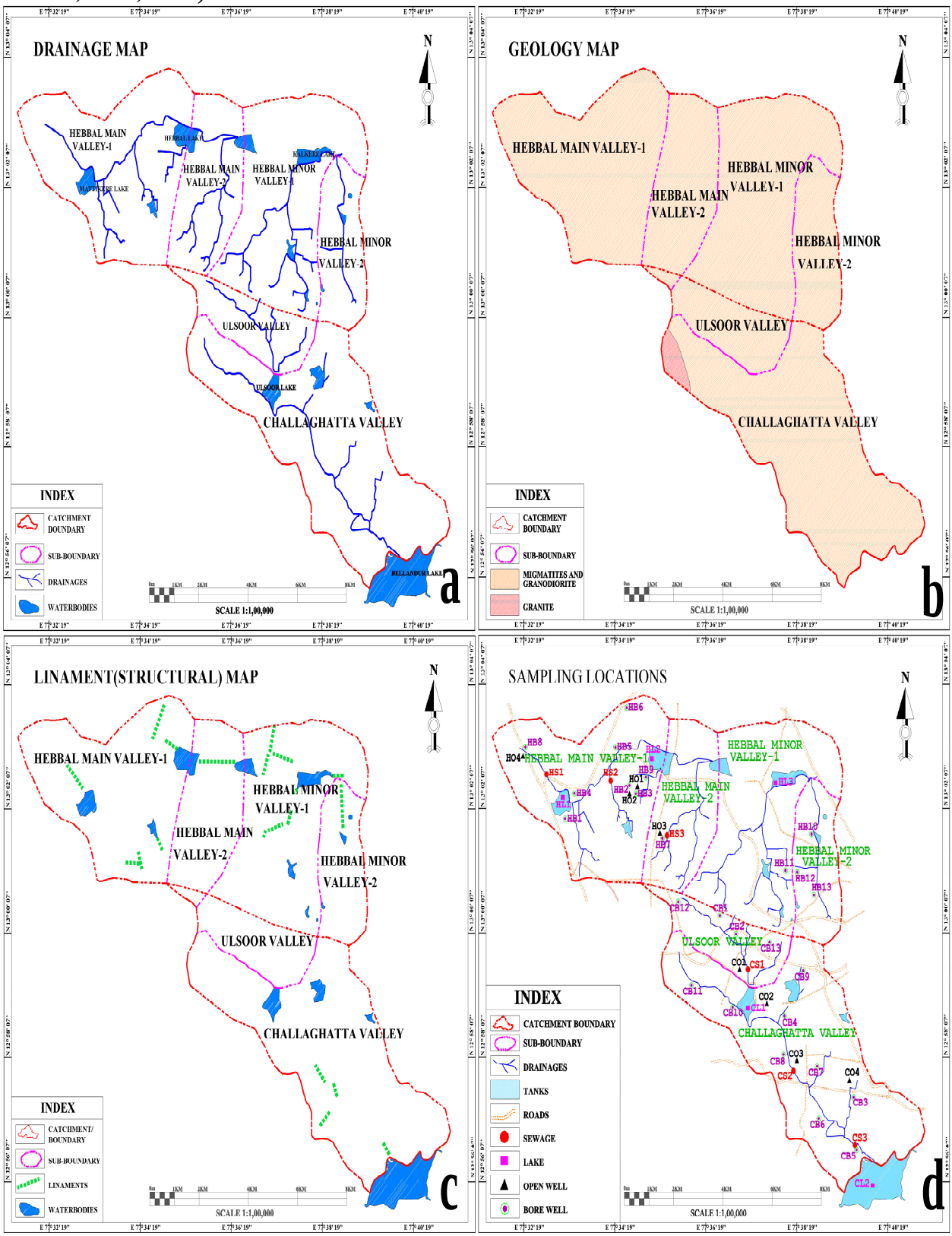
MATERIALS AND METHOD

Sampling and Estimation of Radon (^{222}Rn) and Uranium (^{238}U)

Samples from various locations of the city were collected (40 ml and 250 ml bottles) after purging the well through pumping to ensure sample quality (Fig. 1d). ^{222}Rn monitor (RAD-7) used has a high electric field above a silicon semi conductor detector at ground potential to attract the positively charged polonium daughters, $^{218}Po^{+}$ ($t_{1/2}$=3.1 min; alpha energy =6.00 MeV) and $^{214}Po^{+}$ ($t_{1/2}$= 164 µs; alpha energy =7.67MeV), which are counted as a measure of ^{222}Rn concentration in air. The ions are collected in energy specific windows which eliminate interference and maintain very low backgrounds. A specially fabricated built in aerating system is used to bubble water sample to set free ^{222}Rn in water.

