Radioactivity level estimation by alpha scintillation detector based Smart RnDuo monitor in water samples

Abstract No. 117

Dr. Krishan Kant
PRINCIPAL
Aggarwal College Ballabgarh, Faridabad, Haryana, India-121004

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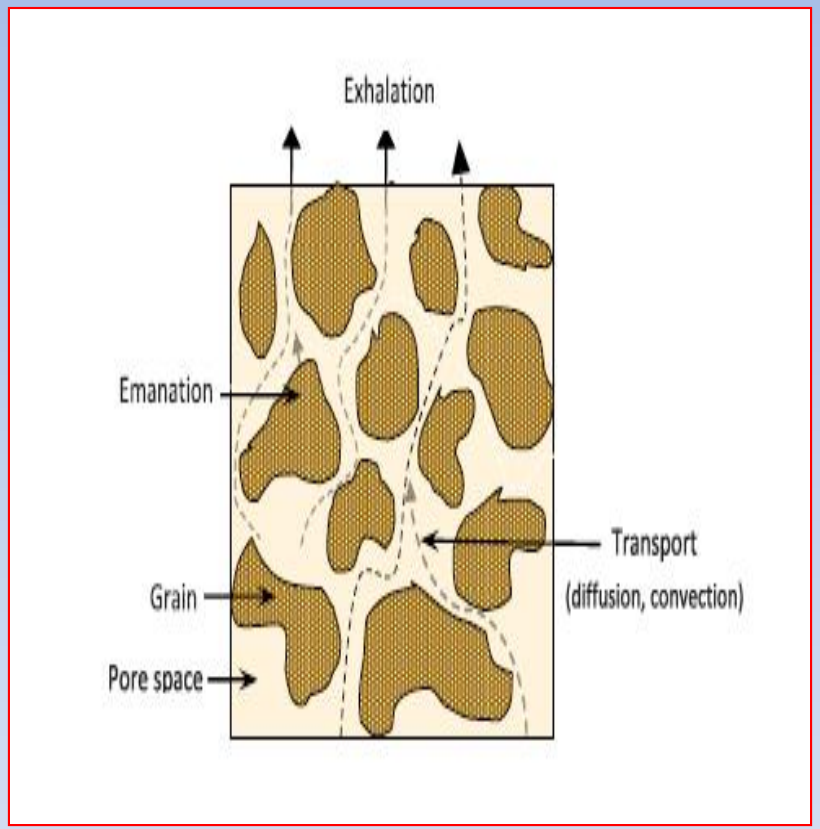
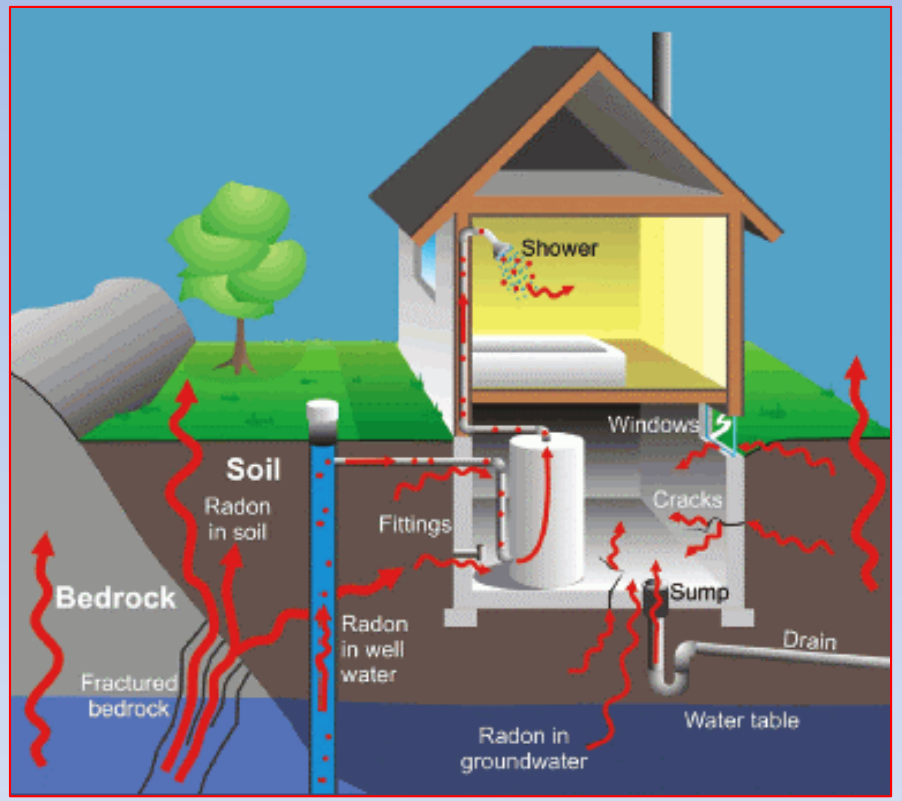
Introduction

