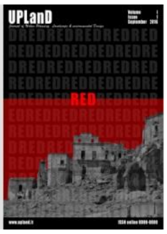
UPLanD – Journal of Urban Planning, Landscape & environmental Design, 1(1), 27-38 [2016]

UPLanD

Journal of Urban Planning, Landscape & environmental Design



Research & experimentation
Ricerca e sperimentazione

A METHODOLOGY HAZARD-BASED FOR THE MITIGATION OF THE RADON RISK IN THE URBAN PLANNING

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HIGHLIGHTS

- The radon is a radioactive gas, that was classified as an oncogenic factor for humans (WHO,1988)
- Most publications define different methodologies for the identification of the radon prone areas
- The radon mitigation has to be integrated by the urban planning
- The spatial definition of different levels of the radon risk allows to associate different levels of protection

ABSTRACT

A type of significant impact is the risk from radon gas in indoor settings, which is not been yet listed among the types of risk canonically considered in planning, such as the hydrogeological, seismic and volcanic risk, by fires and relevant accident risk (Castelluccio et al, 2012). The radon is a radioactive gas, that was classified since 1988 by the WHO as a carcinogen of the Group I (IARC-WHO, 1988), i.e. an oncogenic factor proved on humans.
The European Union, transposing these indications, requires to the Member States, through the EU Directive, 59, 2013, the identification of areas particularly prone to radon, known as radon prone areas in the literature. However, currently there is still no international standard for the mapping of these areas. Moreover, this Directive defers the mitigation of the phenomenon to the building regulations.
This research shows a methodology to build the risk maps of radon at the urban scale, as you can regulate and specify mitigation actions only at this spatial level.

ARTICLE HISTORY

Received: November 08, 2016
Reviewed: November 12, 2016
Accepted: November 16, 2016
On line: December 22, 2016

KEYWORDS

Radon prone areas
Radon Risk
Urban planning
Spatial analysis
Mitigation actions

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1. INTRODUCTION

The risk assessment, through the knowledge of the existing elements of danger in a territory, is the basis for the development of planning tools, which aims at ensuring the protection of public health, the safety of the population and the present assets (Moroni, 2001; Sgobbo, 2016).

A type of significant impact is the risk from radon gas in indoor settings, which is not been yet listed among the types of risk canonically considered in planning, such as the hydrogeological, seismic and volcanic risk, by fires and relevant accident risk (Castelluccio et al, 2012).

The radon is a radioactive gas, that was classified since 1988 by the WHO as a carcinogen of the Group I (IARC-WHO, 1988), i.e. an oncogenic factor proved on humans. Recent studies state that radon is the second factor responsible of lung cancer after tobacco smoke (WHO, 2009), causing 21.100 deaths annually in the USA (EPA, 2003), and between 1.800 and 7.000 deaths per year in Italy (Ministry of health, 1998). Once inhaled, in fact, the radon damages the lung tissues irrevocably, favoring the risk of contracting lung cancer also for lower concentrations than 200 Bq/m^3 (Darby et al, 2006). Bq / m^3 is the unit of measurement commonly used to express the concentration of radon and it is the unit of measurement of radioactive decay in a gaseous medium, such as air.

The main source of radon is the soil (Nero, 1984). This gas is also present everywhere on Earth, because it is originated by the radio, in the radioactive decay chain of the uranium, which is present throughout the Earth's crust. From the soil, through a mechanism called "exhalation", the radon reaches the atmosphere and within it is dispersed by the air currents, while, being heavier of about seven times than the air, it tends to accumulate in closed environments, reaching also very high concentrations (Nero, 1989). The amount of radon, hat exhales on surface from the soil, depends on both the properties of the rocks, in terms of the content of uranium and radio, and on the properties of the soil, in terms of permeability and porosity (Choubey et al, 2005).

Other input sources of radon in indoor environments are the building materials, which are considered as radon emissive, and drinking water and sanitation system (Abu-Samreh, 2005), also if the latter contribution can be considered negligible according to the literature. Also the contribution of construction materials is much lower than that of the soil. The entry of radon into the building can be more or less hindered, depending mainly from the foundation structure: a raft foundation in reinforced concrete, for example, acts as a barrier to radon, much more than a load-bearing masonry foundation (Zannoni et al, 2006). As this relevant problem has a global importance, the WHO has developed an entire manual dedicated to radon in 2009, which requires national authorities to set a threshold beyond which predict investment for mitigation.

