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Environmental Distribution of the Radon in a Heavily Populated Area: Preliminary Hazard Evaluation and Inference on Risk Factors in Pescara, Central Italy

Francesco Stoppa

Dipartimento di Scienze, Università G. D'Annunzio, Chieti, Pescara, Italy.
Email: fstoppa@unich.it

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ABSTRACT

The presence of ionizing sources is a high-risk condition if related to a poor management of the hygiene and health of the anthropic environment. Increased hazard derives from the addition of artificial sources to natural sources and the consequent possible late occurrence of epidemic cancer. Therefore, the expenses for medical treatments and potential losses of human lives are thought to be relevant. Although the role of natural exposure is still poorly assessed, it is reasonable that it accounts for a chronic hazard, while the artificial one may constitute an acute hazard. In theory, the medium and large-scale monitoring of the Radon is simple and can be applied in detail to sensible targets. However, mitigation of Radon risk is particularly complex due to the intrinsic structural vulnerability of the urban environment and the general lack of epidemiological data that constrain the extent of specific biological damage. In Italy was suggested a limit to the exposure in working place, instead limits for other private and public facilities are not well established. Despite legal advice, the sensitivity of the social system is low due to the elusive nature of the Radon hazard, and the case considered in this paper account for unpreparedness of the Sanitary and Environmental Authorities when facing to a possible crisis. A monitoring field survey revealed Radon concentrations of at least three times higher than that expected geologically in a fairly localized area of Pescara, Central Italy. The values are about 25 - 30 *times the maximum allowed in the buildings. However, these measures are underground and average indoor values in the area were still acceptable. The measures repeated after a year confirms an upward tendency of the previous values. However, it was not possible to go deeper in the investigation about the nature of this underground anomaly because of the strong opposition of some members of the Environmental and Sanitary Authorities. Some rumours filtered by one of this Institution, suggesting a possible correlation of the anomaly with the uncontrolled disposal of radio-iridium needles used in the nearby hospital. A further legal action instructed against the Author discouraged the publication of the data so far. This account for a situation of increased risk. Even if hazardous natural Radon emissions can be investigated, it is difficult to evaluate vulnerability factors related to non-natural diffusion of radio-nuclides progenitors of the Radon (i.e. uranium and radium). Confidence on notional calculation of the hazard by means of algorithms, decreases the alert threshold and promotes the potentially involved authorities to discourage further studies. This increases the vulnerability of the system. Due to negligence and violation of safety norms in Italy, accidents involving ionization agent dispersion in the environment are likely and are an instructive study case. The result of this study may promote mitigation actions and, hopefully, a decrease of the radioactivity risk in a populated area. This paper is intended as a case history depicting unexpected Radon distribution in a city. In these conditions, the density of population and the system unawareness contribute greatly to raise the risk especially if a natural explanation could not find. The suspect of an artificial source, far more hazardous than natural Radon itself, is still up for the investigated area.*

Keywords**:** *Radioactive Pollution, Radon Measurements, Radon Distribution, Radon Risk Analysis, Pescara-Italy*

1. Introduction

This Radon is an important contributor to the natural environmental radioactivity. Among the 26 known isotopes of the Radon the most important is the ^{222}Rn, which has a mean lifetime of 5.517 days. The short half-life of ^{222}Rn is 3.82 days, a fact which precludes slow transport over great distances, and this make important its near-surface sources [1] or concentration/transport along permeable discontinuities [2]. Radon becomes very mobile exploiting the permeability of the rocks and the presence of water and can be quickly carried to the surface and enters building [3-11]. It accumulates in basements being much heavier of the atmospheric air but can be distributed by plumbing system, heat system and indoor ascending air column (*i.e.* stairs and elevator).