- ^{238}U, ^{232}Th and ^{40}K are primordial radionuclides, responsible for natural radioactivity in the soil, rocks and water.
- Dissolved ^{226}Ra in water, rock weathering reactions (or leaching) and alpha recoil process are the major sources of radon in groundwater.
- $T_{1/2}$ is 3.823 days for radon & α-particles of energy 5.49MeV ae released, when it decays.
- Radon in water has dual exposure from inhalation and ingestion.
- The decay products are the isotopes of heavy metals Po, Bi & Pb and they have high diffusivities and ability to stick to surface.
- Radon has been recognized as second leading cause of lung cancer after smoking.
- Also, radon in water used as a tracer for quantifying the infiltration of meteoric water, tracer for monitoring non aqueous phase liquid contamination in groundwater, as a recoil flux monitor for the determination of adsorption/desorption rate constants and retardation factor for radium.

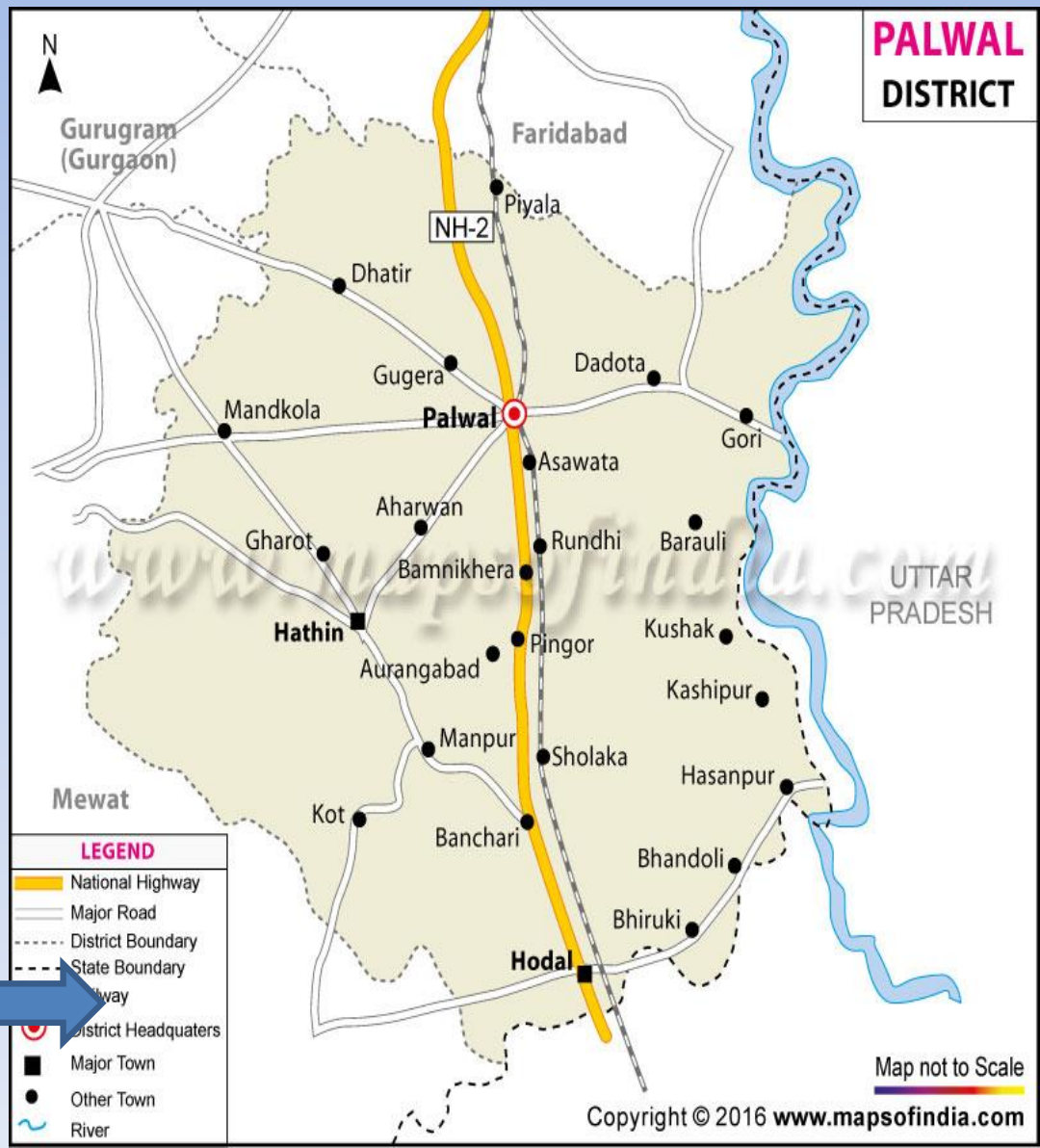
Transportation of Radon/Thoron to environment





