Asian J. of Adv. Basic Sci.: 2(3), 57-65
ISSN (Online): 2347 - 4114
www.ajabs.org

Geological significance of radon gas in soil and underground water: A case study of Nurpur area, district Kangra, Himachal Pradesh, India

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ABSTRACT: Remote sensing satellite data have been used to recognize structures having tectonic significance. Based on satellite data, lineament map of Nurpur and its adjoining area of Kangra district, Himachal Pradesh, has been generated. LR-115 solid state nuclear track detectors have been used for the measurement of soil gas radon at 71 different locations of the study area. Radon monitoring in underground water at 26 different locations of the study area has been carried by scintillometry. The results indicate zones of lineament density and tectonically induced radon in soil and underground water .The results are co-relatable with regional geology of the area.

Keywords: Soil gas radon; lineaments; LR-115 detectors; Tectonics.

INTRODUCTION

Himachal Pradesh lies in the north-western Himalayas with mountainous terrain between the river Ravi in the north-west and Tons (Yamuna) in the south-west falling within the latitude $30^0\ 22^{'} – 33^0\ 10^{'}$ N and longitude $70^0\ 46^{'} – 79^0\ 00^{'}$ E. The district Kangra in the state of Himachal Pradesh lies between 31°40′-32°25′ North latitudes and 75°35′-77°5′ East longitudes.

Geologically Nurpur and its adjoining area in district Kangra, Himachal Pradesh lays between 32°0′-32°25′ North latitudes and 75°45′-76°5′ East longitudes (Fig.1). It comprise dominantly of middle and upper Shivalik which are separated by a regional thrust namely the Jawalamukhi Thrust between these two. Towards the north the region is enclosed by regional longitudinal thrust plane separating Shivaliks from lesser Himalayan Paleogene sediments. Towards the south the area is characterized by alluvium and other recent deposits adjoining the Punjab planes. The Shivalik group is geologically interesting and unique because the conspicuous control of landforms in the group is the result of multicycles erosion, diverse lithology and structure. The area under study represents a thick succession of lower, middle and upper Shivalik sediments which comprises mainly the sandstones, clays and boulder conglomerates and which are succeeded by recent alluvium towards the south .The the region also is traversed by transverse lineaments/faults viz. Dehar lineament and Gaj lineament (Fig.1). Presences of this important structural elements/plane have made the study area tectonically interesting. Similar structural configuration of longitudinal thrust/fault system and the transverse lineaments have been observed in the adjoining Dharamshala area of district Kangra[1].

Radon monitoring in soil air, groundwater and atmosphere has been continued in many tectonically active areas of the world for active fault/lineament studies and earthquake prediction. Some recent measurements of radon and other geochemical and hydrological parameters have been made for sufficiently long periods with reliable instruments and together with measurements of meteorological variables and solid-earth tides[2-4] . Especially in the case of assessing geological profiles and tectonic discontinuities, the radon technique seems to provide an alternative tool to geophysical methods, such as ground probing radar, electromagnetic conductivity testing, electrical resistivity or vertical magnetic gradient surveying. The resultant data are useful in ascertaining fault-related and earthquake-related anomalies and in understanding the underlying mechanisms. Spatial anomalies of radon and other terrestrial gases have been observed for many active faults. Such observations indicate that radon gas concentrations are very much site dependent, particularly on fault zones where terrestrial fluids may move vertically[5].

Radon (^{222}Rn) is a daughter nuclide of radium (^{226}Ra), which in turn comes from the long lived antecedent, uranium (^{238}U). The short half-life of ^{222}Rn (3.82 days) limits its diffusion in soil, so that radon measured at the ground surface cannot be released from a deep origin, unless there exists a driving mechanism other than mere diffusion. Radon is a marker of convection process, fault interaction and of uranium, thorium mineral rocks[6]. The movement of radon through rocks under the earth largely depends on lithology, compaction, porosity and fractural/tectonic features like faults, thrust, joints or fractures[7-8]. The distribution of radon in soil gas has been employed in the monitoring of volcanic activities, the prediction of earthquakes and the mapping of fault zones[9-12].

