



Knowledge, risk perception and awareness of radon risks: A Campania region survey

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ARTICLE INFO

Keywords:

Radon
Knowledge
Risk perception
Awareness
Survey

ABSTRACT

Radon is a naturally occurring radioactive gas that is found in soil, rock, and water. Exposure to high levels of radon is the second leading cause of lung cancer after smoking. This study aims to investigate the level of knowledge and awareness of the risks associated with radon exposure among the general public. An ad hoc cognitive survey was conducted, and the results showed that there is a lack of knowledge and awareness about radon. The majority of participants had never heard of radon, and those who had heard of it were not aware of its health effects. This study suggests that there is a need for increased public education and awareness campaigns on radon and its risks.

1. Introduction

Radon is a radioactive gas that occurs naturally in the environment, especially in areas with high levels of uranium in the soil. It is produced by the decay of uranium and thorium in soil, rock, and water. Radon is colorless, odorless, and tasteless, making it impossible to detect without specialized equipment. When radon is released into the air, it can accumulate in enclosed spaces such as homes, schools, and workplaces. Exposure to radon can lead to an increased risk of lung cancer, making it a significant public health concern. Exposure to high levels of radon is the second leading cause of lung cancer after smoking (EPA, 2003; Loffredo et al., 2021a; Obed et al., 2018). The World Health Organization (WHO) estimates that radon exposure causes between 3 and 14% of all lung cancer deaths worldwide (WHO, 2009; Loffredo et al., 2021b). This study aims to assess the knowledge and awareness of radon exposure risks among the general population, including the potential effects of radon exposure and sources of radon.

In the world of today, people are exposed to numerous risks, both physical and non-physical, that can have negative consequences for their health, safety, and well-being. Risk can be defined as the probability or likelihood of an event occurring that can have negative consequences or outcomes (Wolff et al., 2019; Grothmann & Patt, 2005; Lujala et al., 2015; Lee, 2018). The severity of the consequences or

outcomes can vary from mild to severe, depending on the nature of the risk.

Knowledge and awareness of risks are critical for individuals to make informed decisions and take appropriate actions to mitigate them (Nazir et al., 2021). Individuals who are aware of the risks are better equipped to protect themselves and others from harm. For example, individuals who are aware of the risks of smoking can make informed decisions about whether to smoke or not, and individuals who are aware of the risks of COVID-19 can take appropriate measures to prevent its spread (Aljondi et al., 2021; Ball et al., 2022; Gray et al., 2016; Ivbijaro et al., 2020; Liang et al., 2023; Quintal et al., 2010).

Furthermore, knowledge and awareness of risks can also help individuals to be better prepared in the event of an emergency or disaster. Individuals who are aware of the risks of natural disasters, such as earthquakes, hurricanes, or wildfires, can take appropriate measures to prepare for them, such as having emergency kits and evacuation plans (Chew & Jahari, 2014; Gaiha et al., 2012; Munich, 2012; Pecl et al., 2017; Woolf et al., 2013).

There are several strategies for improving risk awareness and management. These include:

Education and Training: Providing education and training to individuals about the risks they face can help them to be better informed and prepared. This can include providing information on the risks

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<https://doi.org/10.1016/j.jrras.2023.100721>

Received 4 September 2023; Received in revised form 12 October 2023; Accepted 13 October 2023

Available online 17 October 2023

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associated with certain behaviors or activities and how to reduce those risks (Bird et al., 2010; Coppola et al., 2019; Cori et al., 2022; Djounova & Ivanova, 2023; Loffredo et al., 2020).

Communication: Effective communication is essential for improving risk awareness and management. This can involve providing clear and concise information about the risks individuals can face, how to mitigate those risks, and what to do in the event of an emergency (Johnson & Slovic, 1995; Miles & Frewer, 2003).

Risk Assessment: Conducting risk assessments can help individuals and organizations to identify the risks they face and develop appropriate strategies for managing those risks (Johnson & Slovic, 1995; Wiedemann et al., 2008).