Emanation & Exhalation

Geographical representation of Study area District Palwal, Haryana, India.



Methodology/Protocol for the present investigation

SMART RnDuo

SMART RnDuo has its advantage that measurements with scintillation detector are unaffected by humidity and trace gases present in sampled gas.

SMART RnDuo monitor has been calibrated once in a year against standard Radon source (Model RN-1025, Activity: 110.6 kBq) acquired from Pylon Electronics Inc., Ottawa, Canada to ensure the validity of calibration factor in calibration chamber available at Bhabha Atomic Research Centre (BARC), Mumbai, India.

This calibration chamber has the facilities of controlling the affect of humidity and temperature.

Measurements by SMART RnDuo are comparable to RAD7 and Alpha GUARD (world wide accepted online monitors).

Technical Specifications of SMART RnDuo

Detector Type	Scintillation cell
Scintillation coating	Internally coated ZnS:Ag
Scintillation cell volume	153cubic cm
Radon sensitivity	1.2 CPH/(Bq/m^3) or 44.5 CPH/(pCi/L)
Thoron sensitivity	0.8 CPH/(Bq/m^3) or 30 CPH/(pCi/L)
Sampling type	Diffusion / Flow
Sampling flow rate	0.5 to 0.7 L/min with inbuilt pump
Measurement cycle	15/30/60 min
Response time	15 min for attaining 95% of radon/thoron
Min. detection limit	Radon: 8 Bq/m^3 at 1 sigma and 1 h cycle Thoron: 15 Bq/m^3 at 1 sigma and 1 h cycle
Upper detection limit	50 MBq/m^3
Power	Ext. 110-220V AC 50/60 Hz, Internal 6V DC Battery
Dimension	37 cm * 20 cm * 12 cm
Thoron interference	< 5% with sniffing mode of sampling
Effect of sample humidity and trace gases on sensitivity	Practically nil until humidity is not condensed on scintillator surface

- The experimental set-up consists of a water bubbler attached with SMART RnDuo (AQTEK System, India).

- It is microprocessor based device.
- It is a commercially available, technologically advanced portable continuous monitor for detection of radon, thoron and gross alpha in sampled air.
- The SMART RnDuo is internally coated with ZnS:Ag and has scintillation cell with 153 cc active volume.