Radon gas is collected through the energy specific windows and counted for the ^{222}Rn concentration. The time elapsed for the sample collection and analysis is corrected with the $\mathbf{C=C_0e^{-\lambda t}}$, where C= measured concentration, C_0= initial concentration (to be calculate) after the decay correction, t= time elapsed since collection (days). ^{222}Rn activities are expressed in Bq/m^3 (disintegration per second per m^3) with 2 σ uncertainties. The $^{234}U/^{238}U$ is linked to redox evolution in groundwater because of Uranium high solubility and long half-life that allows dating of

groundwater that are tens to hundreds and thousands years old (Ivanovich and Harmon, 1992 and Bourdon, *et al.*, 2003).



Figures 1: a. Sewerage Network; b. Geology; c. Lineament variations and d. Sampling location of Hebbal and Challaghatta, Bangalore.

The decay of ^{238}U produce two short-lived nuclide daughters (^{234}Th and ^{234}Pa) making ^{234}U the flames in solid lattices ^{234}U is bound less tightly than ^{238}U. In the U^{6+} state it is more easily dissolved.

As a result there is a wide range of $^{234}U/^{238}U$ activity ratios between 0.5 and 40 in sediments and rocks and, consequently groundwater uranium concentrations range between 0.1 and 25 ppb a long–lived daughter to accumulate in this decay series respectively (Dillon *et al.*, 1991).
Leaching of uranium from the rocks of the aquifer increases the $^{234}U/^{238}U$ activity ratio.

Samples were collected in 100 ml plastic bottles with cap of inner seal type, filtered and acidified to pH<2 with concentrated HNO_3, labeled and transported to laboratory for analysis. The concentration of ^{238}U was measured using "Laser Flurimetrer" and cross checked with ICPMS (Mass Spectrometer) at Analytical Chemistry Division, BARC, Mumbai.

Statistics Analysis

To examine the interaction between "seasons and types of water" and between "seasons and different valleys", two-way classification model with interaction effects for each of the five variables is attempted. The model is given by,

$$y_{ijk} = \mu + \alpha_i + \beta_j + \lambda_{ij} + \varepsilon_{ijk}$$

i = 1, 2,…, c; j = 1, 2,…, r and k = 1, 2,…, m, c = 3 and r = 3.

a) $y_{ijk:}$ the k^{th} observation associated with the i^{th} level of season and j^{th} level of type of water (or valley);
b) μ: common mean to all the observations;
a) α_i: effect of the i^{th} level of season;
b) β_j: effect of j^{th} level of type of water (or valley);
c) λ_{ij}: the interaction effect of i^{th} level of season with j^{th} level of type of water (or valley);
d) ε_{ijk}: random error associated with y_{ijk}.

The analysis show that $\varepsilon_{Ijk's}$ are independent and identically distributed as normal with mean zero and variance σ^2

$$\text{i.e., } \varepsilon_{ijk} \sim N(0, \sigma 2)$$

The hypothesis for testing the interaction effects is.

a) H_{01}: The main effect of season is equal to zero; i.e., $\alpha_1=\alpha_2=\ldots=\alpha_c=0$
b) H_{11}: At least one α_i is different from zero;
c) H_{02}: The main effect of type of water (or valley) is equal to zero; i.e., $\beta_1=\beta_2=\ldots=\beta_r=0$
d) H_{12}: At least one β_j is different from zero;
e) H_{03}: The interaction is zero; i.e., $\lambda_{ij}=0$;
f) H_{13}: At least one λ_{ij} is different from zero.