Once inhaled and dissolved in the body fluids, Radon is conveyed in the body tissues. ^{222}Rn decays into short-live radioactive isotopes ^{218}polonium and ^{214}lead by emitting high-energy alpha particles causing damage to cellular DNA. This can originate cancer cells if DNA is then reconstructed imperfectly. The health effects of Radon exposure are only observed over long periods and can result in lung cancer [12,13]. However, the human species has evolved in contact with natural ionizing sources and in the vast majority of cases Radon does not constitute a major hazard. Perturbation of this equilibrium comes from the unsustainable use of the land, a mixture of industrial and civil uses and improper handling and disposal of radioactive substances or sources and medical over exposure, as well. All these factors represent a significant contribute to the risk and can lead to serious health problems affecting social health-care expense and facilities.

In Italy there is still no legislation concerning the maximum concentration of Radon in private homes and schools, hospitals and prisons. Legislation does exist for the industrial workplaces and is regulated upon the Legislative Decree No. 241, 26/05/2000. A reference level of 500 Bq/m³ is recommended. A similar value for public facilities and private houses may be considered too high compared to those of many other countries which have adopted much lower reference values: United States recommends 150 Bq/m³, United Kingdom 200 Bq/m³, Germany 250 Bq/m³. However, countries with more radioactive back-ground geological emission, such as Switzerland, have shifted these limits to higher value. In all countries the maximum value suggested for private and public building are 50% of those established for working places. It is argued that average maximum values for private houses and schools should be around 250 Bq/m³ in average (old and new buildings). Italian areas with volcanic or igneous substrata, *i.e.* western coast of Central Italy, NE Sardinia, part of the Sicily and some Alpine areas, have high geological contribute of Radon [14,15]. In these areas indoor Radon is expected to exceed the above precaution limits. In 1990 the European Union has issued a recommendation to take the faster and the higher level of precaution, to identify areas with high risk of Radon in houses, also using indirect parameters such as Radon activity in soil and building materials. This is in fact based on the prejudice that the hazard only comes from natural sources (geologic) or artefacts derived from them. There was a big effort in the literature to associate elevated Rn soil-gas values with high indoor Rn concentrations [e.g. 16,17] and many authors believe that the method can be used to evaluate the potential indoor hazard of areas having elevated soil-gas value [18]. They suggest that it is possible to define a geochemical threshold, based on the ^{222}Rn activity at equilibrium with parent radio-nuclides in the surveyed soil [19].

It is generally assumed that:

$$Cind = Cout + \left(Usoil/\lambda v\right)$$

where *Cind* is the concentration of indoor Radon, Cout is the concentration of outdoor Radon; Usoil is the indoor rate of entry of Radon from the ground; λv is the rate of ventilation. The contribution of input from the subsoil is imagined as determined by a factor related to the geology of the area type ($\tau 1$), by a factor represented by the distance from the ground of the dwelling ($\tau 2$) and a third factor dependent by climate and type of housing, which characterizes the routes of entry and the pressure underground gas ($\tau 3$). The equation above thus becomes as follows:

$$Cind = Cout + \mu\tau 1\tau 2\tau 3 \rightarrow \ln\left(Cind - Cout\right)$$
$$= \ln\left(\mu\right) + \ln\left(\tau 1\right) + \ln\left(\tau 2\right) + \ln\left(\tau 3\right)$$

where μ is a normalization of the value of indoor Radon concentration due to soil source. Radon samples exceeding the computed value may be linked to both natural and artificial accidents which can disturb this equation. Practical experience indicates that the transfer factor ground to home (basements) Radon can varies from 1:2 to 1:100, even if in most cases is low. Therefore, it is more prudent, in populated zone, to build maps of hazard by determining Radon alpha-decay experimentally. The method that seemed most readable, relatively rapid and affordable, to this type of study is to perform standardised measures into underground wells. This reproduces the equilibrium condition for permeable basements, which is the less favorable case. A further comparison of the measured data with those expected basing on the radioactivity of the country rocks and their geology is then needed to evaluate nature of the sources and distribution of the hazard.

2. Spectrometry

The contribution of the radio-nuclides present in the Pescara country-rock types was measured at Centre of Environmental Radioactivity (CRA) of Perugia through a spectrometer γ HPGe. Data processing was done using specific software leading to identify and calculate the corresponding activities of radio-nuclides in the sample (**Table 1**).