The WHO, on the basis of scientific evidence, recommends to not exceed the value of 100 Bq / m3 in the most restrictive measure, and in any case not exceed of 300 Bq / m3 (WHO, 2009). This value is been reflected also by recent European Directive of 2013. (EU, 59 2013). Currently, different reference values can be found in different states, both at international and European level (Gue, 2015). Member States, which are obliged to transpose the European directive by 2018, have to adjust their reference levels (EU, 59 2013). In some cases, including Italy, moreover, a reference level has not been set yet. The directive, also in implementation of the WHO guidelines, requires the Member States to identify the areas most prone to radon, also known in the literature as radon prone areas. However, currently there is still not an international standard procedure for mapping those areas. A survey sponsored by the European Commission revealed that almost all European countries have adopted different mapping techniques, but, among all, two most common used approaches can be recognized: the first approach plans to collect data for the mapping through indoor measurements, i.e. radon in homes; the second approach, instead, works through measures in the soil (Dubois, 2005). For data processing, the most used methodologies are still two: Statistical and Geostatistical (ARPA Lazio, 2013). In Italy, where the identification of radon prone areas is delegated to the regions (Legislative Decree 241/00), there is a late awareness. Only some Regions have already identified the radon prone areas, following the same approach used by the European countries, and only the Tuscan Region has formalized a regional mapping (BURT 49 of 12.5.2012, Resolution 26 November 2012 n.1019).

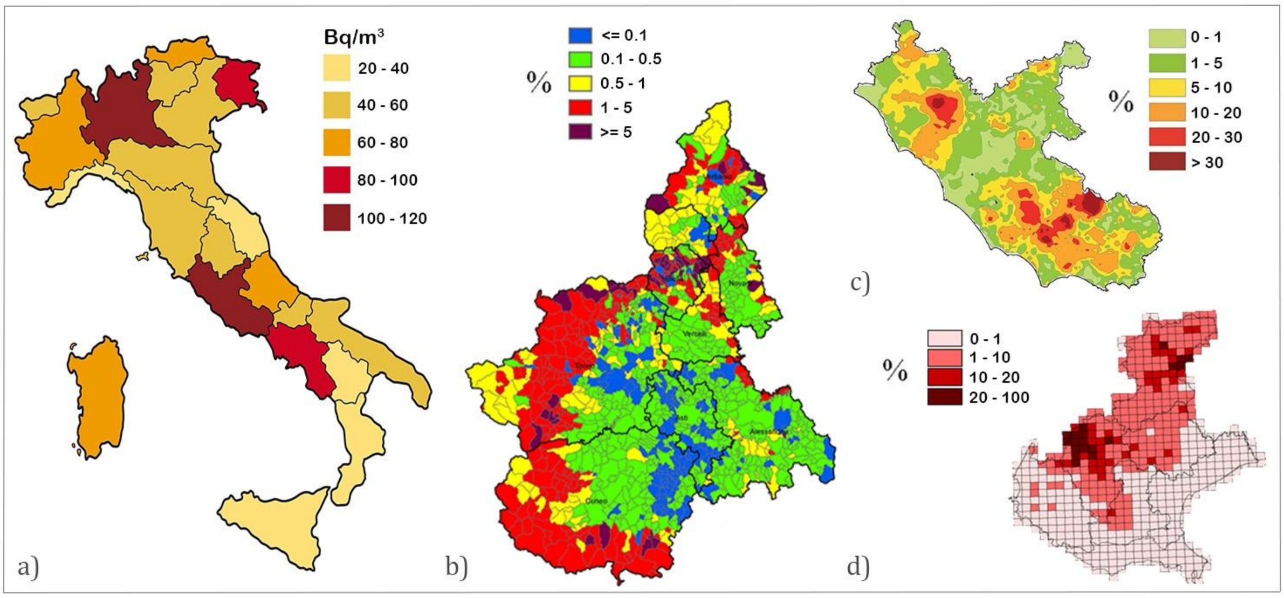

Figure 1: a) The national survey's results on exposure to radon in dwellings, Source: ISPESL (2007). b) The cartographic representation of P%400, probability of exceeding the ground floor of 400 Bq / m3, for Piemonte, (ARPA Piemonte ,2009). c) Map of the percentage of dwellings exceeding the reference level of 300 Bq / m3 to the ground floor for Lazio, (ARPA Lazio & ISPRA 2009). d) Map of the percentage of housing exceeding the reference level of 200 Bq / m3 to the ground floor for the Veneto, (Arpa Veneto, 2009)