Health Risk

An Internationally prescribed radioactivity exposure limit is one msv/year. Radiological effects owing to ingestion of dissolved ^{222}Rn in drinking water are defined in terms of effective radiation dose received by the population during habitual consumption of water. The annual effective dose to an individual consumer due to intake of radon from drinking water is evaluated using the relationship (Alam *et al.*,1999);

$$DW = CwCRwDcw$$

Where, Dw is the annual effective dose (Sv/y) due to ingestion of radionuclide from the consumption of water, Cw is the concentration of ^{222}Rn in the ingested drinking water (Bq/l), CRw

is the annual intake of drinking water (L/y) and Dcw is the ingested dose conversion factor for ^{222}Rn (Sv/Bq). For calculation of effective dose, a dose conversion factor of 5 x 10^{-9} Sv/Bq suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has been used. Annual effective dose due to intake of ^{222}Rn from drinking water has been calculated considering that an adult (Age > 18y), on average, takes 730L water annually (Cevik *et al.*, 2006). Following ingestion of ^{222}Rn dissolved in drinking water, mean effective doses per liter (nSv/l) and annual effective doses (µSv/y) were calculated.

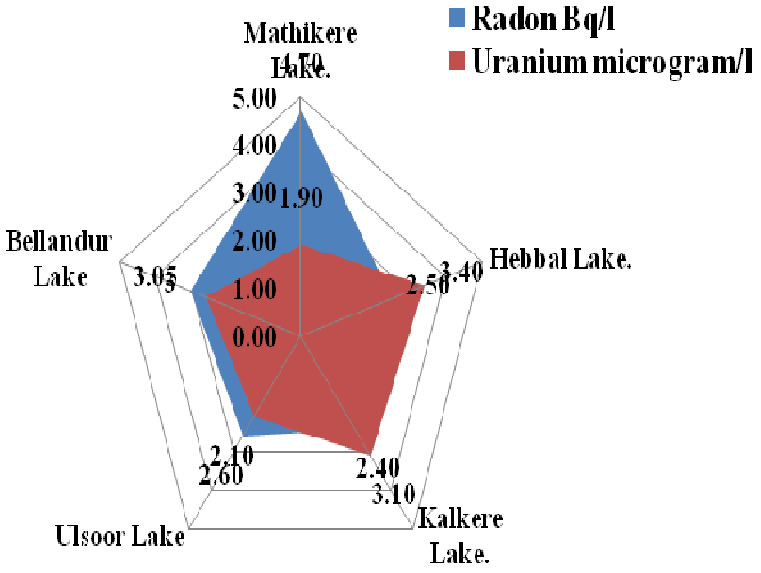


Figure 2: Rader diagram of ^{222}Rn and ^{238}U concentration in Lakes.

UNSCEAR (1988) reported the "average doses from radon in drinking water to be as low as 0.025mSv/year via inhalation and 0.002mSv/year from ingestion" compared with the inhalation dose of 1.1mSv/year from ^{222}Rn and its decay products in air. A study conducted in USA estimates that 12% of lung cancer deaths are linked to ^{222}Rn (Grans, 1985) in indoor air. Erlandsson *et al.*, (2001) estimated approximately 100 fold smaller risk from exposure to ^{222}Rn in drinking-water. The recent works assessed that the risk of stomach cancer caused by drinking-water containing dissolved ^{222}Rn is extremely small compared to lung cancer in the cold countries.

RESULTS AND DISCUSSION

Radon (^{222}Rn) and Thoron (^{220}Rn) are the chains of noble gases produced by the decay of their immediate parent nuclides, Uranium and Thorium. Radon is a chemically inert gas formed through the radioactive decay of ^{226}Ra with a half-life of 3.82 days. Radon decay products are divided into two groups; the short lived ^{222}Rn daughters ^{218}Po (A; 3.05 m), ^{214}Pb (B; 26.8 m); ^{214}Bi (C; 19.7 m) and ^{214}Po (C; 164 µs) with effective half lives ~30min and long lived ^{222}Rn decay product, ^{210}Pb ($T_{1/2}$ = 22years). Because of their short half-lives the ^{222}Rn daughters rapidly approach radioactive equilibrium with their ^{222}Rn parent. Most important radionuclide in this chain is lead isotope ^{212}Pb with half life of 10.6 hours. These daughter products of ^{222}Rn get attached to the aerosol particles in the atmosphere and their elimination from the atmosphere occurs either by radioactive decay or by other removal processes and surface deposition as washout by rain. ^{222}Rn is soluble in water under very high pressure, but is extremely volatile and is readily released from water. Its solubility however, decreases rapidly with increase in temperature (510, 230 and 169 cm^3/kg at 0°C, 20°C and 30°C, respectively) (NCRP, 1988).