Collaboration: Collaboration between individuals, organizations, and communities can help to improve risk management. By working together, individuals and organizations can share knowledge and resources to develop effective strategies for managing risks (Daedlow et al., 2016).

This work shows the results obtained following a cognitive survey on the knowledge and awareness of the risk deriving from exposure to Radon. The questionnaire was developed by the Lab.RAD Laboratory - CESMA, University of Naples, Federico II.

The study was conducted in the Campania region, South Italy, which is very interesting from both a demographic and a radon concentration perspective. In fact, it is classified as the third most populous region in Italy (Istituto Nazionale di Statistica, 2023), and it also exhibits a significant annual radon concentration. This is evident from the results obtained in some studies conducted by Bochicchio et al. (Bochicchio et al., 1996, 1999) on indoor radon levels across all Italian regions. The national survey revealed high annual radon concentrations in five Italian regions, including Campania, which had an arithmetic mean of 95 ± 3 Bq/m³.

Previous studies (Coppola et al., 2019; Loffredo et al., 2020) have shown that radon knowledge results high when respondents are involved in training programs. In addition, it is expected that those who are highly educated are more informed about the origin of radon and the risks associated with its exposure. Additionally, the media and/or means through which we gain information about a new topic influences the

way we perceive it and the risk appraisal we conduct while thinking about it.

This paper will explore the concept of risk, in particular the importance of knowledge and awareness of radon exposure risks, and the strategies to improve risk awareness and management. Furthermore, it aims to investigate the relationship between the education levels of the general population and the knowledge and awareness of the radon risk. Finally, the differences in the perception of risk based on the source of the information are also analyzed.

2. Methodology

The study was conducted using a ad hoc cognitive self-report questionnaire that aimed to evaluate the level of knowledge and awareness of the risks associated with radon exposure. The survey was distributed through online platforms, and the participants were asked to respond to a series of multiple-choice questions related to radon exposure. The survey was composed as follows and as showed in Fig. 1:

1. Demographic information such as age, gender, education, place of birth
2. Questions about previous knowledge on radon
3. Questions about the effects of radon on health
4. Questions on the awareness of radon exposure

Questions on the degree of awareness of radon exposure were measured on a three, five or seven points Likert scale. The questionnaire was individual and anonymous. The survey was administered to a random sample of voluntary individuals aged 18 years and older in Campania region, South Italy. It was carried out in 5 provinces (Napoli, Salerno, Avellino, Benevento and Caserta) from July 2019 to January 2021.

3. Statistical analysis

Data are reported as mean and standard deviation for continuous variables and as absolute frequency with percentages for categorical