Uncertainty of measurements derive from interpolation of the efficiency curve which depends on the uncertainty of the activity of the calibration sources and the fitting of the peaks.

In terms of relative error (ε):

$$\varepsilon\left[(\text{activity} = \left(\text{peak area } \varepsilon\right) + \left(\varepsilon \text{ efficiency}\right)2\right]1/2$$

the magnitude of which is approximately equal to:

$$\varepsilon \text{ peak area} = 2.3\% \ \varepsilon = 1\% - 2\% \text{ efficiency}.$$

Four rock-types have been selected as representative

Table 1. Radioactive nuclides content and activity for rock-types representative of the substrate of the city of Pescara and building materials. Measurements indicated both as Bq/kg and ppm.

Sample	^{238}U			^{232}Th			^{40}K	
		Bq/kg	%		Bq/kg	%	Bq/kg	%
Beach sand	^{214}Pb	14.68	2.30	^{228}Ac	10.20	5.20	342	1.10
	^{214}Bi	13.30	2.60	^{212}Pb	12.95	2.10		
				^{212}Bi	13.47	10.50		
				^{208}Tl	17.63	3.40		
Average		13.99			13.56			
ppm		1.13			3.36			1.32
Pleistoc. sand	^{214}Pb	42.65	1.10	^{228}Ac	20.66	2.70	436	1.00
	^{214}Bi	39.83	1.10	^{212}Pb	24.63	1.50		
				^{212}Bi	24.74	9.50		
				^{208}Tl	28.15	2.80		
Average		41.24			24.55			
ppm		3.34			6.08			1.69
Silt	^{214}Pb	32.92	1.60	^{228}Ac	30.06	2.60	587	1.00
	^{214}Bi	29.46	1.30	^{212}Pb	34.01	1.20		
				^{212}Bi	33.25	5.60		
				^{208}Tl	38.38	2.40		
ppm		2.53			8.40			2.27
Clay	^{214}Pb	47.43	1.10	^{228}Ac	27.77	2.50	496	1.00
	^{214}Bi	42.40	1.00	^{212}Pb	32.06	1.10		
				^{212}Bi	33.46	6.60		
				^{208}Tl	34.19	2.30		
Average		44.92			31.87			
ppm		3.64			7.89			1.92
Limestone	^{214}Pb	9.17	1.51	^{228}Ac	1.66	7.25	6.57	8.52
	^{214}Bi	8.40	1.22	^{212}Pb	2.89	2.90		
				^{212}Bi	2.68	17.28		
				^{208}Tl	6.80	2.94		
Average		8.79			3.51			
ppm		0.71			0.87			0.03
Gypsum	^{214}Pb	58.91	0.80	^{228}Ac	1.13		36.0	4.86
	^{214}Bi	52.01	0.76	^{212}Pb	4.97	5.14		
				^{212}Bi	3.98	27.57		
				^{208}Tl	8.82	4.64		
Average		55.46			4.73			
ppm		4.50			1.17			0.14

of the main stratigraphic units forming the substrate of the city of Pescara. Beach sand (sand 1) that commonly forms the coastal plain, Pleistocene sand (sand 2) and marine clay that form the hills and silts that form the Pescara river alluvial plain. Limestone and gypsum samples from the Pescara province area have been measured only for reference to building materials. The **Table 1** sets out the measures obtained with the spectrometer. Measurements are indicated both in Bq/kg and in ppm. The natural content of ^{238}U, ^{232}Th and ^{40}K was determined to understand how much they take part in the radioactivity of the samples. The values obtained by spectrometry were plotted constructing curves of correlation between the rock types and their natural content of ^{238}U, ^{232}Th, and ^{40}K (**Figure 1**).

Limestone is always low in radionuclides. Gypsum is high in ^{238}U but low in ^{232}Th and ^{40}K. ^{238}U is the biggest and ubiquitous contributor to total radioactivity in the Pescara rocks. ^{232}Th and ^{40}K are important only in clay and silt. There is a constant increase in the radionuclide contents passing through beach-sand, Pleistocene sand, clay and silt.