Table 1: Methodologies used by the regions for the identification of the radon prone area

Region	**Survey**		**Data processing**		**Resolution**
	indoor measures	**measures in soil-gas**	**Statistics**	**Geo-statistics**	
Valle D'Aosta	x	-	x	-	grid mesh 2x2 sq.km.
Piemonte	x	-	x	-	municipal level
Alto-Adige	x	-	x	-	municipal level
Lombardia	x	-	-	x	grid mesh various dimensions: 8x5, 8x2,5, 4x5, 16x10 sq.km.
Veneto	x	-	x	-	grid mesh 6,5x5,5 sq.km.
Friuli Venezia Giulia	x	-	x	-	grid mesh di 3,2x2,8 sq.km.
Emilia Romagna	x	-	x	-	in continuity
Toscana	x	-	x	-	municipal level
Lazio	x	-	-	x	grid continuous mesh 6x6 sq.km.

High heterogeneities are shown by analysing the used mapping methodologies, and this is due to the absence of standardized criteria. In fact, a substantial change in the resolution of the maps is recorded: you pass by a 2km mesh, in the case of the Aosta Valley, at a 6 km in the case of Lazio (e.g. Table 1).

As the regions have used different mapping techniques, the output papers are not comparable (e.g. Fig. 1). However, a survey, conducted at a national level, underlines that the regions in which the average concentration of radon is above the recommended reference levels are primarily Lazio and Lombardy, followed by Campania and Friuli Venezia Giulia (Bochicchio et al, 2005). This analysis emphasizes the need to regard and define the mitigation actions.

In Campania, an inter-university project has been made under the RAD_CAMPANIA program, aimed at identifying the radon prone areas in different and progressive levels of detail, from the regional scale to the scale of the site. Currently all the levels, except the "zone" level, corresponding to that municipal one, have been investigated (Guida et al, 2008). Generally, until now, there are no previous experience of preparation of the map of radon prone areas at the municipal scale.

The answers in terms of mitigation actions are delegated by the European Directive to the building regulations. From the analysis conducted on a sample of urban planning and building regulations (Ruec), it is clear that the proposed provisions are aimed at the new buildings, and are not differentiated on the basis of risk levels, and, moreover, they are not associated with a mapping of radon risk levels. The need to define the radon pron areas to the urban scale is very relevant since it is only at this spatial level that you can regulate and specify the actions to mitigate the risk from radon.

2. Materials And Methods

2.1 Case study

The methodology was applied to the city of Eboli (e.g. Fig. 2). there was an agreement between the Department of Civil Engeneering (DICIV) and the Municipality for the elaboration of the Piano Urbanistico Comunale.

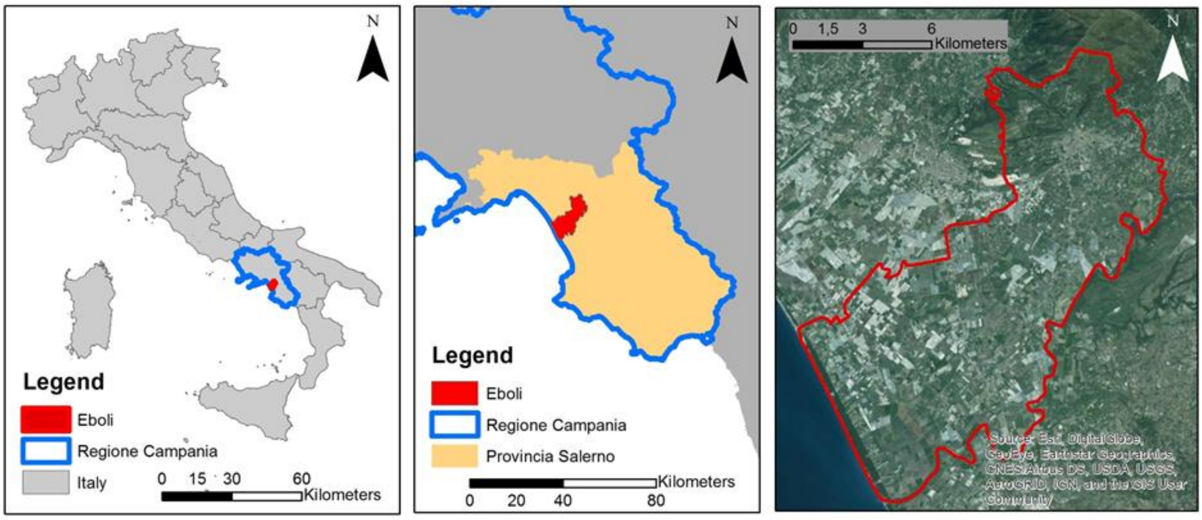

Figure 2: Area study: Eboli (Campania, Southern Italy)