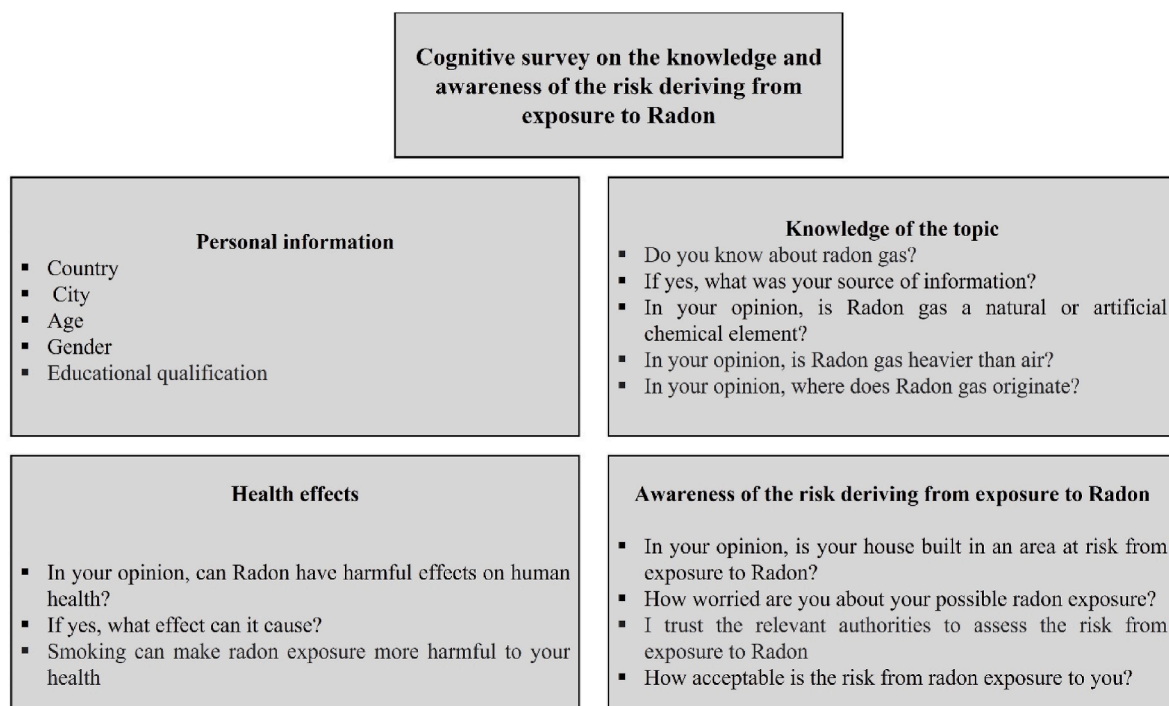


Fig. 1. Questionnaire contents developed to investigate the knowledge and awareness of radon risks.

variables. Difference in answers to the questionnaire items between the two education level groups was computed using Student's *t*-test for independent samples or Mann-Whitney *U* test as appropriate for continuous variables, while χ^2 test or Fisher's test, as appropriate, were used for categorical variables. Multiple logistic and multiple linear regression models were used to investigate whether information source and education level predicted the awareness level of the participants considering as outcomes all the questionnaire items in this domain. For all models, interactions between the predictors were also tested and if they were not significant they were not added to the final models. For regression models in which significant results were found, where applicable, results were reported as beta coefficients with 95% confidence intervals. Answers to items on a Likert scale were considered as continuous variables. The significance level for all analyses was set to $\alpha = 0.05$. All analyses were performed using the statistical software R, version 4.3.0.

4. Results

A total of 586 participants (mean age 32, s.d. 15; female sex 64%, male sex 36%) completed the survey, which took approximately 10 min to complete.

The Fig. 2 shows the distribution of survey participants by province in Campania. Most responses were acquired in the Province of Naples (red dot, 430 participants), followed by Caserta (orange dot, 73 participants), Salerno (green dot, 63 participants), Avellino (blue dot, 15 participants) and Benevento (blue dot, 5 participants). The majority of the participants responded from the cities of Naples (36.4%), Aversa (3.6%), Torre del Greco (2.7%), Salerno (2.2%) Ercolano (2.1%) and Caserta (2.0%).

Table 1 shows the distribution of the answers to the questionnaire in the sample. With regards to the section about knowledge of the topic, 73% declared that they already heard about radon, and more than half of these from school/university (55% of the responders, 41% of the total sample). 66% correctly identified radon as a natural gas and the remaining participants in nearly equal proportions either responded it was artificial (16%) or that they did not know (18%). However, 39% declared that they did not know whether radon was heavier than air. Concerning the section about health and risks deriving from exposure to radon, while 95% of the sample recognized that radon can be detrimental to health, 60% admitted that they did not know if they lived in a zone at exposure risk and 71% declared that they were not at all worried (23%) or moderately worried (48%) about their personal exposure to