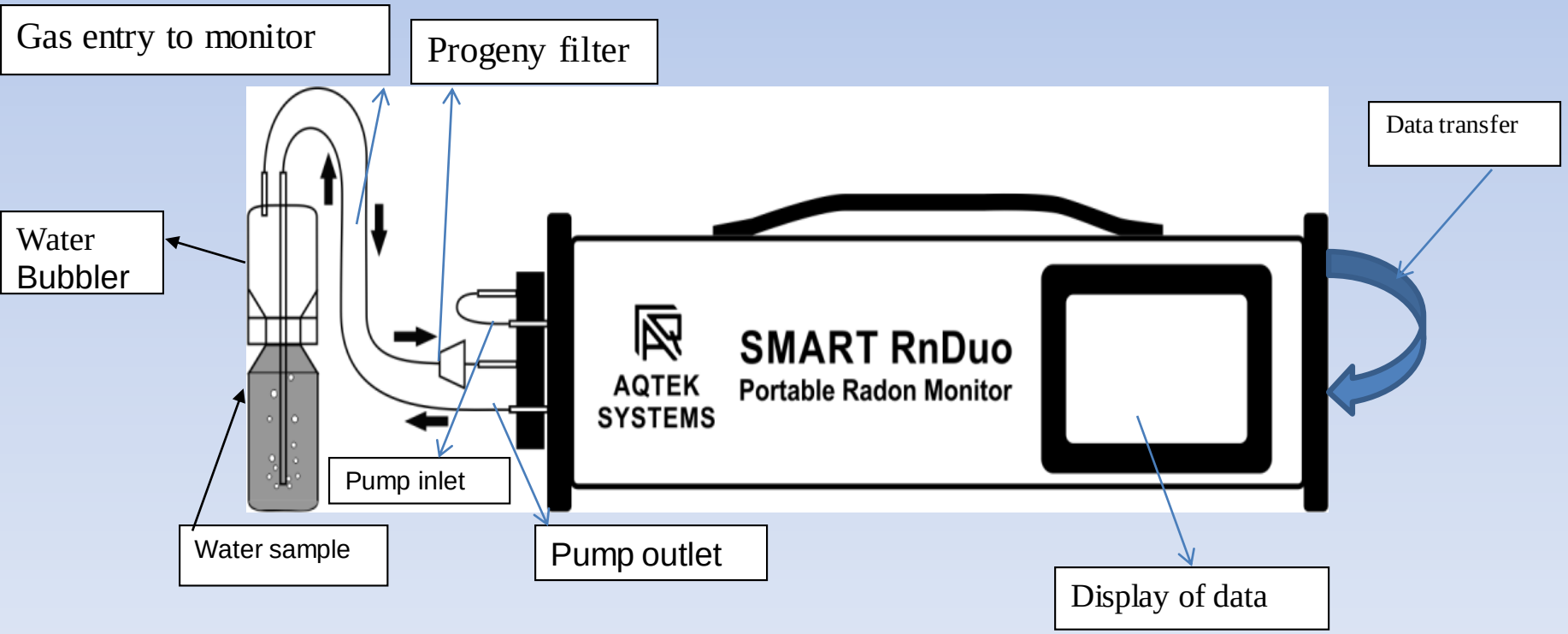
- Typical value of background count in the equipment is about 6 ± 2 counts per hour (CPH).
- Alpha detection efficiency of the equipment is about 75%. The device has radon sensitivity of 1.2 CPH/Bqm^{-3}.

- The minimum detection limit of radon of this device is 8 Bqm^{-3} at 1 sigma and 1 h counting cycle and the upper detection limit was 10 $MBqm^{-3}$.