2.2 Methodology

In view of the significant health effects, the radon must be considered necessarily among the territorial risks that the planning has to manage in terms of mitigation (Moroni, 2001). As, from an operational point of view, the mitigation of territorial risks must be defined on a urban scale, a methodology may be proposed for the implementation of the radon risk mitigation strategies in urban planning. Through the drafting of a radon risk map, this method allows you to consider also the minimization of this risk among the criteria for the location of new settlements, on the one hand, and the identification of the appropriate mitigation actions related to existing housing on the other.

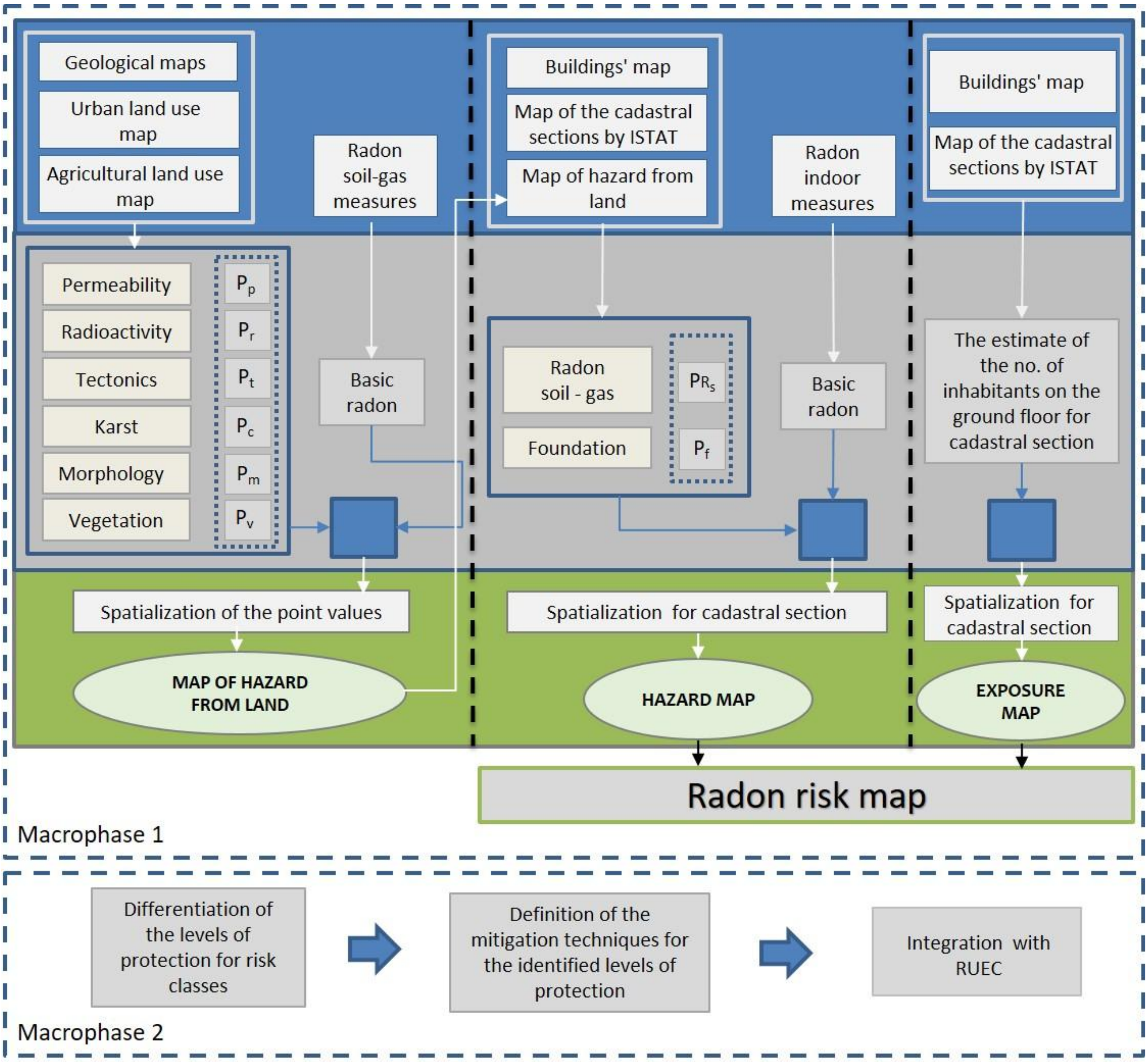

Figure 3: Methodological framework

The proposed methodology foresees two macro steps (e.g. Fig. 3):

1. the construction of the radon risk map at the municipal scale;

2. the definition of the mitigation measures.

It is based on the explicitation of the equation of radon risk, starting with the fundamental equation of risk (UNDRO, 1979), that is expressed as the product of hazard, vulnerability and exposure.

This equation is to be expressed by the following expression:

$$R_{Rn} = P_{Rn} (P_S, P_E) \cdot E_{Rn}$$

This expression takes into account the fact that, since the radon is odorless and colorless, the population has no ability to resist the phenomenon, and, therefore, the vulnerability is equal to 1 or equal to the condition of the maximum damage.

P_{Rn} is the "radon hazard", that is function of two factors:

$$P_{Rn} = f (P_S, P_E)$$

In particular, the main production source of radon is the danger induced by soil properties, Ps, which is supplemented by the risk that can be defined by building PE, as it is related to material properties constitutive of the building assets.

As for the exposure to radon E_{Rn}, you have to consider that this decreases with increasing distance from the ground, therefore, it will be greater on the ground floor of buildings (Bochicchio et al, 2005). In addition, numerous studies (Spencer, 1986) show that the risk of contracting lung cancer attributable to radon increases progressively with decreasing age, becoming maximum for the population between 0 and 19 years. Therefore, the exposure to radon is calculated according to the following index:

