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A reconnaissance study of radon concentrations in Hamadan city, Iran

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Abstract. This paper presents results of a reconnaissance study that used CR-39 alpha track-etch detectors to measure radon concentrations in dwellings in Hamadan, western Iran, significantly, built on permeable alluvial fan deposits. The indoor radon levels recorded varied from 4 (i.e. below the lower limit of detection for the method) to 364 Bq/m^3 with a mean value of 108 Bq/m^3 which is 2.5 times the average global population-weighted indoor radon concentration – these data augment the very few published studies on indoor radon levels in Iran. The maximum radon concentration in Hamadan occurs during the winter period (January to March) with lower concentrations during the autumn. The effective dose equivalent to the population in Hamadan is estimated from this study to be in the region of 2.7 mSv/y, which is above the guidelines for dose to a member of the public of 1 mSv/y suggested by the International Commission on Radiological Protection (ICRP) in 1993. This study supports other work in a number of countries that indicates such permeable "surficial" deposits as being of intermediate to high radon potential. In western Iran, the presence of hammered clay floors, the widespread presence of excavated qanats, the textural properties of surficial deposits and human behaviour intended to cope with winds are likely to be important factors influencing radon concentrations in older buildings.

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1 Introduction

The presence of radon (^{222}Rn) and its decay products in some dwellings in North America (Lubin et al., 1994) and Europe (Darby et al., 1998), together with an increased understanding of the carcinogenic effects of this gas on the human population, has prompted many countries to assess the extent to which they also might have an indoor radon problem. Published studies demonstrate that radon is the largest single contributor to natural radiation exposure for the general public (UNSCEAR, 1993). However, there is limited work published in the international scientific literature on indoor radon concentrations in Iranian homes and workplaces (one exception being Hadad et al., 2007), although some data can be found in less readily available sources (Taghizadeh and Eftekharnejad, 1968; Sohrabi et al., 1993; Samavat, 2002). These though were focussed on High Level Background Radiation Areas (HLBRAs) in northern Iran.

Iran is one of the most mountainous countries in the world (Metz, 1989). Thus the topographic setting and associated climate of Hamadan (at an elevation of 1850 m) suggest that radon concentrations in the winter period in most buildings could be raised (due to temperatures falling as low as −32 °C, with consequently closed doors/windows etc.). In windy and rainy periods that occur in the autumn, average temperatures are in the region of 10 °C, with many householders opening doors and windows for ventilation. The short summer period may experience temperatures as high as 39 °C, but averages in July are around 25 °C. Strong winds can affect the region throughout much of the year, with north and north-west winds in the spring and winter periods which are often humid, persistent west-east winds in the autumn and local winds that develop due to air-pressure differences

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Fig. 1. Location map showing Hamadan in relation to the capital of Iran, Tehran, the high background radiation area of Ramsar and the towns discussed by Hadad et al. (2007).

between elevated areas and the lower plains (Beaumont, 1973; Metz, 1989).

The behaviour of radon gas in buildings constructed on alluvial fan sequences is not well known, and most previous studies with a geological interest have focused on the significance of near-surface bedrocks. Beneath the unconsolidated materials at Hamadan the bedrock geology consists, in part, of limestones of Oligo-Miocene age which crop out as high ground to the south-east of the city, and in the south, eastern and western parts, granites, diorites and contact and regional metamorphic rocks occur.

A potential for higher indoor radon concentrations on Holocene alluvial fans along the Wasatch Range Front (Utah, USA) was suggested by Solomon (1993) and Black and Solomon (1996). Lico and Rowe (1992) noted that Quaternary alluvial fan material (acting as an aquifer, as in Hamadan) occurred at the base of the Carson Range in Nevada, USA, and contained raised radon concentrations because of its contact with fractured Cretaceous granitic bedrocks with high uranium content. A significant normal fault also probably acted as a conduit for deeper radon enriched groundwaters in the area. Other reports have highlighted the importance of surficial deposits more generally (e.g. fluvio-glacial sands/gravels; see Smethurst et al., 2008) in the construction of maps of radon potential from geological data. Breitner et al. (2008) noted that homes built on Finnish eskers (elongated sinuous ridges composed of fluvio-glacial sands and gravels) were not only radon prone, but that 59% of homes built in their study area on the Hollola esker were above the Finnish national reference concentration of 400 Bq/m^3. In the UK, unconsolidated surficial (i.e. “superficial” or “drift” in UK terminology) deposits are responsible for 5% of the variability of indoor radon, with bedrock geology responsible for 24% (Appleton et al., 2008).