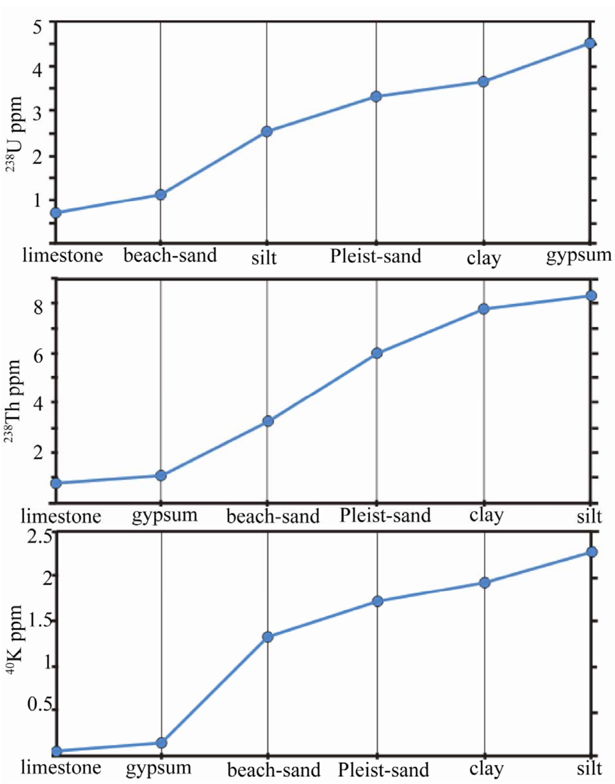


Figure 1. Radionuclide content of Pescara rock types expressed in ppm. The values obtained by spectrometry were plotted putting the rock in order of increasing content of ^{238}U, ^{232}Th, and ^{40}K.

3. Measures of Environmental Radon

The measure stations were distributed in all districts of the city, making measures of all the geological units with a sufficient number of stations and in different locations spaced not more than 1 km in a straight line. Most of the stratigraphic units of Pescara are heterogeneous and consist of several rock types. It was analyzed the most abundant and representative rock type for each unit. Medium and long term environmental measures on site consist of a PVC pipe with inside diameter of 64 mm and 1.5 m long. The pipe has an open end that is buried to a depth of one meter while the other end is fitted with a screw back with gasket. The measurements were carried out in dry and sealed pipe condition. The dosimeters consist of cellulose-nitrate film sensitive to α-radiation energies lower than 4 MeV. The dosimeters were put in the pipe suspended halfway after a convenient time necessary to equilibrate the air in the pipe with that in the ground. The dosimeters were recovered after an exposure time of 168 hours and protected by further exposure to Radon and quickly processed for counting. Even if for outdoor measurements time is considerably greater we consider this method is suitable in approximating indoor measurement conditions. α radiation emitted by ^{222}Rn and its decay products ^{218}Po and ^{210}Po, with energies of 5:49, 6 and 7.69 MeV respectively, cause damage tracks along the route taken in the film of cellulose nitrate. An alkaline bath is used to improve the tracks before their counting. To estimate the concentration of ^{222}Rn from the detector, the density of the traces must be divided by the calibration factor E and h exposure time:

$$Ci = R_{6.5}/(Eh)\left(Bq/m^3\right).$$

The method [20] has an uncertainty which gets less than 20% for values > 50 Bq/m^3. The unit of measurement of radiation is the Curie, which is equivalent to 3.7 × 10^{10} disintegrations per second, but for the Radon has been widely used the Becquerel (Bq) which is equivalent to one disintegration per second.

The area of the municipality of Pescara can be divided into four main lithostratigraphic zones having different average concentration of Radon. **Table 2** shows the number of disintegration tracks and the calculated concentration of the underground measures made in the above rock types.

Four outdoor measures performed for reference in the Pescara area gave constant values of 4 Bq/m^3 which are below the detection method.

Underground values are always well up the detection limit and range from near 100 to >7400 Bq/m^3. Intervals of 500 Bq/m^3 are here considered significantly different

Table 2. Underground radon measurement.