$$E_{Rn} = \frac{N_{ab,PT}}{I_{p0-19}}$$

This index expresses the ratio between the number of theoretical inhabitants present on the ground floors of the building assets, $N_{ab, PT}$, and the exposure index, I_{p0-19}, that is calculated as ratio of the population belongs to the age group 0-19 years and the total population, P_t, and it is found to be between 0 and 1.

3. Results And Discussions

3.1 Macrophase 1

For the implementation of the methodology, a geodatabase is been designed to organize the acquired data from previous investigations and measurements in situ. The macrophase 1 included the construction of the following maps:

- the map of the hazard from the soil;
- the map of the overall hazard;
- the exposure map;
- the radon risk map.

In order to map the hazard there is been the acquisition of a series of data, relating to the experimental results of radon measurements, in soil and within buildings, which are been obtained as a result of the measurement campaign conducted on a pattern of 30 buildings, that are located in the town of Eboli (SA).

The measurement protocols, respectively, for the indoor measurements and in the soil-gas, are those defined in the RAD_Campania Program.

After the acquisition of these data, you proceeded to the spatialization of point measurements, getting first the map of the hazard from the soil and, subsequently, that of the overall hazard.

For this reason, you determine initially the "basic radon in the soil", corresponding to each litotype present in geolithological map. You recognize that each litotype has a sort of "basic radioactivity" (ANPA, 2000), which is increased to a greater or lesser measure depending on the incidence of some parameters, that are known by the literature and have made a significant contribution to the radon exhalation from the ground (Guida et al, 2008):

- the permeability and the radioactivity, obtained by the geolithological map;
- the tectonics and the karst, obtained from the hydrogeological map;
- the morphology, obtained from the geomorphological map;
- the vegetation, obtained from the use map of the agricultural land and the use map of the urban land (e.g. Fig. 4).