In the case of the Hamadan alluvial fan, the gravels (and sands) are mostly derived from the Alvand granites and the associated metamorphic aureole, laid down in a poorly sorted clay matrix (H. Mohseni, personal communication). This provides potential source material in the form of uranium enriched minerals and rock fragments. Many cities are built on surficial sediments whose significance in terms of their permeability associated sedimentary texture, and hence their ability to act as a store, transport pathway and exhalation source in some cases, is not well understood.

This work presents data obtained for radon levels in Hamadan city, Hamadan Province, western Iran (see Fig. 1). This city is not currently known to have a radon problem. It is built mostly on poorly sorted alluvial fan deposits, which is a common scenario in Iran (Fisher, 1968; Beaumont, 1989; Gillmore et al., 2007).

Hamadan (population greater than 700 000) has a variety of dwelling styles. It is one of the oldest cities in the world and has undergone significant urban development at different times (Hiromasa, 1978; Metz, 1989). The dwellings are mostly constructed of two storeys, the most modern of which have a solid concrete base, with open clay tile/brick walls, a steel framework and often clad with polished decorative stone slices. Older buildings are constructed of stones and fired bricks with clay/earth floors, whilst the oldest historic buildings are made from mud brick (adobe). In the modern buildings, the walls are covered with clay and lime on the inside and then painted. Many such dwellings utilize double glazing, but the older homes are usually single glazed (Mohandesin-e moshaver-e Mozh’deh, 1984).

One of the aims of this reconnaissance study was to determine the average indoor radon concentrations, focussing on the brick built dwellings with single glazing which make up more than 80% of the total dwellings (Mohandesin-e moshaver-e Mozh’deh, 1984). Such buildings have more cracks in the floor when compared to relatively new buildings. As a result, it is reasonable to expect higher radon concentrations in such buildings, than in the newer styles. If many homes were found with high radon concentrations by this reconnaissance study, this would suggest that the housing stock in Hamadan should at the very least be tested further. As the adobe built dwellings in Hamadan are mostly abandoned and derelict (Mohandesin-e moshaver-e Mozh’deh, 1984) they were not tested.

2 Measurement method

CR-39 alpha track-etch detectors were placed in homes (and workplaces) between 2005–2009. The detectors used were supplied mostly by RadoSys (Hungary) and details about how such detectors operate and their strengths and

Table 1. Radon levels in Hamadan houses during the autumn season, exposure period of 90 days. The bottom line shows averages for sitting rooms (S), bedrooms (B) and the overall average (M). Households and detector numbers have been coded to protect the identity of individuals. Double glazed property marked with a *. Note that some results are probably below the lower limit of detection (marked in red).

Detector identification	Household	Bedroom (B) Sitting Room (S)	Radon level Bq/m^3
GA1	HA	S	21
GA2	HA	B	77
GA3	HB	S	13
GA4	HB	B	21
GA5	HC	B	25
GA6	HC	S	5
GA7	HD	S	25
GA8	HD	B	26
GA9	HE	B	91
GA10	HE	S	26
GA11	HF	B	13*
GA12	HF	S	13*
GA13	HG	S	13
GA14	HG	B	38
GA15	HH	S	4
GA16	HH	B	7
GA17	HI	S	38
GA18	HJ	B	18
GA19	HJ	S	4
Averages			25 M 16 S 35 B

Table 2. Radon levels in Hamadan buildings during the winter season for 85 days. The bottom line shows averages for sitting rooms (S), bedrooms (B) and the overall average (M). Double glazed property marked with a *.