In nature, radioactivity of groundwater shows great variation. It is derived primarily from radioactive source rocks and minerals with which the water is in contact. Water borne transport of radon is a common process in nature. The concentration of excess radon depends on several factors including the geomorphology and the tectonics of any area and has been used as diagnostic tool for locating fracture zones, estimating fracture aperture (Nelson et al., 1983) and predicting earthquakes events[13].

The present study is aimed to determine a possible connection between tetonicaly induced eventual radon anomalies in soil and underground water with regional geology of the area. An attempt has also been made to understand the factors that control the occurrence of radon in groundwater in Nurpur area of Himachal Pradesh, India.

MATERIAL AND METHODS

Measurements of soil gas radon: Using satellite data (1:50000, Toposheets No. 43P/15, 43P/16, 52D/4, LISS-III) visual interpretation and ground truth, a tectonic/lineament map of the study area was generated for the first time (Fig.1). Interpretation of data reveals that the study area is dissected by numerous faults/lineaments of regional and local nature. Visual interpretation of the tectonic map reveals three zones of inferred tectonic activity: zone (I) traversed by regional longitudinal plane between middle and upper Shivaliks (locations No. 1-29), zone (II) showing the presence of transverse Dehar and Gaj lineaments (locations No. 30-53) and confined in the upper Shivalik system thereby cutting the regional plane, zone (III) comprising alluvium and other recent deposits traversed by lineaments of local nature only (location No.54-71) (Fig. 1)

The passive track etch technique[14-15] has been used to measure the levels of soil gas radon concentrations at different locations of the study area located in three zones discussed above. The LR-115 solid state nuclear track detectors having a size of about 1.5 cm x 1.5 cm were attached to inside upper closed end of PVC tubes (25 cm long, 5 cm diameter). The tubes were placed in 50 cm deep holes, dug in soil, covered from top using tile and soil, along and across the lineaments/faults to expose the detectors to soil gas radon for a period of two weeks. The retrieved detectors were then chemically etched in 2.5 N NaOH solution for two hours at 60°C to enlarge the tracks caused by α-particles generated by the decaying radon. The tracks in an area unaffected by water condensation were counted manually using Carl Zeiss binocular optical microscope at a magnification of 400X. The track density so obtained was converted in to the units of k Bq m^{-3} using the calibration factor[16] of 1 Track cm^{-2} d^{-1} =0.034 k Bq m^{-3}.

Radon monitoring in underground water: Radon monitoring in underground water was carried out by scintillometry, using silver activated zinc sulphide phosphor, ZnS (Ag), as the scintillation material. Water samples taken for the study were collected either from hand pumps or tube wells from different locations in Nurpur area, district Kangra, Himachal Pradesh. Alpha Scintillometer (GBH 2002) was used to record alpha counts from one liter of water over an interval of 10 minutes. Radon gas emanating from radium dissolved in water was sucked by a pump connected to a radon bubbler with an extraction efficiency of more than 90%. The electronic digital counter records the alpha counts and radon concentration in water is measured by using the calibration constant[17] of 10 counts = 1 Bq l^{-1}. The detection limit for the Lucas cells used in alpha Scintillometer is 0.02Bq l^{-1}.

RESULTS AND DISCUSSION

Remote sensing data provides the synoptic coverage of any desired area and has been successfully used to recognize structures having tectonic significance. Lineament map of Nurpur area can be classified in three zones based on the trends revealed (Fig.2). All the major lineaments and the curvilinear were delineated from the satellite imageries (LISS-III). Three lineaments trends filtered reveal: (1) trend parallel to the regional longitudinal structural plane between the middle and upper Shivaliks (Zone I). This trend conforms with the Main Boundary Thrust passing through the adjoining Dharamshala region[1] and comprises an important tectonic plane of the region namely Jawalamukhi Thrust , (2) trend somewhat orthogonal to above which follow the transverse lineaments viz. Gaj and the significant Dehar lineament (Zone II) and decipher somewhat an intersection pattern with Zone I , (3) trend visible in the recent alluvium shows lineaments and the curvilinear somewhat of local nature only . Neo-tectonic activities controlled along numerous lineaments / faults in the region have resulted in the contemporary morphological adjustments including drainage shifts and the development of the fluvial deposits along a preferred orientation, recurrence of slope failure along the main structural line and their offshoots[18-19]. Profiles of radon gas in soil and underground water in the study area conforms to the inferred results of the lineaments density/trend map (Fig.1). The zone wise radon gas activity in soil and underground water recorded at different locations along and across the various thrust/lineaments of Nurpur and its adjoining areas of district Kangra, Himachal Pradesh are given in tables 1&2 respectively.