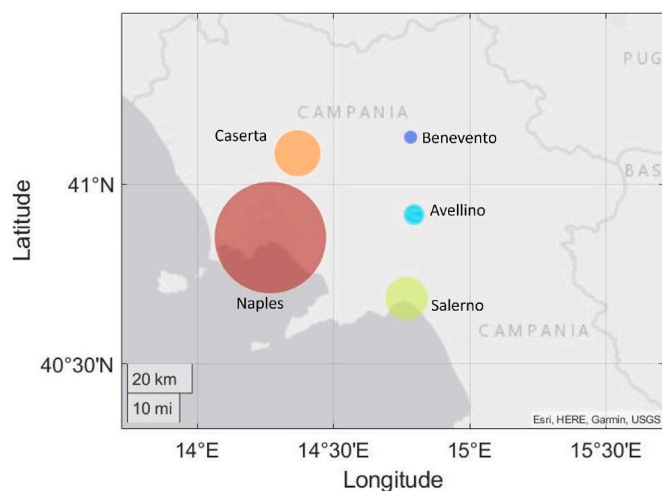


Fig. 2. The map of the distribution of survey participants in the Campania region. In particular, the provinces (Naples, Salerno, Caserta, Avellino and Benevento) can be distinguished from the figure. The sizes of the dots describe the percentage of participation.

Table 1

Distribution of the answers to the survey items in the complete sample of 586 participants.

Have you ever heard of radon gas?	Frequency (%)
No	155 (26%)
Yes	430 (73%)
NA/Missing	1 (0.2%)
If yes, what was your source of information?	
Other	24 (4.1%)
Internet	100 (17%)
Media	72 (12%)
School and/or University	240 (41%)
NA/Missing	150 (26%)
In your opinion, is radon gas a natural or artificial chemical element?	
Artificial	92 (16%)
Natural	389 (66%)
Don't know	104 (18%)
NA/Missing	1 (0.2%)
In your opinion, radon gas is heavier than air?	
Yes	249 (42%)
No	108 (18%)
Don't know	229 (39%)
Where do you think Radon gas originates?	
In atmosphere	83 (14%)
In the soil	366 (62%)
In nuclear power plants	120 (20%)
Don't know	16 (2.7%)
NA/Missing	1 (0.2%)
In your opinion, can Radon have harmful effects on human health?	
Yes	558 (95%)
No	7 (1.2%)
Don't know	21 (3.6%)
In your opinion, is your house built in an area at risk of radon exposure?	
Yes	57 (9.7%)
No	175 (30%)
Don't know	354 (60%)
How concerned are you about your possible radon exposure?	
Not at all concerned	133 (23%)
Moderately concerned	280 (48%)
Concerned	123 (21%)
More than concerned	27 (4.6%)
Extremely concerned	7 (1.2%)
Don't know	16 (2.7%)
I trust the relevant authorities to assess the risk from exposure to Radon	
Very little confidence	277 (47%)
Moderate confidence	214 (37%)
Confidence	75 (13%)
Much confidence	14 (2.4%)
Lots of confidence	3 (0.5%)
Don't know	3 (0.5%)
How acceptable is the risk from radon exposure to you?	
Completely unacceptable	137 (23%)
Unacceptable	289 (49%)
Moderately acceptable	106 (18%)
Acceptable	28 (4.8%)
Completely acceptable	5 (0.9%)
Don't know	21 (3.6%)
Can cigarette smoking make radon exposure more harmful to health?	
I don't know/not sure	46 (7.8%)
I completely agree	32 (5.5%)
I agree	56 (9.6%)
I disagree	1 (0.2%)
NA/Missing	451 (77%)

radon. On the other hand, 72% answered that they found unacceptable (49%) or completely unacceptable (23%) the risks derived from exposure to radon and only 3% declared that they had high or very high confidence in the local authorities' ability to assess the risks of radon, while nearly half of the sample (47%) had very little confidence.

Results on the difference between educational groups (Table 2) show that, among the responders, those with a lower education received information about radon significantly more frequently from the internet (28%), while those with a higher education were primarily informed through school and/or university (60%, $p < 0.001$). Those with a lower level of education more frequently answered that radon is an artificial gas (19%) compared with those with a higher education level (11%, $p =$

Table 2

Distribution of the answers to the questionnaire items divided by education level. P-value computed with Student's *t*-test for independent samples or Mann-Whitney *U* test as appropriate for continuous variables, or with χ^2 test or Fisher's test, as appropriate, for categorical variables. Significance level $\alpha = 0.05$. Significant p-values are highlighted in bold. n.c. = not calculable.