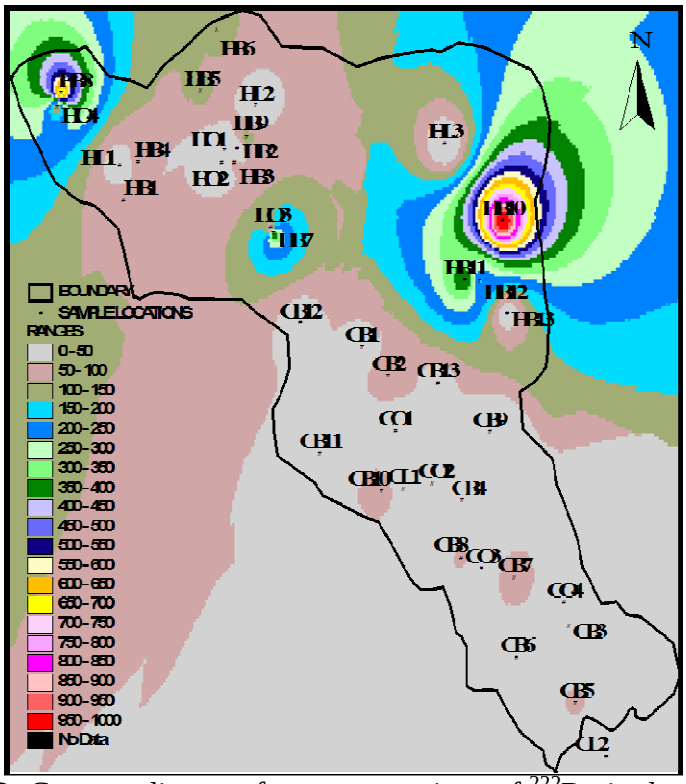


Figure 3: Contour diagram for concentrations of ^{222}Rn in the study area.

Although most of the ^{222}Rn produced in soil from radium is retained in the earth, where it decays, a small portion diffuses into the pore spaces and hence into the atmosphere. One square meter of typical soil contains 0.03 Bq/g radium and it releases between 1,000 and 2,000 Bq/g of ^{222}Rn to the atmosphere each day (UNSCEAR, 1988). Other sources of ^{222}Rn include groundwater that passes through radium-bearing rocks and soils, traditional building materials such as wallboard and concrete blocks, uranium tailings, coal residues and fossil fuel combustion. ^{222}Rn is the major source of naturally occurring radiation exposure to humans. Exposure occurs via the ingestion of ^{222}Rn dissolved in water and the inhalation of airborne ^{222}Rn. Water drawn from surface supplies do not generally contain appreciable levels of ^{222}Rn and is expected to be in the order of 10 Bq/m^3 (UNSCEAR, 1988).

Uranium and Radium are present in varying amounts in all rocks and soils, but in groundwater Uranium is present in dissolved and particulate form due to minerals such as Uranite, Pitchblende and Cornalite or as secondary minerals in the form of complex oxides of silicates, phosphates, vanadates, lignite and monazite sands etc (Mahesh *et al.,* 2001).