The table 1 shows that the soil gas radon concentration in Zone (I) varies from 1.14 k Bq m^{-3} (Jassur) to 20.37 k Bq m^{-3} (Talara) and 1.67 k Bq m^{-3} (Baranda) to 17.30 k Bq m^{-3} (Hadwal) in Zone (III). It is clear that the values recorded in these two zones are comparable. Among the transverse lineaments in Zone (II) the soil gas radon values varies from 2.08 k Bq m^{-3} (Kothi) to 82.22 k Bq m^{-3} (Masatgarh Road) along Dehar lineament. It is clear that the values of soil gas radon along transverse Dehar lineament and the longitudinal Jawalamukhi Thrust are very high compared to any other lineament of the study area. This shows that the region along Dehar lineament and Jawalamukhi Thrust including the Masatgarh region is tectonically more active. Moreover, the tectonics of the regions falling under Zones (I) and (III) seems to be identical. The average values of soil gas radon in Zones (I), (II) and (III) are 6.33, 22.12 and 6.93 k Bq m^{-3} respectively**.** The table 2 shows that the radon gas concentrations in underground water in Zone (I) varies from 3.50 Bq l^{-1} (Talara) to 11.81 Bq l^{-1} (Bharmar) and 4.39 Bq l^{-1} (Dhameta) to 9.27 Bq l^{-1} (Dehri) in Zone (III). In Zone (II) the radon activity values in underground water varies from 5.52 Bq l^{-1} (Kaldun) to 26.65 Bq l^{-1} (Siyuni).

It is clear from the table 2 that zone-I which is characterized by regional longitudinal thrust plane including the Jawalamukhi thrust shows average concentration of 7.27 Bq l^{-1} which is comparable with the abundance observed in the zone-III of study area (7.52 Bq l^{-1}). The average value of radon concentration in underground water in zone-II is 12.6 Bq l^{-1}. However the abundances decipher an increasing trend in zone-II characterized by the longitudinal thrust planes and the transverse faults, trending north-south, like Dehar lineament & Gaj lineament (Fig1). Although the overall abundance of radon in the water of the region is low, however the higher abundance along the transverse fault is significant. Locations proximal to the intersection zone of Jawalamukhi thrust and the Dehar lineament, like Siyuni(32), Bagga(33), Dehar Khad(36) shows the concentration on the higher side(Fig.1). The results when compared to concentration observed in soil are comparable (Table 1).

Soil gas radon concentration in the zone-II also shows higher abundance compared to zone-I and zone-III. Localities which are close to the transverse Dehar lineament has deciphered significantly higher proportions of the soil gas radon, like Dehar Khad(36),Kuthed(34), Masatgarah Road(37) and Batt-Bhalun(43) (Fig. 1) These results on the whole hint on the role played by natural geomorphology and structure in the radon abundance observed in the study area. The results further support the presence of north-south transverse Dehar lineament which cut across varied lithounits including sandstone, conglomerates, sand rocks, alluvium and other recent deposits. Since the abundances along the transverse lineament are high irrespective of the lithology, emanation of radon appear to be controlled by a same source through a deep seated fracture/ fault which play an important role in increasing the high radon concentration in soil and groundwater.