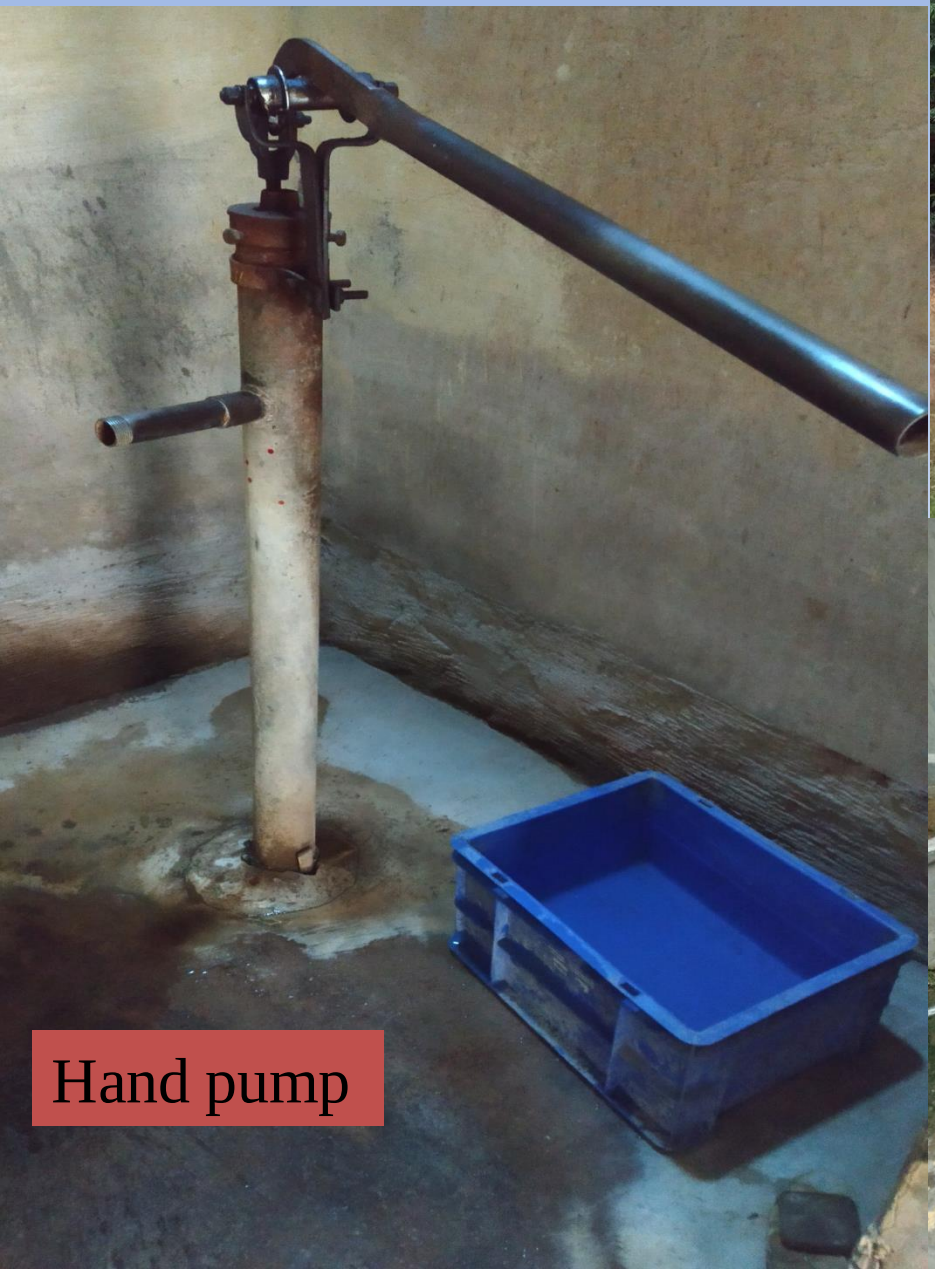
- Equipment has an in-built micro pump of flow capacity 0.7 l/min for air sampling and has no effect of humidity and trace gases variation on measurement of radon.
- The alpha scintillations were continuously counted for user-programmable counting period by photomultiplier tube (PMT).

- The algorithm based on the theoretical decay and growth of decay products of radon during the ongoing measurement cycle and the radon concentration in history was used to calculate the radon concentration displaced on the screen of the device.

A Schematic of SMART RnDuo with Bubbler



Ground water sources



Hand pump

BORE-WELL

WATER SUPPLY

Measurement of dissolved radon concentration

Dissolved radon concentration in water is calculated by [[Kaur et al. 2019; Singh et al. 2019]

$$C_{water}(Bq.l^{-1}) = C_{air}[K + V_{air}/V_{water}] \quad (1)$$

The uncertainty error in the measurement of radon concentration in water (E_{water})

$$E_{water}(Bq.l^{-1}) = E_{air}[K + V_{air}/V_{water}] \quad (2)$$

Where

C_{air} is average radon concentration measured by SMART RnDuo monitor ($Bq.m^{-3}$),

K is partition coefficient for an air–water interface having value ~ 0.25,

V_{air} is the volume of air enclosed in the closed loop setup (m^3).