A survey of Canadian groundwater sources reported elevated levels of ^{222}Rn in the range of 1.7 to 13.7 Bq/m^3 in Halifax County, Nova Scotia (McGregor and Gourgon, 1980). Another survey detected 3 Bq/m^3 ^{222}Rn in well water in Harvey, New Brunswick, with 80% of the wells containing ^{222}Rn below 740 Bq/m^3 (McBride and Davies, 1981). Hess *et al.,* (1985) estimated geometric mean of ^{222}Rn in public water supplies, public groundwater supplies and private wells as 2.5, 4.8 and 34 Bq/m^3 respectively in USA. Analysis of groundwater in New Jersey, showed values ranging from <3 to ~600 Bq/l with median concentration of 51.4 Bq/l and <400 Bq/l. The dissolved ^{222}Rn was inversely related to dissolved gross α-particles or with ^{238}U concentrations.

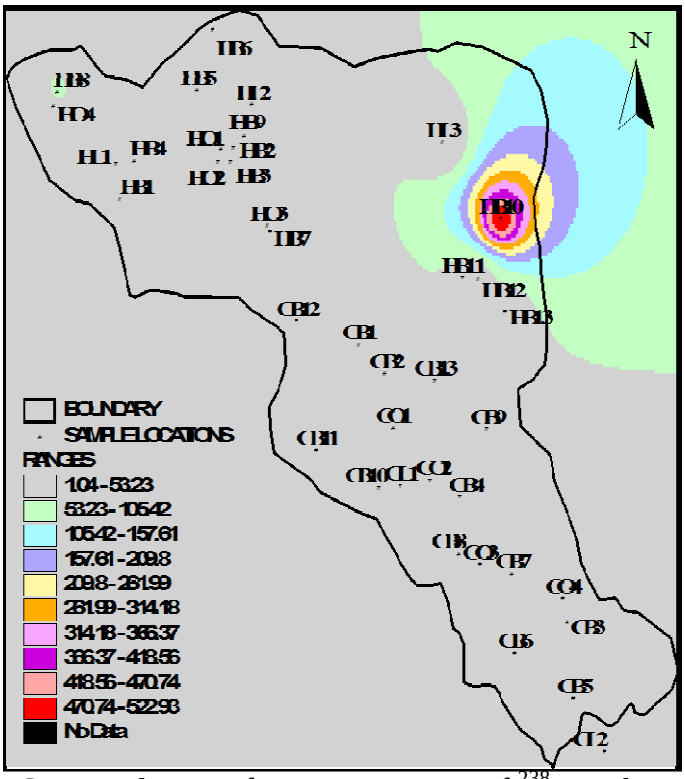


Figure 4: Contour diagram for concentrations of ^{238}U in the study area.

The concentrations of both ^{238}U and ^{226}Ra vary with changes in groundwater chemistry, but those of ^{222}Rn did not. Thus, the concentrations of ^{222}Rn are not controlled by the geochemical composition of the groundwater, but by the ^{238}U and ^{226}Ra content of the rock and the physical characteristics of the aquifers.

Table 1: Individuality of Uranium in natural Uranium.

Uranium Series	*Half life in years*	*Ratio in %*	*Specific activities in Bq/g*
^{238}U	4.47×10^9	99.3	12,455
^{235}U	7.04×10^8	0.7	80,011
^{234}U	2.46×10^5	0.005	231×10^6

The dissolved ^{222}Rn concentration in the drinking water of Dehradun city has been found to vary from 27 to 154 Bq/l in hand pumps and; from 26 to 129 Bq/l among tube wells (Ramola *et al.*, 1999). The Uranium concentrations in groundwater and drinking water of Kolar and Chikkamagalore districts ranged from 0.3 to 1442.9 and 0.2 to 27.9µg/l respectively (Manjunath, 2002 and Sridhar *et al.*, 2008). Krishnaswami *et al.*, (1982) reported the ^{222}Rn at an average concentration about 40 Bq/m^3 in groundwater. Relatively higher concentration of ^{222}Rn (25 to 29 Bq/l) were reported by Chubey *et al.*, (2003) for groundwater from quaternary alluvial gravels associated with Uranium rich sediments in the Doon valley of the outer Himalayas. Further, even in North-Eastern states (Assam, Meghalaya, Tripura, Nagaland, Arunachan parades, Mizoram and Manipur), Virk, (2002) reported the minimum and maximum dissolved ^{222}Rn in potable spring water to vary from 0.1 to 441.2 Bq/l. Recently, Nagaiah *et al.*, (2001) reported 121 Bq/l of ^{222}Rn from Bangalore City, whereas Somashekar *et al.*, (2010) reported the highest average dissolved ^{222}Rn concentrations in surface water as 1.45 and lowest as 0.213 Bq/l, while in the groundwater the dissolved ^{222}Rn concentrations varied from 55.69 to 1000 Bq/l.