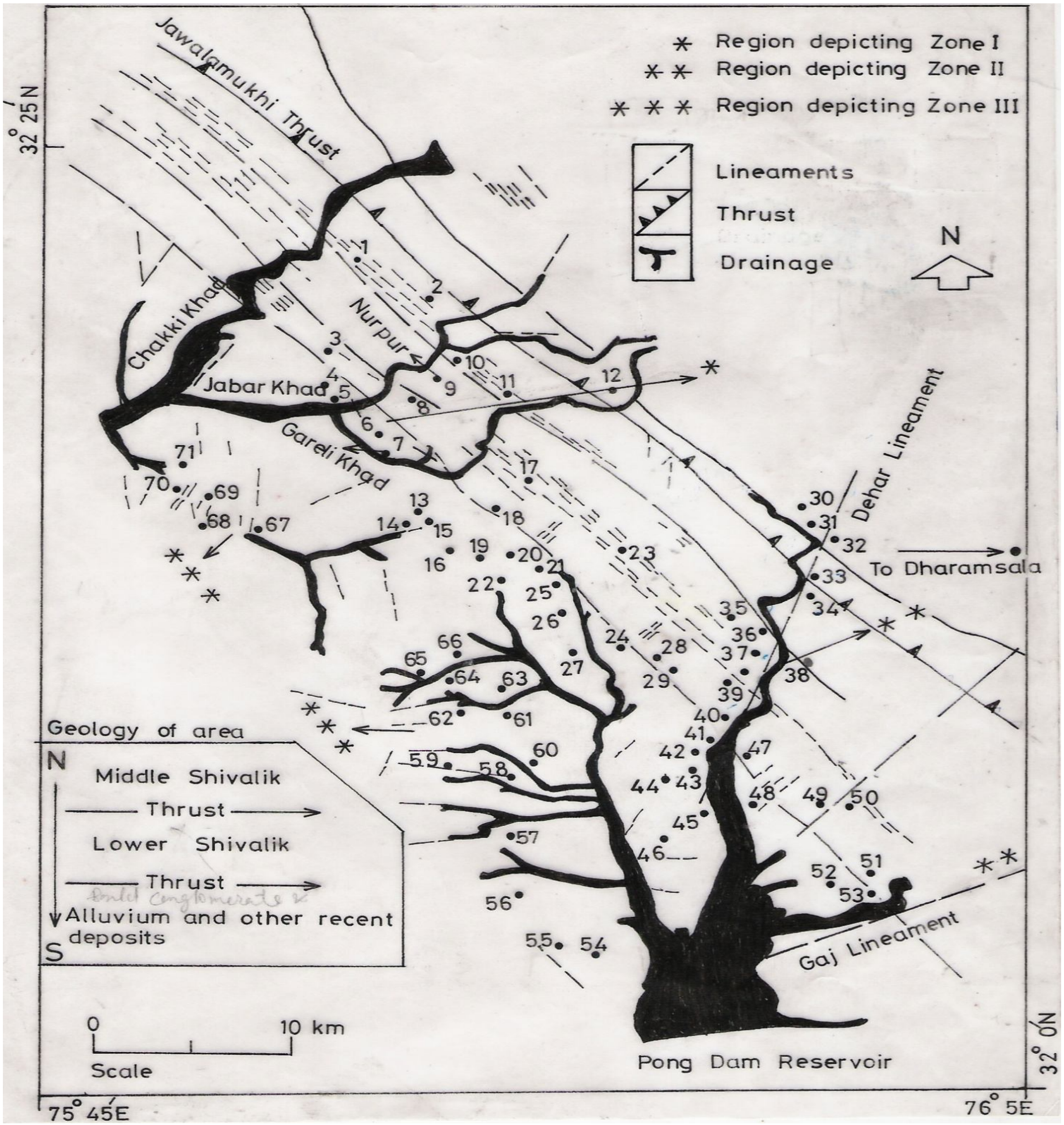

Fig. 1: Lineament map of Nurpur area

Table 1: Zone-wise soil gas radon concentration recorded at 71 locations of Nurpur Area, District Kangra, Himachal Pradesh, India.