Measure station	Average tracks	Bq/m^3
39	240	721
40	290	702
43	375	1061
42	110	333
41	2145	7391
4	143	504
2	1355	4525
11	643	2203
37	940	2609
48	546	1784
31	34	103
35	56	164
30	496	1661
24	343	1104
36	850	2881
26	17	55
18	484	1608
21	133	437
14	31	114
23	1345	4419
45	164	526
34	144	456
38	585	1779
47	20	46
33	906	2760
49	34	107
32	39	116
3	589	2049
1	1049	3539
25	239	715
46	740	2528
29	921	2952
27	676	2142
44	11	24
22	1040	3447
19	394	1365
13	325	1144
20	1138	3946
5	125	403
18	553	1750
6	669	2386
12	306	1038
15	125	431

among measure groups and are shown in term of frequency in **Figure 2**. Most of the measures with values below 500 Bq/m^3 (30% of the total) are from the coastal plain. This reflects a low content of Radon parent isotopes, efficient exchange between porous soil and atmosphere due to tide oscillations.

The values of concentration between 500 and 3000 Bq/m^3 account for 60% of the total of the measures and is a range representative of the Pescara country rocks α-emission (2318 Bq/m^3). Values from 3000 to 5000 Bq/m^3 show a sharp decrease and account for about 10% of the measures. This general distribution is considered readable because there is a good correlation between the content of radioactive isotopes and the underground α-emission by means of a reasonable statistical distribution.

Average values of Bq/m^3 for the 4 main stratigraphyc units of Pescara city area are: A Holocene seashore-sands and fossil dunes with an average concentration of 718 Bq/m^3, B Holocene silts, average 2376 Bq/m^3, C Pleistocene sands, average 3008 Bq/m^3, D Pleistocene clay average 1570 Bq/m^3. These averages do not correspond neatly to their natural radio nuclides contents. Clay has the highest radionuclide content (**Figure 1**) but an average Radon activity which is lower then Peistocene sends that are lower in radionuclides. However, beach sand radon activity is in good agreement. Average Radon values of silt also fit in well with average radionuclide contents. Variation in the same geological unit could be related to a variable quantity of water which is the second most important factor in Radon distribution after the abundance of parent radioactive isotopes. There is a significant gap of measures between 5000 and 7000

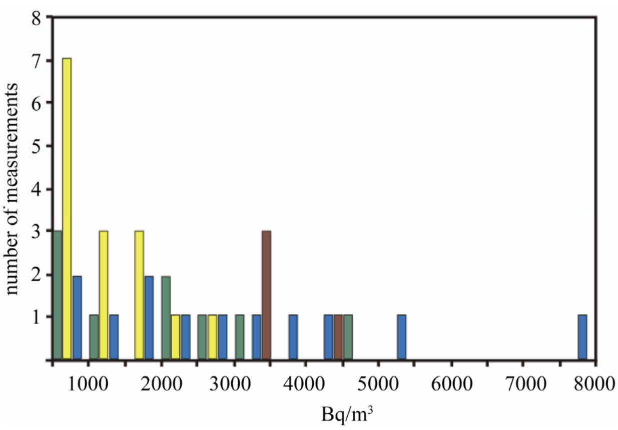


Figure 2. 500 Bq/m^3 intervals of underground Radon values are shown in term of their frequency (numbers of measure/station). Unit A Holocene sands (blue), Unit B Holocene silts (yellow), Unit C Pleistocene sands (brown), Unit D Pleistocene clay (green).

Bq/m^3 explainable with the general absence of high radioactive soils in Pescara area.