Variable	Graduate and Postgraduate, N = 216	Lower and Higher Middle School N = 370	p-value
Age	41 (12)	26 (14)	<0.001
Gender			0.387
F	133 (62%)	241 (65%)	
M	83 (38%)	129 (35%)	
Have you ever heard of radon gas?			0.122
No	49 (23%)	106 (29%)	
Yes	166 (77%)	264 (71%)	
NA/Missing	1	0	
If yes, what was your source of information?			0.039
Other	10 (6.0%)	14 (5.2%)	
Internet	26 (16%)	74 (28%)	
Media	31 (19%)	41 (15%)	
School and/or University	100 (60%)	140 (52%)	
NA/Missing	49	101	
In your opinion, is radon gas a natural or artificial chemical element?			0.015
Artificial	23 (11%)	69 (19%)	
Natural	158 (73%)	231 (63%)	
Don't know	35 (16%)	69 (19%)	
NA/Missing	0	1	
In your opinion, radon gas is heavier than air?			0.119
Yes	85 (39%)	164 (44%)	
No	49 (23%)	59 (16%)	
Don't know	82 (38%)	147 (40%)	
Where do you think Radon gas originates?			<0.001
In atmosphere	29 (13%)	54 (15%)	
In the soil	159 (74%)	207 (56%)	
In nuclear power plants	21 (9.8%)	99 (27%)	
Don't know	6 (2.8%)	10 (2.7%)	
NA/Missing	1	0	
In your opinion, can Radon have harmful effects on human health?			>0.999
Yes	206 (95%)	352 (95%)	
No	2 (0.9%)	5 (1.4%)	
Don't know	8 (3.7%)	13 (3.5%)	
In your opinion, is your house built in an area at risk of radon exposure?			<0.001
Yes	34 (16%)	23 (6.2%)	
No	57 (26%)	118 (32%)	
Don't know	125 (58%)	229 (62%)	
How concerned are you about your possible radon exposure?			0.100
Not at all concerned	37 (17%)	96 (26%)	
Moderately concerned	113 (52%)	167 (45%)	
Concerned	44 (20%)	79 (21%)	
More than concerned	10 (4.6%)	17 (4.6%)	
Extremely concerned	3 (1.4%)	4 (1.1%)	
Don't know	9 (4.2%)	7 (1.9%)	
I trust the relevant authorities to assess the risk from exposure to Radon			<0.001
Very little confidence	119 (55%)	158 (43%)	
Moderate confidence	78 (36%)	136 (37%)	
Confidence	15 (6.9%)	60 (16%)	
Much confidence	2 (0.9%)	12 (3.2%)	
Lots of confidence	0 (0%)	3 (0.8%)	
Don't know	2 (0.9%)	1 (0.3%)	
How acceptable is the risk from radon exposure to you?			0.267
Completely unacceptable	44 (20%)	93 (25%)	
Unacceptable	101 (47%)	188 (51%)	
Moderately acceptable	49 (23%)	57 (15%)	

Table 2 (continued)

Variable	Graduate and Postgraduate, N = 216	Lower and Higher Middle School N = 370	p-value
Acceptable	11 (5.1%)	17 (4.6%)	
Completely acceptable	2 (0.9%)	3 (0.8%)	
Don't know	9 (4.2%)	12 (3.2%)	
Can cigarette smoking make radon exposure more harmful to health?			n.c.
I don't know/not sure	5 (63%)	41 (32%)	
I completely agree	0 (0%)	32 (25%)	
I agree	3 (38%)	53 (42%)	
I disagree	0 (0%)	1 (0.8%)	
NA/Missing	208	243	

0.039) and more frequently answered that it originated from nuclear plants (27%) rather than in the soil (56%) compared to the other group (respectively 10% and 74%, $p < 0.001$). Concerning the questions on the awareness of the risks of radon, those with a higher education had significantly lower levels of trust in the ability of the local authorities to assess the health risks posed by radon ($p < 0.001$) and in particular more than half (55%) chose the lowest point on the Likert scale. This result is also confirmed by the analysis conducted using multiple linear regression (Table 3), which showed that regardless of the source of information, those with a lower level of education were significantly more prone to trust the local authorities ($b = 0.38$, $p < 0.001$). The source of information and education level are not associated with the knowledge of whether radon is heavier than gas nor with the awareness of the health risks posed by radon. No association was also found with how acceptable the risk posed by the exposure to radon is. Finally, the source of information is associated with how worried participants were about their exposure to radon. In fact, participants that learned about radon at school/university were significantly less worried ($b = -0.26$, $p = 0.009$) than those who learned about radon on the internet (Table 4).