Zone I (Regional Longitudinal Thrust Plane)		**Zone II (Transverse Lineaments)**		**Zone III (Lineaments of Local Nature)**	
Location No. and Name	**Soil Gas Radon (kBq m^{-3})**	**Location No. and Name**	**Soil Gas Radon (kBqm^{-3})**	**Location No. and Name**	**Soil Gas Radon (kBqm^{-3})**
1. Parnala	2.79	30. Kotla-1	6.13	54. Dhameta	7.15
2. Khajan	7.31	31. Kotla-2	6.53	55. Hadwal	17.30
3. Basa	3.93	32. Siyuni	16.52	56. Mandhot	1.73
Samletion	4.79	33. Bagga	3.77	57. Fatehpur	1.69
4. Bhalun	5.03	34. Kuthed	54.28	58. Sunet	3.89
5. Jabar Khad	1.14	35. Kaldun	5.27	59. Bagroli	11.88
6. Jassur	5.58	36. Dehar Khad	69.63	60. Banal	15.81
7. Gareli Khad	4.40	37. Masatgarh Road	82.22	61. Parol	6.21
8. Jach	9.40	38. Bagruh		62. Larhun	3.26
9. Nurpur	3.50	39. Lahru	81.82	63. Chamral	7.31
10. Baldun	1.57	40. Jawali	25.02	64. Rehan	6.49
11. Baghni	7.31	41. Dhan	19.36	65. Chattar	2.20
12. Khajjian	16.24	42. Pharian	18.96	66. Dehri	8.51
13. Ganoh	6.37	43. Batt-Bhallun	19.00	67. Gangath	10.85
14. Panjahra	20.37	44. Kardiyal	65.93	68. Atara	5.35
15. Talara	4.79	45. Chalward	6.49	69. Roparian	8.73
16. Garan	3.89	46. Papahan	3.10	Di Sar	
17. Banoli	4.95	47. Bhodela	12.82	70. Sarmel	4.87
18. Gurial	1.80	48. Harsar	2.98	71. Baranda	1.67
19. Raja Ka Talab	12.98	49. Manara	3.61		
20. Diyal	4.05	50. Kudret	6.88		
21. Larath	4.79	51. Amleta	5.23		
22. Baroh	10.46	52. Bagriala	8.10		
23. Chachiyon	2.36	53. Kothi	5.15		
24. Sidhpur Ghar	4.13		2.08		
25. Bhuhal Khad	8.77				
26. Harnota	7.31				
27. Bharmar	9.75				
28. Mawa	4.09				
29. Darkati					
Average Value of Soil Gas Radon (k Bq m^{-3})	**6.33**		**22.12**		**6.93**

Table 2: Zone-wise radon concentration in water recorded at 26 locations of Nurpur Area, District Kangra, Himachal Pradesh, India.

Zone I (Regional Longitudinal Thrust Plane)		**Zone II (Transverse Lineaments)**		**Zone III (Lineaments of Local Nature)**	
Location Name (No.)	**Radon conc. In water (Bq l^{-1})**	**Location Name (No.)**	**Radon conc. In water (Bq l^{-1})**	**Location Name (No.)**	**Radon conc. In water (Bq l^{-1})**
Jassur (6)	6.28	Siyuni (32)	26.65	Dhameta (54)	4.39
Nurpur (9)	6.18	Bagga (33)	14.73	Banal (60)	9.03
Khajjian (12)	5.91	Kuthed (34)	10.51	Larhun (62)	6.26
Ganoh (13)	6.95	Kaldun (35)	5.52	Rehan (64)	8.69
Talara (15)	3.50	Dehar Khad (36)	13.87	Dehri (66)	9.27
Garan (16)	9.52	Masatgarah Road (37)	9.83		
Raja Ka Talab (19)	6.81	Bagruih (38)	11.15		
Larath (21)	8.28	Lahru (39)	10.13		
Harnota (26)	7.53	Jawali (40)	9.95		
Bharmar (27)	11.81	Pharian (42)	12.86		
		Batt-Bhallun (43)	13.40		
Zone wise average value of radon conc. (Bq l^{-1})	**7.27**		**12.6**		**7.52**

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Rocks highly fractured /thrusted possibly increase the ratio of rock surface area to water volume, as a result of which emanation efficiency of radon increases[20]. Because, the water gets enriched in radon by dissolving radon which emanates from the deeper part of the crust through deep seated thrusts & faults[8], low radon emanations in zone-III comprising the alluvium and other recent deposit could possibly be related to the high water carrying capacity and high porosity and permeability of the lithounits. The turbulent flow within such deposit is likely to cause de-emanation of gases which find easy pathways through high porosity of the deposits for movement into the atmosphere. Results further reveal that the absence of any active structure trend does definitely contribute to diminishing pattern of radon emanation in the area under study.