Detector identification	Household	Bedroom (B) Sitting Room (S)	Radon level Bq/m^3
GW1	HA	S	169
GW2	HA	B	180
GW3	HB	B	109
GW4	HB	S	94
GW5	HC	S	60
GW6	HC	B	165
GW7	HK	B	210
GW8	HK	S	124
GW9	HE	B	184
GW10	HE	S	176
GW11	HL	B	60
GW12	HL	S	34
GW13	HM	B	143
GW14	HF	B	224*
GW15	HF	S	128*
GW16	HG	B	71
GW17	HG	S	56
GW18	HH	S	360
GW19	HH	B	364
Averages			153 M 133 S 171 B

limitations are outlined by Cliff and Gillmore (2001) and Phillips et al. (2004). Over a total time period of 11 months (rather than 12 due to problems of access and recovery), 70 detectors were left for time periods that reflected various seasons, measuring radon concentrations in bedrooms and sittings rooms following as far as possible the protocols established by the UK Health Protection Agency (HPA). One detector was also placed in the open atmosphere for a 3 month period to assess whether any radon was present. This returned a result that was below the lower limit of detection.

After exposure, all detectors were wrapped in their protective aluminium foils and returned to the metrology laboratory for processing at Bradford University (and later at Kingston University, UK, which is a laboratory validated by the UK Health Protection Agency for measurement in domestic properties). In the laboratory detectors were chemically etched with a 32% concentration by weight of NaOH solution at 60 °C for 4 h and then washed with distilled water and dried. The tracks for were counted using an automated RadoSys RadoMeter microscope and computer unit. The typical sensitivity of this system for a RadoSys alpha track-etch detector is 45 tracks per square mm per one hour exposure to a level of 1 kBq/m^3. The annual effective dose (D e) for households was calculated using the following formula suggested by UNSCEAR (2000): D e=C Rn F.T.D. Where, C Rn is ^{222}Rn concentration (in Bq/m^{-3}), F is the ^{222}Rn equilibrium factor indoor (assumed to be 0.4), T is the indoor occupancy time ($0.8\times24\,\mathrm{h}\times365.25\approx7010\,\mathrm{h/y}$), and D is the dose conversion factor (9×106 mSv/h per Bq/m^3).

3 Results

Tables 1 to 3 show the results of data collected and Fig. 2 the location of homes measured. The range of radon concentrations varied from 4 to 364 Bq/m^3 for homes. The mean radon concentrations for autumn, winter and for the spring combined with the summer seasons for 5 months (April to August 2006) was 145 Bq/m^3. The mean radon concentrations for the autumn (October to December 2005) and winter (January to March 2006) were 25 Bq/m^3, 153 Bq/m^3, respectively. The maximum measurement was 364 Bq/m^3 in a ground floor bedroom during the winter. The minimum on the other hand of 4 Bq/m^3 was observed both for a bedroom

Table 3. Radon concentrations during the combined spring and summer period, for 146 days. The bottom line shows averages for sitting rooms (S), bedrooms (B) and the overall average (M). Double glazed property marked with a *.

Detector identification	Household	Bedroom (B) Sitting Room (S)	Radon level Bq/m^3
GSS1	HE	B	257
GSS2	HE	S	162
GSS3	HK	B	205
GSS4	HL	B	218
GSS5	HG	B	123
GSS6	HG	S	117
GSS7	HF	S	90*
GSS8	HF	B	112*
GSS9	HA	B	163
GSS10	HA	S	114
GSS11	HC	B	101
GSS12	HC	S	81
Averages			145 M 117 S 165 B

and a sitting room during the autumn respectively, but it should be noted that this is below the lower limit of detection (LLD) for CR-39 SSNTDs, which is in the region of 10–20 Bq/m^3 for around 100 days exposure. The radon levels in the winter season were found to be higher than in the windy autumn season. The double glazed property (most of the results were for single glazed) showed some of the lowest results in the Autumn, with higher results in the winter, and lower results in the spring and summer period. The effective dose equivalent, for those living in Hamadan homes, with a mean radon concentration of 108 Bq/m^3 to the population, is equal to 2.7 mSv/y.

4 Discussion

The expectation that radon concentrations would be relatively low in the autumn in homes, due to windows / doors being open was proved correct by these new data. The maximum mean level was observed during the winter period, as one might expect from UK data (see Phillips et al., 2004). In the winter season, due to the relatively cold weather (typically below minus 10 °C) windows and doors are closed, with more restricted air ventilation (together with heating), and hence accumulated radon concentrations in rooms are higher. It is interesting to note that radon concentrations in the summer and winter are not dissimilar. This may be because of inhabitants closing doors and windows in the summer to keep hot air from entering the buildings, although in the year of measurement the summer was wetter and cooler than in the previous year.