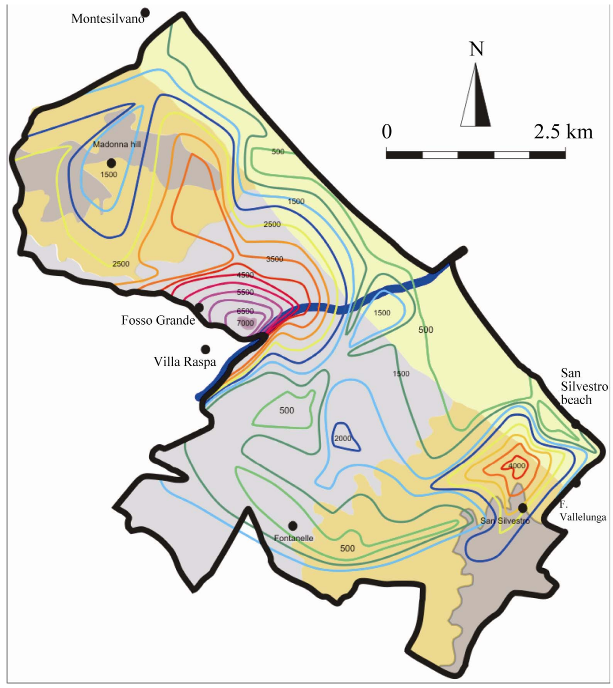
The values above 7000 Bq/m^3 which are well outside of the range for Pescara Radon value, refer to measures located in a relatively small area of the city. In this area, measures have been repeated twice in two different holes. It was checked if there was artefacts on the surface or underground which may influence the measure. We did not find any visible source of radioactivity or able to concentrate locally Radon. The measures proved to be real.

4. Distribution of Radioactivity

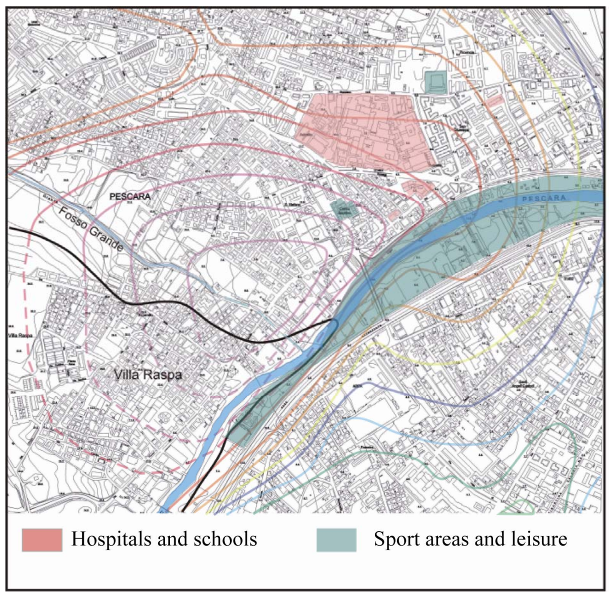
The map of the concentration curves, constructed by the method of linear interpolation of triangles, is the fastest way to visualise the broad distribution of gas Radon near the interface rock-atmosphere (**Figure 3(a)**). It may be expected that isochemical curves envelop and soften the cumulate effects due to local rock-type distribution, position of the underground water table, presence of geological discontinuities and other possible sources. This preliminary map is only for a general Radon hazard evaluation. However, is easy to read and understandable to non-geochemists and of practical use to orientate further investigation. It can enter in the management of the urban land-use planning. It can be used as a first order layer in the risk assessment when overlapped by a population density/age and/or quality and vulnerability of the building, public or private use and other sensible risk factor.

Starting from the coastline and moving up hill is seen that the concentration values increase towards inland. There is a regular increase from 500 to 3500 Bq/m^3 passing through unit A, D and C in the north part that goes from the border with the town of Montesilvano up the hill of Madonna (**Figure 3(a)**). Isochemical curves are somewhat parallel to the geological formation boundaries. A similar situation is seen to the south of the city next to the border with Francavilla al Mare municipality where values passes from 500 to 4000 Bq/m^3 within a few thousand meters going from the beach of San Silvestro to San Silvestro hill near the Vallelunga ditch (**Figure 3(a)**).