The ratio V_{air}/V_{water} in the present study is ~ 2.93.

E_{air} is the average of measurement error in later three readings reported by the equipment.

Calculations of ingestion /inhalation dose

Inhalation effective dose due to radon and its progeny

$$D_{ing}(\mu Svy^{-1}) = C_{water}(Bq.l^{-1}) \times 365 ly^{-1} \times 10^{-3} \times 3.5\ nSvBq^{-1} \qquad (3)$$

Inhalation effective dose due to thoron and its progeny was

$$D_{inh}(\mu Svy^{-1}) = C_{water}(Bq.l^{-1}) \times R_{a/w} \times F_E \times O \times F \qquad (4)$$

The uncertainty error in the estimation of the effective ingestion and inhalation dose was calculated by substituting E_{water} in place of C_{water} in Eqs. (3) and (4) respectively.

where,

$R_{a/w}$ is the ratio of radon in air (Bqm^{-3}) to radon in water (Bqm^{-3}) = 10^{-4},

F_E is equilibrium factor between radon and its progenies = 0.4,

O is average indoor occupancy time per individual = 7000 hy^{-1} and

F is dose conversion factor for radon exposure = {$9nSv(Bqhm^{-3})^{-1}$}.

Table-1. Gamma level, dissolved radon concentration, inhalation, ingestion, annual dose , pH, TDS, EC in underground water samples collected from Palwal district, Haryana, India.