It would be pertinent to mention here that apart from the longitudinal thrust planes like MBT (Main Boundary Thrust) and MCT (Main Central Thrust), the transverse lineaments (north-south) cutting the lesser Himalayas and Shivalik system of adjoining areas of Dharamshala have also shown significant evidence of neo-tectonic activities[21] .Another significant feature observed is that the longitudinal trend between lower Shivaliks and upper Shivaliks is represented by the important thrust plane of the region known as Jawalamukhi thrust. However the other similar trend lines are the contract zones of middle & lower Shivaliks and subsequent younger formations including the recent deposits. Towards the south of Jawalamukhi thrust the formation of the Shivaliks are repeated (Fig.1).Intersection of Jawalamukhi thrust and Dehar lineament including the enhanced proportion of radon along this transverse structural plane is interesting and points to the active nature of the same.

The values of soil gas radon observed in the present investigations are comparable to those reported at Jaut Pass area, Pyrenees , France to investigate active tectonic structure[12] , Stivos area in the Langadas Basin Northen Greece[22] and in the soil of Taal volcano , the Philippines[23] . The values are lower than those reported across Orlica fault in the Krsko Basin, Slovenia[24] , but are higher than those reported in selected fault sites along the area of Almopia (region of Macedonia, Greek – FYROM borders) , the Mygdonia basin (region of Macedonia , North Aegean border, Greece and the Souli or Patoussi depression[15] .

The values of radon gas concentrations recorded in ground water of Nurpur area are higher than those reported in Amritsar, Gurdaspur , Hoshiarpur and Bathinda districts of Punjab, India , but are either lower or comparable to those reported in Kullu, Hamirpur , Palampur , Dalhousie areas of Himachal Pradesh, India[25-26] . The higher values of radon concentrations in ground water of Kullu and Hamirpur areas of Himachal Pradesh may be due to the presence of uranium mineralization in the area[27] . Also Palampur and Dalhousie areas of Himachal Pradesh lie in the vicinity of Main Boundary Thrust (MBT) of Himalayas and are seismotectonically very active[26].

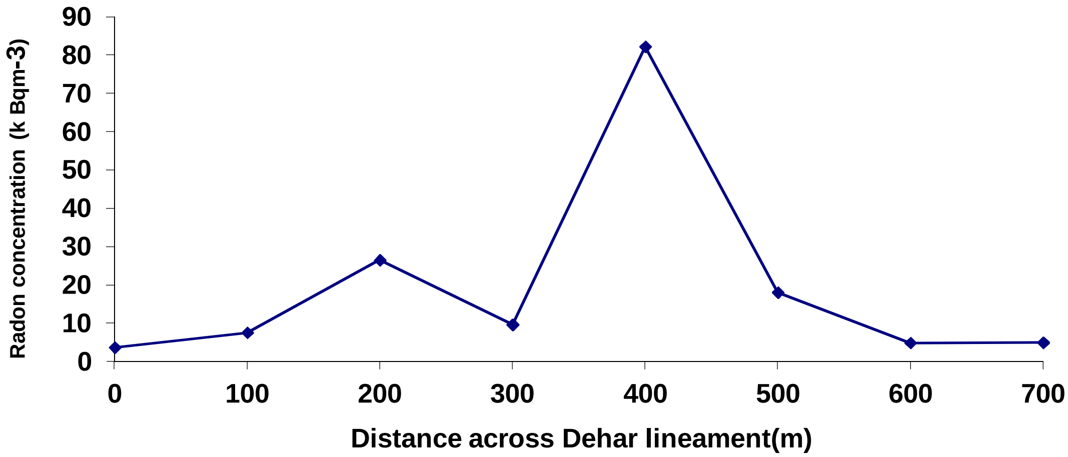

Figure 2: Radon profile across Dehar Lineament.