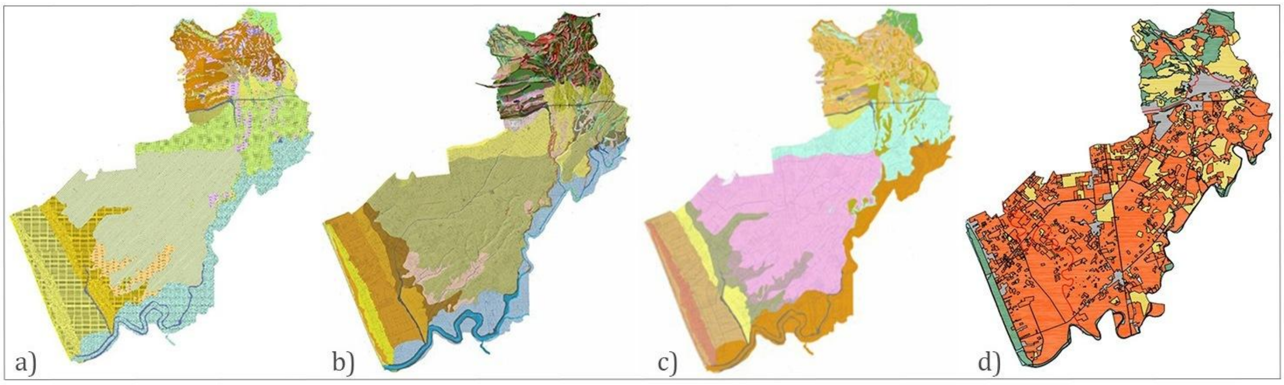

Figure 4: Geolithological map (a), the geomorphological map (b), the hydrogeological map (c) and the land use's map (d)

These parameters affect in a different way, with an intensity, which is expressed by scores, according to the literature, with a range between 1 to 3, where 1 corresponds to a positive impact and 3 to a negative (Guide et al, 2008).

The calculation of the basic radon for a specific litotype is carried by the ratio between the value of the concentration of radon in the soil, obtained from the experimental measurement performed in an i-th point, belonging to that lithotype, and the product of the scores assigned to the above parameters. Being known the measurement of radon at several points belonging to a same lithotype, you determine the basic radon on the lithotype as the geometric average of the basic radon calculated individually for each point.

Known the "basic Radon" for each lithotype, it is possible to estimate the concentration of radon in the other points of the soil, multiplying that value and the scores given to the parameters defined above and associated with the other parts of soil, thus getting the hazard from soil (e.g. Fig . 5).

Subsequently, you proceed to determine the "radon from building", corresponding to the characteristic construction materials of the buildings within the measuring sample. You admit that each building presents its basic radioactivity depending on the building material. However, this measure is amplified in a more or less significant measure, depending on the incidence of the two following factors:

- the radon potentially exhaled from the ground, that is obtained by the previous map of the hazard for ground;

- the type of foundation, obtained from census data on population and housing, spatialized according to the census tracts (ISTAT, 2011).

The intensity of these parameters is expressed by scores, according to the scientific literature, in a scale from 1 to 3, where 1 corresponds to a positive impact and 3 to a negative one (Guide et al, 2008; Brochin et al, 1998).

The basic radon, similarly to what is done for the previous step, is calculated by purging the measured value from the contribution of these factors, and, subsequently, it is multiplied by the scores attributed to those factors at the points devoid of experimental measurements, with the purpose to spatialize the value of radon from the building on census basis (e.g. Fig. 5).

In order to define the exposure map (e.g. Fig. 5), is estimated the maximum number of people theoretically hosted in the ground floors of buildings, based on census areas, using the endowment of volume per capita fixed by D.M. 1444/68, so that the volume of the ground floors of buildings is translated in inhabitants.