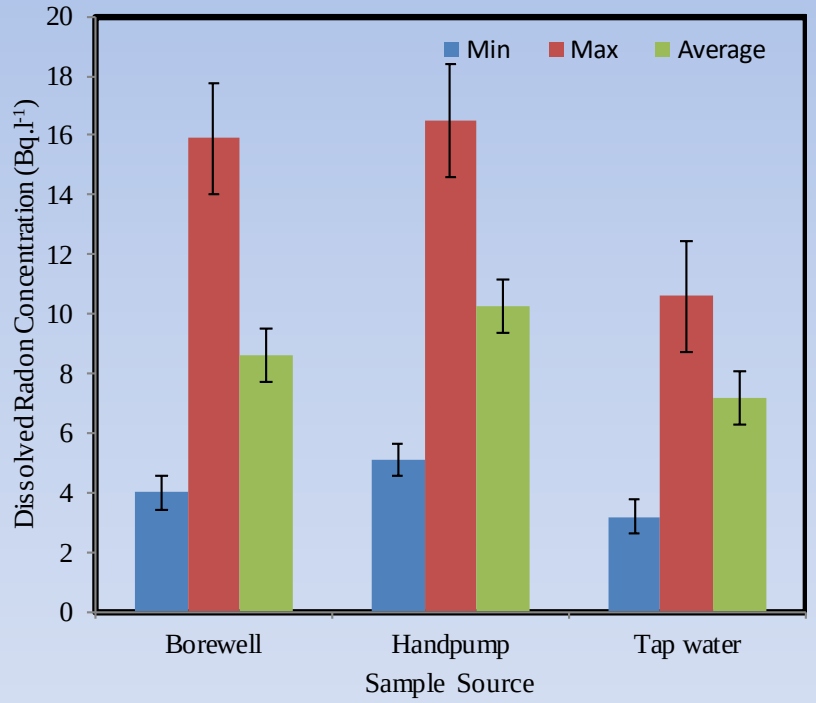
Sample Code.	GPS Coordinates Latitude N Longitude E	Source Depth (m)	Gamma Level (μRh^{-1})	C_{water} ($Bq.l^{-1}$)	D_{ing} (μSvy^{-1})	D_{inh} (μSvy^{-1})	Annual effective dose (μSvy^{-1})
BW01	28º12'35.1"E 77º16'07.9"N	32.0	18.1	5.3±0.4	6.8±0.5	13.3±1.0	20.1
BW02	28º10'44.1"E 77º19'36.1"N	33.5	15.3	4±0.3	5.1±0.4	10.0±0.8	15.0
BW03	28º08'29.8"E 77º20'08.9"N	30.5	14.2	12.3±0.4	15.7±0.5	31.1±1.1	46.8
BW04	27º54'04.0"E 77º26'04.0"N	51.8	17.2	6.5±0.4	8.4±0.5	16.5±1.0	24.8
BW05	28º48'12.4"E 77º22'08.1"N	36.6	19.3	4.5±0.3	5.7±0.4	11.3±0.8	17.1
BW06	28º03'38.5"E 77º11'43.6"N	15.8	16.9	15.9±0.7	20.4±0.9	40.2±1.7	60.5
BW07	28º03'27.3"E 77º11'08.9"N	31.7	18	11.6±0.6	14.8±0.7	29.3±1.5	44.1
HP08	28º12'30.7"E 77º16'09.3"N	18.3	17.9	11.2±0.6	14.3±0.7	28.2±1.4	42.4
HP09	28º11'20.8"E 77º14'37.4"N	0.0	22.3	11±0.6	14.1±0.7	27.8±1.4	42.0
HP10	28º10'44.4"E 77º19'35.9"N	12.2	14.7	8.4±0.5	10.7±0.6	21.1±1.3	31.8
HP11	28º08'32.9"E 77º20'26.5"N	15.2	13.3	5.1±0.4	6.5±0.5	12.8±1.0	19.3
HP12	27º53'43.8"E 77º26'40.7"N	24.4	14.1	9.5±0.5	12.2±0.7	24.0±1.3	36.2
HP13	27º53'53.2"E 77º25'32.4"N	18.3	20.2	10.4±0.5	13.3±0.7	26.3±1.4	39.6
HP14	28º07'00.6"E 77º17'13.6"N	10.7	18.8	16.5±0.7	21.1±0.9	41.7±1.7	62.8
WS15	28º08'43.3"E 77º20'03.6"N	33.5	17.3	3.3±0.3	4.2±0.4	8.4±0.8	12.6
WS16	28º12'34.4"E 77º16'07.1"N	33.5	17.5	3.2±0.3	4.0±0.4	7.9±0.8	12.0
WS17	28º11'23.0"E 77º14'45.8"N	0.0	21.7	10.2±0.5	13.0±0.7	25.7±1.4	38.7
WS18	28º53'53.2"E 77º25'32.2"N	61.0	18.1	5.5±0.4	7.0±0.5	13.9±0.9	21.0
WS19	28º07'48.0"E 77º17'57.1"N	15.2	18.3	10.4±0.5	13.3±0.7	26.2±1.4	39.5
WS20	28º06'19.0"E 77º16'34.7"N	15.2	17.5	10.6±0.6	13.5±0.7	26.7±1.4	40.2

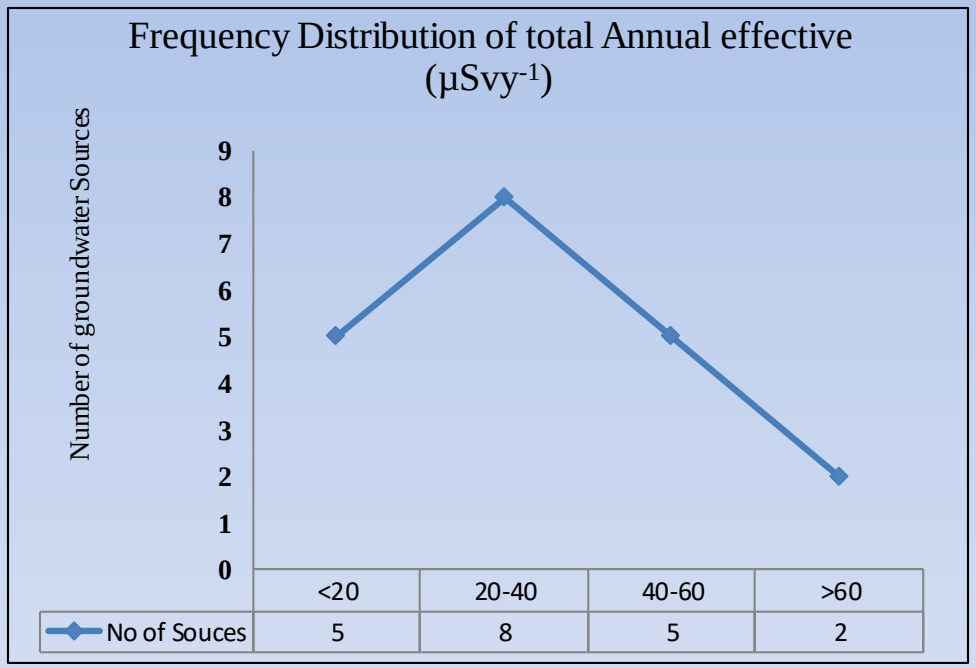
Table-2. Variation of radon, inhalation, ingestion, annual dose , pH, TDS, EC in underground water samples collected from Palwal district, Haryana, India.