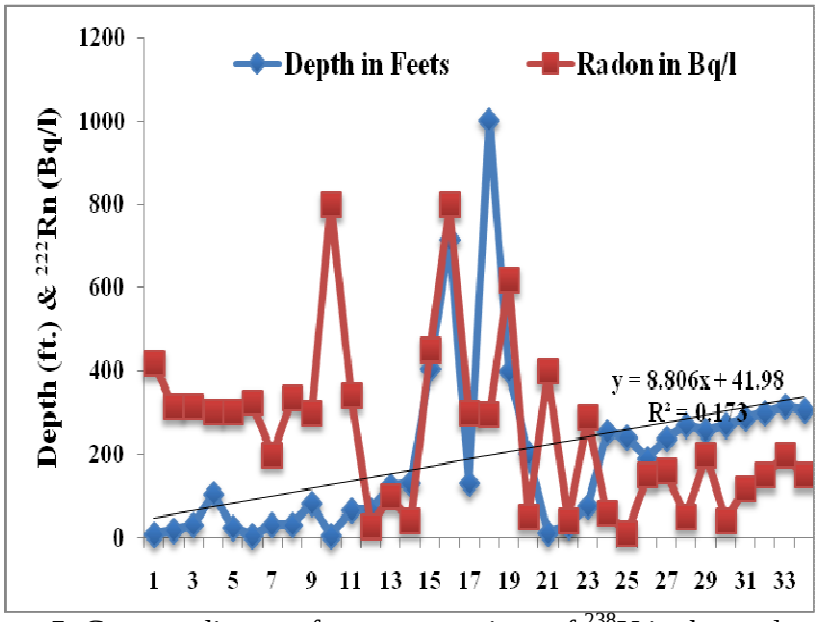


Figure 5: Contour diagram for concentrations of ^{238}U in the study area.

In the study area, the dissolved ^{222}Rn and ^{238}U concentrations in surface and groundwater varied from 2.4 to 4.7 Bq/l; 1.9 to 3.4 µg/l and 6 to 1000.22 Bq/l; 1 to 523 µg/l respectively (Figs. 3 & 4). The highest dissolved ^{222}Rn and ^{238}U concentrations in surface water are from Mathikere (4.7 Bq/l) and Hebbal Lakes (3.4 µg/l) (Fig. 2). In the groundwater the highest and lowest concentrations of both the radioactive isotopes is the same in a locations like Kalyannagar and RMS 2nd stage. The overall ^{222}Rn concentration in the groundwater of Hebbal and Challaghatta valleys among 91% of samples is found to be beyond the permissible limits (11.1 Bq/l). This included locations like M. S. Ramaiyanagar, Gokul, Kerena Layout, Campus of Madras Engineering battalion of Indian Army, Domlur 2nd stage, Krishna Reddy Layout, Bellandur Lake, Devinagar 2nd cross, Ganganagar, HMT Layout, Anandanagar, Sindy Colony, K. S. Gardens, Domlur, 11th stage, Muthyalnagar, RMS 2nd stage, Devinagar 1st cross, SBM Colony, Mathikere, Divandra palya, GKBK-agriculture Collage, Kalyannagar, Chalkere 1st cross, Pillanna garden 3rd stage, Batanary Road, Frazer town, Murgesh palya, Indiranagar, Tenment 2nd stage, Kempapur, Marathahalli, Karnataka Course, 100ft. Road, Krishnamurthynagara, Dickinson Road, Shivajinagara, Near Jayamahal Road and Jeevanahalli, which might be due to changes in geological regime or exposure of younger granitic rocks associated with high abstraction of groundwater (Figs. 3 & 4). Alternately, 91% of ^{238}U concentrations are below the permissible limits (15 µg/l) except in locations like HMT layout, Anandanagar and Kalyannagar that supports the geogenic origin of ^{222}Rn in groundwater (Figs. 1b & c) (Torgersen *et al.*, 1992).