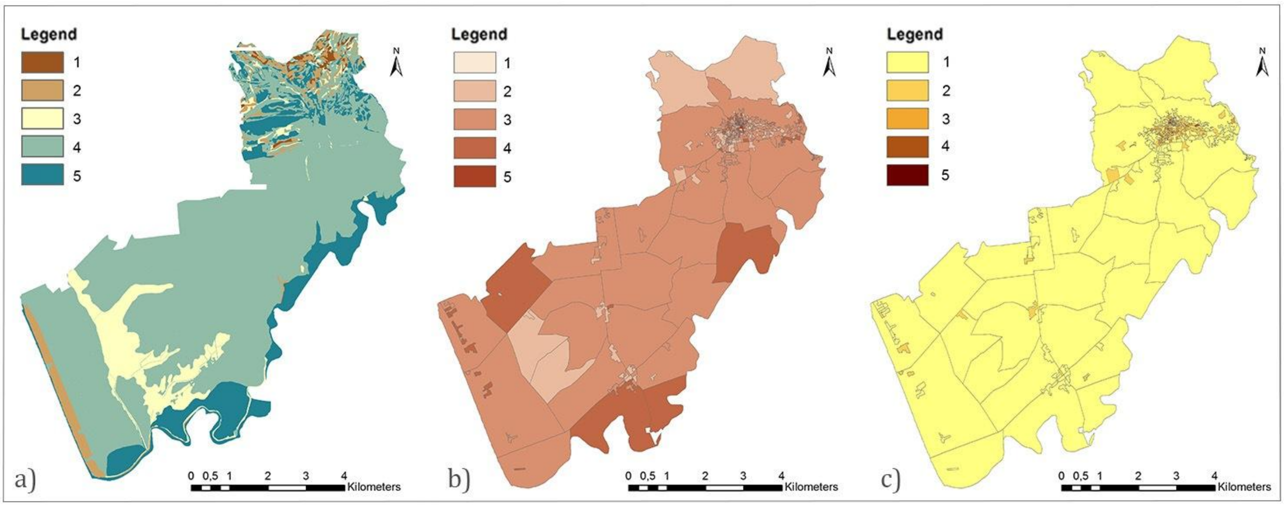

Figure 5: Produced maps, relating to the hazard and exposure to radon for the town of Eboli (SA): Map of hazard from land (a), the overall hazard map (b), and the exposure map (c)

Once the map of overall hazard and the exposure map are obtained, for the construction of the radon risk map, there is a reference to a risk matrix similar to that on the hydrogeological risk.

This matrix relates the level of the damage, expressed as the product of the vulnerability, set equal to 1, and the exposure, with the hazard levels.

These levels of intensity were obtained, in the absence of reference thresholds, through the method of the spatial classification called Natural break (Jenks, 1969) that requires as input data the allocation of the number of classes.

You fix five intensity classes, as provided for in the provincial-level map (Guide et al, 2008). Finally you obtain the radon risk matrix (e.g. Fig. 6), according to a scale of intensity whose classes are labeled in a risk that may be "very low", R2; "Low", R2; "Medium", R3; "High", R4; "Very high", R5.