In the alluvial valley, in the unit B area, the gradient of the curves is very different north and south of the Pescara River due to a large pick of Radon in the north section. A rather complex pattern Radon distribution with a maximum located between the Pescara Hospital, the Pescara River and Fosso Grande creek, which extends towards Villa Raspa. The Pescara river seem to limit the anomaly resulting in an accumulation of isochemical curves which become parallel passing from 500 on the right bank to over 7000 Bq/m^3 on the left bank of the river. The isochemical curves change abruptly from N-S direction to a E-W direction. The situation changes in the



(a)



(b)

Figure 3. (a): The map of the concentration curves, constructed by the method of linear interpolation of triangles, is the fastest way to visualize the broad distribution of gas Radon near the interface soil-atmosphere; (b): Detail of Figure 3(a) showing the Radon isochemical curves in Bq/m^3 in the "hot spot" located SW of the Pescara hospital.

south bank of the river which in contrast shows the lower concentrations throughout the B unit, with a maximum represented by the curve 2000, which has a very limited extent. In addition, the area show relative minimum bounded by the isochemical curve 500, near Fontanelle area (**Figure 3(a)**).

Four main features rise from the isochemical map analyses, a general overlap of Radon measures in the 4 stratigraphic units, the low value related to the coast line and recent alluvial plain, the influence of the river and the presence of a Radon peak which is not related to a particular geological feature. The data collected and presented are too limited to allow the sure statement of the origin of the distribution but allow some general assumptions.

5. Discussion about the Origin of the Pescara Positive Anomaly

There are some hypothetical natural causes that can explain such an anomaly. These include the concentration of natural radio-nuclides by reduction in organic complexes or accumulation of radioactive heavy minerals. The substrate in which the measurements were made is of silico-clastic nature thus the possible presence of detritus of radioactive minerals is compatible with the alluvial depositional environment of river Pescara. However, in the Pescara river basin there are not rocks that may contain sensible radio-nuclides or that can be related to high values of underground Radon.

Among more obvious anthropic sources of radioactive pollution, two are more likely in the investigated area: radio-nuclides used in lightning rods to improve field of ionization and radioactive sticks used in the treatment of the cancer.

A radioactive lightning rod has a radioactive substance inside the metal tip, mainly ^{226}Radio that is capable to emit harmful radiation for centuries. Radioactive tip has the task to ionize the air and then makes it conductive to capture lightning in a larger radius from the lightning rod itself. The installation of radioactive lightning rods in Italy began in 1945, when at least a dozen construction companies were born. They were installed until the 1981when legislation completely prohibited the use in Italy. Unfortunately, their disposal is still ongoing, it is estimated that some thousand are still in use but perhaps even more. It is quite difficult to distinguish radioactive lighting rods from the others. The more critical point is that we don't know how many and where the dismissed radioactive rods were disposed.

Interstitial radiation therapy involves the injection of radioactive preparations (radio, iridium) in the form of needles, wires or seeds in the cancer tissue: it has the advantage of concentrating high doses of radiation in a limited area and in a short time. It was largely used for local application in cancers of the mouth, tongue, skin, anus. The variant intra-cavity radiation therapy involves the insertion of interstitial radiation transmitters in the vagina or uterus, for example. It happened in the past that anti-cancer radio devices were misused. In some Abruzzi Hospitals, including that of Pescara, was reported lost of radio-iridio needles. When dispersed in the environment they suffer from rapid degradation and disintegration. Highly radioactive particles can be carried by sewage disposals especially in uncontrolled waste. Can enter the river system and be transported downstream by emitting large amounts of Radon and radioactivity.

6. Mitigation

Regarding radioprotection considerations, the values measured in boreholes or are not comparable with the indoors one. The ground values (>7000 Bq/m^3) are relatively low if compared with those of volcanic areas (such as Rome area) and would be significant in case of underground workplace (caves, mines, cellars, etc.). However, the combination of an unevaluated radioactive hazard, potentially unrelated to a natural source, in a densely populated area imply a serious risk which must be assessed and mitigated. Amount of the exposed value depends from extension and evolution of the radioactivity, and its acute or chronic release in the environment.

The presence of a peak of radioactivity in the ground which is not immediately explained by geological causes puts a light on a potential risk that may extend beyond the indoor Radon in an area of the city of Pescara. The Pescara Radon hotspot, may suggest a possible emergence downstream of the Hospital and/or the Fossa Grande waste disposals located about 2.5 km WNW of the anomaly. Presence of highly active radionuclide artefacts comport a bigger hazard than Radon itself. Part of the underground Radon in the future may also affect private homes and public buildings located in areas with a higher concentration of this radioactive gas.