The depth of well's varied between a lowest of 14 ft. and a highest of 800 ft. and the deep wells showed much higher ^{222}Rn concentrations as against the shallow wells and surface water. The ^{222}Rn concentrations vs. corresponding depth confirm that the ^{222}Rn activity is almost a function of depth (Fig. 5) with higher activities at deeper depths with some exceptions as observed by Torgersen *et al.*, (1992). This may be due to the presence of younger granites and weaker structures like fractures and linaments (Figs. 1b & c). The ^{238}U concentrations are self-regulating from depth, but not the ^{222}Rn concentrations in the two valleys. Consequently Bangalorians at some locations are vulnerable to health risk because of higher ^{222}Rn concentration in groundwater.

Test of Significance (t-Test) Between ^{222}Rn and ^{238}U

Test of significance is important in accepting the validity of conclusions derived from a set of data. Significance here does not mean "important" or "consequence" it is here to mean "inductive of" or "signifying" a true difference between two sets of variables.

In carrying out this test using "paired samples**"** or "correlated t-test (two samples mean)", the first stage is to formulate a hypothesis that there is no significant difference between two population means, Radon and Uranium called "null hypothesis" (Table 2).

Table 2: Group Statistics of ^{222}Rn and ^{238}U.

Variable	***Group Statistics***				
	Group	***N***	***Mean***	***Std. Deviation***	***Std. Error***
	Radon	-9.8045*	0.66710	0.000	-11.3769
	Uranium	-9.1435*	0.66710	0.000	-10.7158

The observed difference between the Radon and Uranium is significant at 5% level (Table 3). So, the null hypothesis is rejected and it is concluded that the difference in Radon and Uranium levels are true.

Table 3: Independent Samples Test of ^{222}Rn and ^{238}U.

Independent Samples Test										
		Levine's Test for Equality of Variances		***t-test for Equality of Means***						
		F	***Sig.***	***T***	***df***	***Sig. (2-tailed)***	***Mean Difference***	***Std. Error Difference***	***95% Confidence Interval of the Difference***	
									Lower	***Upper***
Variable	Equal variances assumed	8.66	0.004	2.57	76	0.01	89.42	34.84	20.03	158.81
	Equal variances not assumed			2.57	50	0.01	89.42	34.84	19.47	159.37

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REFERENCES

[1]. Alam, M. N., Chowdhry, M. I., Kamal, M., Ghose, S., Islam, M. N.and Awaruddin, M., Radiological assessment of drinking water of the Chittagong region of Bangladesh. *Radiat. Prot. Dosim.,* **1999**, 82: 207-214.

[2]. Bleise, A., Danesi, P. R. and Burkart, W., Properties use and health effects of depleted Uranium: a general overview. *J. Env. Radio*, **2003**, 64: 93-112.

[3]. Cevik, U., Damla, N., Karahan, G., Celebi, N. and Kobya, A. I., Natural radioactivity in tap waters of eastern black sea region of Turkey. *Radiat. Prot. Dosim.* **2006**, 118: 88-92.