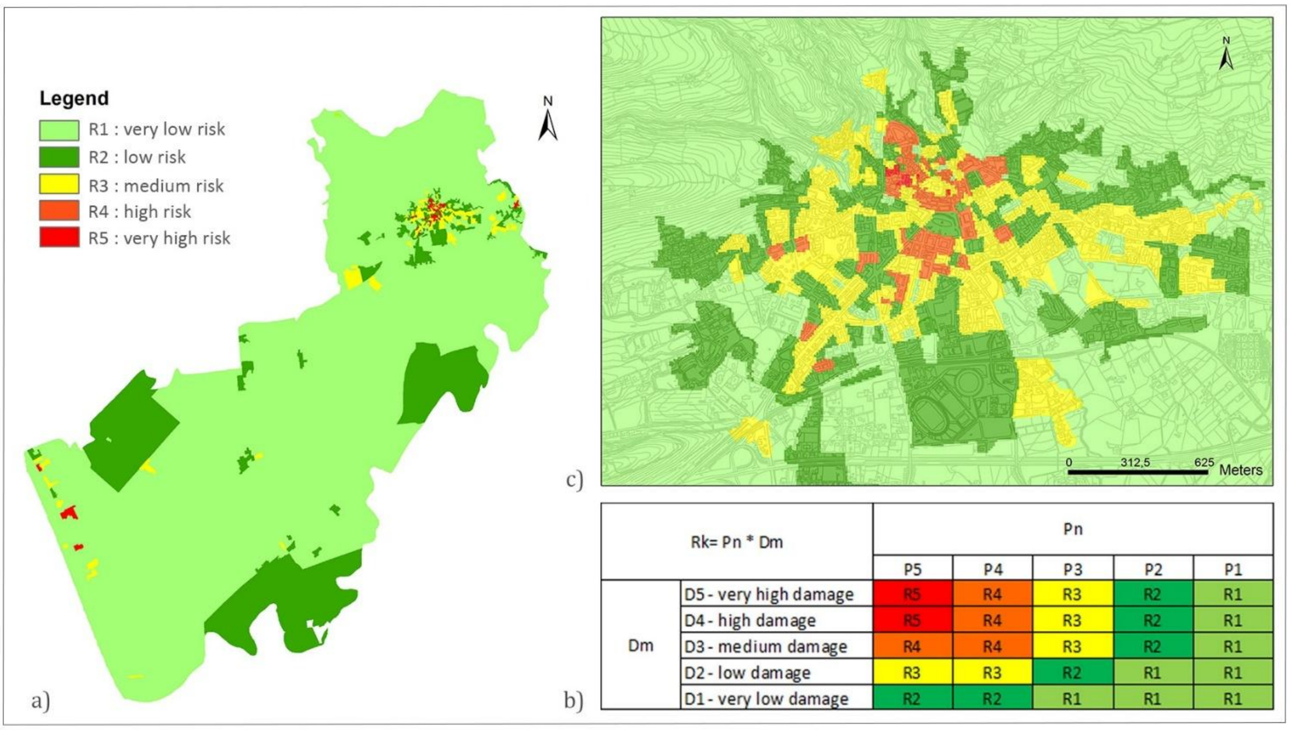

Figure 6: a) Radon risk map for the town of Eboli (SA). b) Radon risk matrix c) Details on the town of the radon risk map.

3.2 Macrophase 2

The risk map obtained in this way constitutes the basic support for the mitigation actions, according to the approach proposed both by the BRE (Building Research Establishment Ltd, UK) and by SRPI (Swedish Radiation Protection Institute, SE), with the recommendations on protective measures of "basic" and "full" type (Moroni, 2001). In addition, a level of protection, in function of the level of risk, has been defined, to which specific categories of intervention correspond. These requirements may supplement the *Regolamento Urbanistico Edilizio Comunale* (Ruec) with a special section devoted to radon protection. Specifically for R1 and R2 classes, no protection is expected; for R3 class, a basic protection is expected; for R4 and R5 classes, an enhanced security is expected (e.g., Table 2).

Table 2: Levels of protection for the different identified risk classes

Risk class	Building protection	Mitigation techniques
R1: very low	no	no
R2: low	no	no
R3: medium	basic	passive
R4: high	advanced	combination of active and passive techniques
R5: very high	advanced	combination of active and passive techniques

The corresponding mitigation techniques are classified in passive and active techniques (Table 3). However, you can notice that the choice of the most appropriate mitigation technique must be done on a case by case basis by the designers at the building scale, in relation to the specific case (APAT, 2005), and according to the levels of intensity expressed by the risk map (e.g. Table 3).

Table 3: Active and passive mitigation techniques

Passive Techniques	sealing
	natural ventilation of the interior
	natural ventilation of the crawl space
	natural ventilation of the cellar
	air conditioning with heat recovery
Active Techniques	depressurization of the soil by means of radon wells located under the building
	depressurization of the soil by means of radon wells located outside the building
	pressurization of the soil
	pressurization of the building
	ventilation of pipelines
	forced ventilation of the crawl space
	forced ventilation of the cellar
	air conditioning with heat recovery

4. CONCLUSIONS

The application of the proposed methodology enables an accurate definition of the strategic actions of the radon risk control, since it takes place downstream of its quantification. In particular, the dangers connected with the value of the soil risk source may suggest the identification of preventive measures to limit the risks, that is, targeted at reducing the probability of occurrence of the potential event, directing the location of new settlements in areas connoted by a low level of hazard. However, the consultation of the risk map can drive the definition of preventive and mitigating actions, i.e. targeted at reducing the extent of potential damage.

Therefore, the support basic analysis for the preparation of the municipal development plan have to be integrated with the above calculations. This integration is fully sustainable from the point of view of economic intervention since the basic geological component can be obtained partially through the integration of the contents of the geological studies required by law (Campania Law n.9/1983 subsequent amendments) for the preparation of the urban plan.

Further developments of the methodology reside primarily in the validation of the model through the use of a significant sample of measurements that can discriminate all the range of possible solutions. From the point of view of implementing, the next step is to link these mitigation actions in rewarding mechanisms in terms of transfer of building loans in order to enable the implementation of the measures.

Finally, from a standpoint of the building component, the framework of the planned measures would provide an organic arrangement of intervention technologies that can find a real formalization in the appropriate standard sheets, which can be attached to Ruec.

ACKNOWLEDGEMENTS

Thanks to the Research Group of Geomorphology - University of Salerno, directed by Prof. D. Guida and Eng. A. Cuomo, for the geological and geomorphological analysis and their support to the field survey and the data interpretation.

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