The Radon anomaly lies in a densely populated residential area (**Figure 3(b)**). In addition, there are sport centres, the city's main hospital, a kindergarten and an elementary school. As mentioned, measures of indoor Radon in the schools seem reassuring, however, the nature of the hazard is not completely understood and a subsequent risk assessment should be made. A quantitative study at small-scale (1:5000) is required in constructing seasonal isochemical card with the aim to circumscribe the amount and nature of the goods and human life exposure. Specific statistical data and insurance data can be used but they would add a little considering the high population density.

The vulnerability is a measure of non-response of a community to a possible radioactive treat. In a heavily built area is not easy to perform radioactivity survey. A major problem arose from the distrust of the inhabitants which are concerned about possible consequence of find radioactivity in their property. This non collaborative behaviour has to be taken into account and suggest possible difficulties in mitigation preparedness. Vulnerability merges both geological and anthropogenic factors: soil permeability, water table oscillation and exchange with the river, ratio of outdoor/indoor and artificial/natural exposure. Vulnerability is increased by the lack of a historical analysis of the use of nearby suspicious site such as uncontrolled landfill and waste disposals or other industrial uses. To our knowledge specific epidemiology of lung cancer, young-people leukaemia and other critical and potential Radon-related disease is not yet available. Previous experience about neglecting or misinterpreting the Radon data indicates that Authority and citizens awareness is very low.

Nature of the hazard is complex and may be complicate. The present state of the art suggests that an unevaluated radioactive pollution is possible. A Radon hazard certainly exists and has to be considered. Evaluation measures should comprise spectrometric analysis apparatus and speditive measure of Radon in the soil and water the extent and intensity of the anomaly. Also extending the monitoring to the public and private buildings to evaluate entering ratio of indoor Radon. It would also be appropriate to combine measures of Radon with spectrometry and in situ measurements of gamma exposure (boreholes) on soil and sweepings suspected of contamination, including coring operated in buried waste disposals.

7. Conclusions

The distribution of the measures in the City of Pescara is mostly explainable with the natural contribute of radioactivity by Uranium, Thorium and K contents in the rocks. The general distribution reflects both surface morphology and substrate composition. The measures also show that this contribute is modified by the position of the underground water table and sea shore. This situation does not account for the values located among the Pescara Hospital, the Pescara river and the Fosso Grande creek. This area falls within isochimichal curves between 5000 and 7000 Bq/m^3. Those values are not observed or expected in the sedimentary rocks in Pescara area. Since the Radon anomaly corresponds to the underground section of the Fosso Grande, it is likely that this feature has role in the anomaly formation. Radon could be conveyed downstream from the waste disposal located along Fosso Grande creek. The vapor pressure in the underground section of Fosso Grande could facilitate the exchange with the adjacent underground water table or favour the penetration of the Radon in the soil.

The ANPA (Agenzia Nazionale Protezione Ambiente, Italy) and CRR (Centro di Radioattività Regionale, Abruzzo) performed lately five measurements in well within an area roughly between the Hospital and the Pescara river. In 3 cases they found values above 7000 Bq/m^3 with a maximum of 8974 Bq/m^3, the other two measures gave lower values between 2200 and 5300 Bq/m^3. The director of ANPA-CRR, G. Damiani suggested that these values were completely normal if compared with those obtained elsewhere for "glacial debris with fragments of granite, uranium-rich oil shale soils containing aluminum (*sic*!)". However, none of these rocks exist in Pescara and Abruzzo. A series of events with legal implications, in fact paralyzed every effort to know more about the problem. The unpreparedness and lack of cooperation among research institutions, weakness of administrative control and negation of a potential problem demonstrate the high vulnerability of the social context. So the nature and distribution of the hazard remains unevaluated in an area which hosts a large hospital, several schools, a segment of a river park, tourist and sports facilities. This study demonstrates that this can lead to a substantial underestimation of the Radon risk in the Pescara area.

8. Acknowledgements

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