5. Discussion

The Campania region, southern Italy, is an area very affected by the rather high presence of radon gas, mainly due to the presence of some rocks of volcanic origin, such as tuff, which characterizes Naples and its province above all and which, unfortunately, is one of the rocks most producing this gas. Since the main source of radon is the earth's surface, for premises or other businesses, the chances are high that any ground or underground has been dug into these rocks. In addition, other types of premises affected by radon exposure are shops, car parks, subways, and cellars where a poor air exchange could contribute to a high concentration value. Different monitoring studies have been conducted in the Campania region. The radon concentration varied with the floor where it was measured. In more survey, the statistical tests performed on the

Table 3

Multiple linear regression model investigating the impact of the source of information on radon and the participants' education level on the people's trust on relevant authorities. Results reported as beta coefficient with 95% confidence interval. Significance level $\alpha = 0.05$. Significant p-values are highlighted in bold.

Survey item: I trust the relevant authorities to assess the risk from exposure to Radon	Beta	95% CI	p-value
Education			
Graduate and Postgraduate	-	-	
Lower and Higher Middle School	0.38	0.20, 0.57	<0.001
If yes, what was your source of information?			
Internet	-	-	
Media	0.03	-0.25, 0.32	0.828
School and/or University	0.13	-0.09, 0.35	0.256

Table 4

Multiple linear regression model investigating the impact of the source of information on radon and the participants' education level on the personal concern about radon exposure. Results reported as beta coefficient with 95% confidence interval. Significance level $\alpha = 0.05$. Significant p-values are highlighted in bold.

Survey item: How concerned are you about your possible radon exposure?	Beta	95% CI	p-value
Education			
Graduate and Postgraduate	–	–	
Lower and Higher Middle School	–0.13	–0.30, 0.04	0.136
If yes, what was your source of information?			
Internet	–	–	
Media	0.00	–0.26, 0.25	0.993
School and/or University	–0.26	–0.46, –0.07	0.009

data present a statistically significant dependence of the radon concentration from the floor (Loffredo et al., 2021b, 2022; Madureira et al., 2016; Ivanova et al., 2021). Furthermore, the works carried out previously have shown that Campania is a region exposed to radon risk because in various areas, the measurements made exceed the reference level of 300 Bq/m³ (Loffredo et al., 2021a, Loffredo & Quarto, 2023; Guida et al., 2013) established by the Italian Legislative Decree 101/2020 (Decreto Legislativo n. 241, 2000), which transposes the European Directive on Fundamental Safety Standards (BSS)-2013/59. And it is in this scenario that the questionnaire for the survey on knowledge and awareness of the risk due to exposure to radon gas was born.

Risk perception has been shown to be critical in the role of radon testing and interventions in the general population (Sandman & Weinstein, 1993; Weinstein et al., 1990). Our results clearly show that the vast majority of the sample has a grounded knowledge of the risk posed by radon exposure on health. This information, as it emerges, is largely shared within the community throughout all media and at all educational levels, regardless of age, gender or birthplace.