Parameters	Borewell			Hand-pump			Tap water		
	Min	Max	AM	Min	Max	AM	Min	Max	AM
^{222}Rn ($Bq.l^{-1}$)	4±0.3	15.9±0.4	8.6	5.1±0.4	16.5±0.6	10.3	3.2±0.3	10.6±0.5	7.2
D_{ing} (μSvy^{-1})	5.1±0.4	20.4±0.9	11	6.5±0.5	21.1±0.9	13.2	4±0.4	13.5±0.7	9.2
D_{inh} (μSvy^{-1})	10±0.8	40.2±1.7	21.7	12.8±1	41.7±1.7	26	7.9±0.8	26.7±1.4	18.1
Annual effective dose (μSvy^{-1})	15	60.5	32.6	19.3	62.8	39.2	12	40.2	27.3
Gamma level (μRh^{-1})	14.2	19.3	16.8	13.3	22.3	16.5	17.3	21.7	18.6
pH	6.7	7.88	7.3	6.56	7.34	7.1	6.25	7.81	7.27
TDS (ppt)	0.3	5.95	2.1	0.88	8.88	3.2	0.13	1.84	1.11
EC ($mS.cm^{-1}$)	0.43	8.43	2.9	1.26	5.08	4.5	0.18	2.61	1.56

Radon in water varies as Hand-pump>Borewell >Tap water

Statistical analysis of Data





Summary

•A wide variation is observed in the distribution of radon level in the water samples. The underground water directly comes in contact with the rock that continuously produces radon and escapes path of radon is limited in underground water.

•In comparison to other regions, the observed radon concentration in underground water samples of the studied region is lesser which may be attributed to alluvium nature of underground rock which comprises of sands, silt, kankar, and gravel and have low uranium content.

•The measured dissolved radon concentration varies from 4±0.3 to 15.9±0.4Bq.l^{-1} with an average of 8.6Bq.l^{-1} in bore-well water samples, from 5.1±0.4 to 16.5±0.6Bq.l^{-1} with an average of 10.3Bq.l^{-1} in hand-pump water samples, from 3.2±0.3 to 10.6±0.5Bq.l^{-1} with an average of 7.2Bq.l^{-1} in tap water samples. The dissolved radon concentration was observed to be well below the limits (100Bql^{-1}) recommended by WHO, UNSCEAR.

•The estimated annual effective dose varies from 15 to 60.5µSvy^{-1} with an average of 32.6µSvy^{-1} in bore-well water samples, from 19.3 to 62.8µSvy^{-1} with an average of 39.2µSvy^{-1} in hand-pump water samples, from 12 to 40.2µSvy^{-1} with an average of 27.3µSvy^{-1} in tap water samples.

•BW03, BW06, BW07, HP08, HP14 have high radon level than MCL limit (11Bql^{-1}) of USEPA

•A weak positive correlation was observed between the measured radon and physicochemical parameters. (with pH correlation coefficient R=0.02; with TDS, R=0.37; with EC, R= 0.35).

•The estimated annual effective dose for all samples collected from Palwal, Haryana (India) was found to be less than the limit of 0.1 mSv^{-1} as recommended by WHO.

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Thank
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