[4]. Choubey, V. M., Bartarya, S. K. and Ramola, R. C., Radon in groundwater of eastern Doon valley, Outer Himalaya. *Radiation Measurements*, **2003**, 36: 401-405.
[5]. Dillon, M. E., carter, G. L., Arora, R. and Kahn, B., Radon concentration in groundwater of the Georgia piedmont. *Health Physics*, **1991**, 60(2): 229-236.
[6]. Erlandsson, B., Jakobsson, B. and Jonsson, G., Studies of the Radon Concentration in Drinking Water from the Horst Soderasen in Southern Sweden. *J. Environ. Radioact.,* **2001**, 53:145-54.
[7]. Grans, I., Natural Radionuclide in Mineral Waters. Sci. Total Environ. **1985**, 45: 93-99.
[8]. Hess, C. T., Michel, J., Horton, T. R., Prichard, H. M. and Coniglio, W. A., The occurrence of radioactivity in public water supplies in the United States. *Hlth. Phy.*, **1985**, 48(5): 553-586.
[9]. Ivanovich and Harmon, Uranium Series Geochemistry: Reviews in Mineralogy and Geochemistry: Mineralogical Society of America, **1992**, 1-19.
[10]. Bourdon, B., Henderson, G. M., Lundstrom, C. C. and Turner, S. P., Uranium Series Geochemistry: Reviews in Mineralogy and Geochemistry: Mineralogical Society of America, **2003**, 1-19.
[11]. Jiban Singh, M., Somashekar, R. K. and Aninda, M., Application of sulphur-34 to trace natural and anthropogenic sources of sulphur in groundwater contamination in Hebbal and Challaghatta, Bangalore-a case study, JREST (ISSN: 2315-5698), **2012**, 1(11): 303-310.
[12]. Krishnaswami, S., Graustein, W. C., Turekian, K. K. and Dowd, J. F. (**1982**). Radium, thorium and radioactive lead isotopes in ground waters: application to the in-situ determination of adsorption–desorption rate constants and retardation factors. *Water Resources Research,* 18: 1633.
[13]. Mahesh, H. M., Avadhani, D. N., Someshekarappa, H. M., Karunakara, N., Narayana, Y. and Siddappa, K., Uranium concentration in water samples in the environment of costal Karnataka and Kaiga. *Proc. Nat. Sem. Atom. Energ. Ecol. Env.*, **2001**, 113-116.
[14]. Manjunath, S., PhD. Thesis published by University of Mysore: Investigation of the environmental radioactivity in Uranium bearing quartz pebble conglomerate horizon around Chakamangalore. *Dept. of Studies in Phys, Manasagangotri, Univesity Mysore.* **2002**.
[15]. McBride, J. L. and Davies, K. L., Natural radioactivity measurements for the Harvey area, York County, N.B. Radiation Protection Services. Fredericton: New Brunswick Department of Health. **1981**.
[16]. McGregor, R. G. and Gourgon, L. A., Radon and radon daughters in homes utilizing deep well water supplies, Halifax County, Nova Scotia. *J. Env. Sci. Eng.*, **1980**, 15(1): 25.
[17]. Nagaiah, C., Sannappa, M. S., Chandrashekar, M.S. and Parmesh L. (**2008**), Concentration of Radon and its daughter products in and around Bangalore City, Radiat. Prot. Dosim.. 1:1-7.
[18]. NCRP (National Council on Radiation Protection and Measurements). (**1988**). Measurement of radon and radon daughters in air. NCRP Report No. 97. Bethesda: NCRP.
[19]. Ramola, R. C., Chouby, V. M., Saini, N. K. and Bartaya S. K. (**1999**). Occurrence of Radon in drinking water of Dehra dun city, India. *Ind. Build. Env.*, 6: 67-70.
[20]. Somashekar, R. K., Deljo Davis, Shivana, K., Jibna Singh, M. and Parkash K. L. (**2010**). Radon-Ovccurrence, estimation and hydrological applications. A Workshop volume on Radon contaminaton in groundwater and application of isotopes in groundwater studies, CGWB, Bangalore, p. 13-34.
[21]. Sridhar Babu, M. N., Somashekar, R. K., Kumar, S. A., Shivanna, K., Krishnamurthy, V. and Eappen, K. P. (**2008**). Concentration of uranium levels in groundwater. *Int. J. Env. Sci. Tech.* 5(2): 263-266.
[22]. Torgersen, T., Habermehl, M. A. and Clarke, W. B. (**1992**). Crustal helium fluxes and heat flow in the Great Artesian Basin, *Australia: Che. Geo.*, 102: 139.152.
[23]. UNSCEAR. (**1988**). Sources, effects and risks of ionizing radiation. Report to the General Assembly, with annexes. United Nations. New York: UNSCEAR.
[24]. UNSCEAR, (**1982**). Ionizing Radiation: sources and biological effect. UN Report, New York.

[25]. Virk, H. S., Sharma A. K. and Navjeet Sharma. (**2002**). Radon and helium monitoring in some thermal springs of North India and Bhutan. *Cur. Sci.,* 82(12): 25.