However, this general information and knowledge about radon is not cognitively associated with the perceived risk of self-exposure to radon, thus inducing a bias in the risk assessment. In fact, over 90% of the sample declared that they either were not at personal risk of radon exposure or they did not know. This result confirms previous findings reported by Hill et al. (Hill et al., 2006) on a sample where a low agreement between actual radon risk and perceived risk was found, and is also in accord with a pioneering research conducted by Weinstein, that found that individuals were less likely to judge their house at risk of radon compared to that of others (Weinstein et al., 1988). This is commonly referred to as optimistic bias, where people tend to judge personal and family risks less rationally than general population risks (Sjöberg, 2003). It is of extreme importance to try to fill the gap between the knowledge about the health risks posed by radon and the perceived risk of self-exposure and provide the general population with a mean to overcome such biases. A way to try to fill this gap is to implement target health protective interventions. A recent systematic review (Cori et al., 2022) explored the best strategies to increase public awareness of the risk. Schools interventions promoted by students themselves, web searches and newspapers were found to be the most common and effective media. All studies in the review also highlighted the importance of dissemination of the personal risk when it comes to radon exposure. Additionally, communication that was localized – i.e. particularly tailored and targeted to the population it was addressed to in regards to socio-cultural status – proved to be the most effective.

The gap between the knowledge and the low perceived risk is also a cause of an overall low concern towards the health risks associated with radon, expressed by more than 70% of the present sample. Risk perception, in fact, is a psychological process which can be shaped by

the individual response to danger, cultural context and subjective experience (Cori et al., 2022). While subjective experience can hardly be affected, given that radon is odorless, tasteless and colorless, the role of the socio-cultural context is particularly evident from our data, since a higher education level corresponds to a significantly higher concern towards the radon health risks. This finding is in contrast to that reported by Poortinga et al. (2008) (Poortinga et al., 2008) but is in agreement with a more recent study that showed that radon risk perception is associated with years of professional experience of the employees interviewed (Cori et al., 2022). Additionally, in agreement with Poortinga et al. (Poortinga et al., 2008) our findings in Table 3 show that higher education is associated with lower trust in the local authorities, regardless of the source information.

This result is in contrast with the trust that citizens show to have in institutions in relation to other issues such as politics, justice and health etc. For these issues, in fact, trust grows as the level of education increases, even if with territorial differences (Istituto Nazionale di Statistica, 2022) 16% of subjects with a high level of education declare that they think their house is built in a radon risk area. With respect to this perception of risk, they do not find prevention and control actions by local and national institutions. Legislative Decree 101 (art.19) establishes that, in order to protect the general population from exposure to radon, local authorities must promote campaigns and related actions to encourage homeowners to carry out radon measurements in their homes. Furthermore (art. 14), the decree reports the need for awareness and information campaigns on the risks deriving from exposure to radon in closed environments and the synergistic action with cigarette smoke. At present, none of these actions have been undertaken in the Campania region where the survey was conducted. This could justify the low trust of the interviewees who declare to have very little trust (47%) or moderate trust (37%) in the actions of the authorities.

Results reported in Table 4 show that the concern about radon exposure is associated with the source of information, and in particular that participants who learned about radon at school or at the university were significantly less concerned about their exposure in comparison to those who were informed through the internet or media, regardless of their educational level. This finding could be explained by the fact that media and internet sources of information may tend to dramatize and cause alarmism when reporting about environmental risks as they might be driven by private interests (Sandman, 1994), while information delivered via institutional means could be less biased.

Finally, the present study aims to preliminarily introduce and evaluate, for the first time in Italy, an ad hoc cognitive survey adopted to investigate the risk perception of radon, which allows to explore in the population three cognitive domains related to radon, in particular knowledge, risk perception and risk awareness. The survey, based on that of Poortinga et al. (Poortinga et al., 2008), was translated and localized into Italian and is ready to be extensively validated in future research.

6. Conclusion

The Campania region is considered overall an area at high risk of radon exposure and all residents are considered vulnerable. In this study we have performed a cognitive survey on the knowledge, risk perception and awareness of the risk deriving from exposure to radon. The questionnaire, administered through online platforms, was composed of 17 items. The general population, randomly selected, participated to the study. The results obtained show that among participants there is a vast percentage who are knowledgeable about the topic of radon and the risks associated with it. Also, most people acquired the information through school/university. Very interesting is the result of the present study which shows that looking at the association of trust in local authorities with educational level, the trust is higher for those with a lower level of education. The risk perception by the population and the risk communication by the authorities could play a fundamental role in risk

prevention, in particular by having an impact on radon exposure. Consequently, a synergistic approach between populations and field experts could improve the critical issues associated with radon mitigation.

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