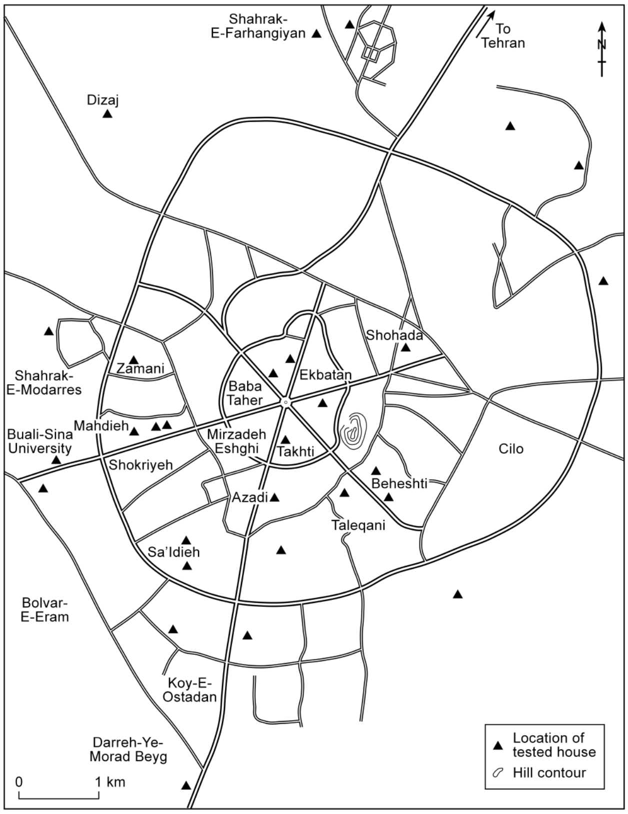

Fig. 2. Plan view of the street layout of Hamadan showing districts together with the location of indoor radon measurement sites.

A recent study of radon in homes in Iran was published by Hadad et al. (2007) focussed on four northern cities (Lahijan, Arbadil, Sar-Ein and Namin, see Fig. 1). The average radon concentrations in these cities were (in order) 163, 240, 160 and 144 Bq/m^3. These were in a region close to an area known for its high background radiation levels (Ramsar, with its associated hot water springs and ^{226}Ra/^{222}Rn content, Fig. 1; Samavat, 2002). The mean radon concentration in this study for Hamadan was 108 Bq/m^3: the highest concentration of 364 Bq/m^3 being observed in a ground floor bedroom with a simple mud floor, and the lowest observed in a ground floor bedroom which had a floor covered with a better engineered clay material. Earth floors may crack easily (through drying out or shrinking and swelling if they contain bentonite) and allow radon gas to permeate through the ground to the floor level inside of such homes. Seasonal variation showed that during the winter period due to the closure of entrance doors and windows, radon gas accumulated in the more restricted spaces and led to increased radon levels.

The Quaternary fan deposits in this study in Hamadan are in part the source of local water supply (which is the case in many Iranian settlements; Beaumont, 1974), with many vertical well shafts. This may be influencing the flux of radon. Some of these are connected to horizontal

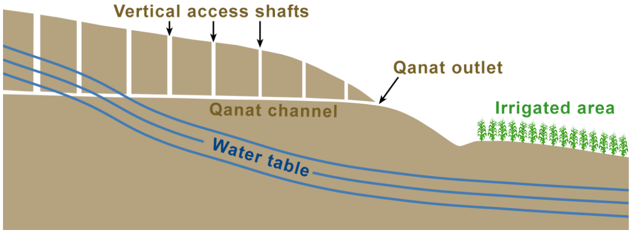

Fig. 3. Cartoon cross-section through a typical qanat.

qanats distributing water, with average tunnel dimensions of 1.2 m height and 0.8 m width, stretching for typically 0–5 km (Beaumont, 1989; see Fig. 3), and also providing easy pathways for radon. The mother wells for these qanats are normally at depths of between 10 m and 50 m (maximum recorded 250 m) (Beaumont, 1974). A survey by the authors of atmospheric radon down some of these vertical well shafts, near to the homes measured, noted high concentrations (with a maximum of 36 600 Bq/m^3, measured near the water surface), suggesting that radon-rich groundwaters may be playing a significant role in the transportation of radon through the alluvial fan system. Various authors (Faraji, 1987; Farshad and Zinck, 1998) note that Hamadan is well supplied (in Iranian terms) with underground water, with over 1500 qanats, 3000 springs, 6000 deep wells and 5000 semi-deep wells. Rivers also discharge from the mountains around Hamadan and are utilised in agriculture, but their flow can be highly variable (Beaumont, 1973). Gomes et al. (2008) highlighted the fact that groundwater from coarse geologically young sediments show radon potential based on groundwater measurements, despite low uranium content, in northern Portugal.