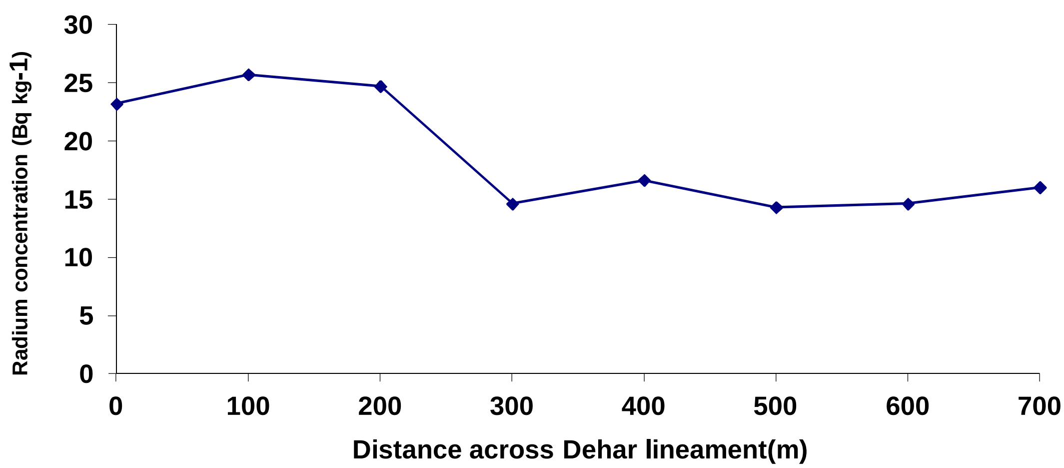

Figure 3: Radium profile across Dehar Lineament

To verify that high soil gas radon values along the active Dehar region are related to some geological anomalies where the gas measured corresponds to the deep origin, rather than to increased uranium and radium contents having only superficial roots, soil samples from some selected sites along and across Dehar lineament have also been analyzed by ‘fission track technique’ and ‘can technique’ reported elsewhere[28.] Also soil gas radon concentration was measured at some sites across the Dehar lineament. Figs. 2 and 3 shows the profiles of soil gas radon and radium across the Dehar lineament. It is clear from these figures that soil gas radon levels increases as one approaches the lineament line, to reach a maximum at the point above or nearest the lineament trend. The value of radium concentrations across the lineament/fault does not show any significant variations. From this study it is concluded that the striking variation of soil gas radon across Dehar lineament is not related to any anomalous distribution of uranium and radium along Dehar lineament as their content in soil samples is low and practically constant to about 1.5 mg kg^{-1} and 18.5 Bq kg^{-1} respectively. Similar behavior of radon gas and radium profiles have been observed across Almopia , Stivos, Gerakarou, Nicomidino and Monoliassa faults in Greece[15]. Higher values of soil gas radon in the tectonically active adjoining Dharamshala region along transverse lineaments have also been reported[1] . Moreover, according to Srivastava et al[29]., the seismicity related patterns of 1986 and 1987 earthquakes in the region are attributed to the activity of the lineaments trending normal to the regional trend. Higher abundances of the soil gas radon along transverse lineament i.e. Dehar lineament and its correlation with the structural elements becomes more significant keeping in view the seismic history of the area**.**

CONCLUSION

- **(i)** Profiles of radon gas in soil and underground water in the study area conforms with the inferred results of lineaments density/trend map.
- **(ii)** Lineament trends observed in the study area conforms to the Main Boundary Thrust passing through the adjoining Dharamshala region and comprises an important tectonic plane of the region namely Jawalamukhi Thrust.
- **(iii)** The region along Dehar lineament and Jawalamukhi Thrust including the Masatgarh region is tectonically more active. The results support the presence of north-south transverse Dehar lineament which cut across varied lithounits including sandstone, conglomerates, sand rocks, alluvium and other recent deposits.
- **(iv)** Since the abundances along the transverse Dehar lineament are high irrespective of the lithology, emanation of radon appear to be controlled by a same source through a deep seated fracture/fault which play an important role in increasing the high radon concentration in groundwater.
- **(v)** High values of soil gas radon along Dehar lineament are related to some geological anomalies (tectonically induced radon) rather than to increased uranium and radium contents.

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