The limestones of Oligo-Miocene age which crop out as high ground in the south-east of the city of Hamadan, (see Fig. 2 – small area highlighted by contours) are known to contain caves to the north, some of these have been shown to contain high radon levels. Jabarivasal and Gillmore (2008), highlighted a maximum concentrated of 4317 Bq/m^3 with cave guides receiving an estimated yearly dose of around 16.5 mSv in the Alisadr caves. This is significant because Oligo-Miocene limestone partly underlies the permeable alluvial fan sands and gravels that underlay the city.

Some metallic ore mineralization has also taken place in the area, with deposits of gold and antimony (Maanijou and Aliani, 2001). Gillmore et al. (2005), Grattan et al. (2004) and el-Rishi et al. (2007) noted elsewhere that raised indoor radon concentrations can occur in regions that have been mined, partly because of the presence of associated uneconomic uranium minerals, partly because of introduced ground permeability (Appleton, 2005). In the Hamadan area there are 142 active mines, although mostly for building materials (Markaz-e aamaar-e Iran, 1996). The igneous and metamorphic bedrocks may well also be a source for uranium, radium (and hence radon gas). The folded (and fractured) nature of the bedrock geology (with faults such as the Keshin Simin and the Tafrijan-Mangavi-kandelan) will contribute to the transport of radon gas to the partially overlying alluvial fan sequences. Appleton (2005) notes that drier permeable soils and bedrock such as limestones and coarse glacial deposits and fractured/cavernous bedrock together with hill slopes, are usually associated with high levels of indoor radon, whilst Solomon et al. (2005) noted that alluvial fan sediments act as storage and transport conduits for ^{222}Rn enriched groundwater.

Pleistocene alluvial fans exist in the UK in areas known for high indoor radon concentrations, such as at the edge of Dartmoor and the Mendip region in SW England (Gillmore et al., 2001). The fans in Dartmoor are rich in coarse sediments, span the boundary between granites and metamorphic aureole rocks, and are overlain by head deposits (aeolian and solifluction in origin) (Gilbertson, 1973). However, no attempt has been made to correlate indoor radon with such surficial deposits in the UK. Although there are similarities between the geological setting of Hamadan and regions around Dartmoor for example, the Iranian fans are much larger in scale, and occur in a semiarid as opposed to a temperate climate.

5 Conclusions

The mean radon concentration in Hamadan's dwellings, noted in this reconnaissance study, is relatively high when compared with the average global population-weighted radon concentration of about 40 Bq/m^3 indoors (Magalhaes et al., 2003). This may be due, in part, to the construction style of the majority of buildings in Hamadan, where the floor is covered with clay rather than concrete, together with the prevalence of older brick buildings. The presence of these clay/earth floors may play a significant role regarding raised indoor radon gas concentrations, with gas being released through the floor and penetrating inside such buildings. The geology of the area though is probably the primary control on indoor radon. In particular the surficial geology, that is, the presence of highly porous ground materials, which act as a local water conduit, together with the extensive construction and use of qanats providing additional gas pathways. The movement of water through the fan sequence will also influence transport of the gas. The importance of the existence of permeable ground materials where radon concentrations are concerned was noted by Gillmore et al. (2005) in the UK, Solomon (1993) in the USA (the latter with respect to alluvial fans), and Smethurst et al. (2008) in Norway.

The annual absorbed dose is estimated in the city of Hamadan, in this reconnaissance study, to be 2.7 mSv. This dose when compared with the ICRP recommendation of 1 mSv/y for a member of the public is relatively high (ICRP, 1993), although it is lower than that observed in Ardabil, northern Iran, by Hadad et al. (2007) which was 5.00 mSv/y. As a result of this study, it is therefore recommended that a more extensive study of radon in dwellings in such regions (in particular on alluvial fans) should be undertaken to more fully quantify the risk to householders. Local authorities can then take appropriate action through a targeted response to reduce risks in areas of risk.

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