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INFLUENCE OF GEOLOGICAL PARAMETERS ON THE INDOOR RADON CONCENTRATION IN THE CITY OF TREBINJE

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Abstract: The paper deals with the analysis of the indoor radon concentration results measured in four schools of Trebinje city and taking into consideration their geological background and its characteristics. There have been 13 measurements and the results showed the range of 75 Bq/m^3 to 4244 Bq/m^3. Some of the indoor radon concentrations were very high, up to 15 times higher than recommended ones reaching the level of 300 Bq/m^3.

In each of the four schools there are spots with the high geogenic potential and, 38 % results show a concentration higher than 1100 Bq/m^3, which further characterize this area as Radon Priority Area. From the geological point of view, the geological sheet Trebinje represents a part of Mesozoic and Paleogenic complex which build the outdoor Dinarides part. There are also different varieties of calcium carbonate and dolomite areas with sporadic occurrence of sandstones (pescari) and marlstones (laporci) accumulated at the end of the Paleogene period so that lithological content is pretty simple.

The main part of the terrain is represented by sediments originated from Mesozoic and Paleogenic structures which appear along with greater dislocation in narrow strings.

Keywords: radon, radon concentration, Cr – 39 detectors, limestone, dolomite, dislocations.

1. INTRODUCTION

Radon is a colorless and odorless radioactive gas originating from the isotope $_{222}$Rn and is the product of radium a$_{226}$Ra in the decay chain of uranium $_{338}$U, present in various concentrations in all materials originating from the ground. Dominant sources of radon and thoron are**:** rocks (ores) and soil**.** The highest concentrations of radon are recorded in ore deposits, magmatic and granite rocks, and clays. In addition, the source can be any water (underground or surface). The source of radon can also be construction materials. Many factors affect radon exhalation: soil grain size, humidity, pressure difference, temperature, porosity and etc. It is transported from the inside to the surface of the soil: by diffusion (about 90%), advection (< 5%) and convection (< 5%). It can accumulate indoors to concentrations that are considered a high risk to human health (WHO 2009). BSS requires that the reference level for long-term measurements of Rn indoor concentration does not exceed 300 Bq/m^3 for apartments and workplaces.

Factors influencing concentration of radon indoors are classified into three groups:

1. Geochemical and geological characteristics of regional and local soil

2. Ambient conditions responsible for radon emanation and transport of radon through the soil including: grain size, water content, porosity; as well as rock thickness, permeability and existence of faults and karst,

3. Construction characteristics including type of construction material, cracks in foundations and walls, ventilation rate (Ciotoli et al., 2017).

There are many scientific studies that try to solve this question using different analytical techniques (Zunic et al., 2019, Zunic et al., 2017a, 2017b;

Ciotoli et al., 2017; Ivanova et al., 2017; Kropati et al, 2015; Bossev et al., 2014, Bochicchio et al., 2014; Carpentieri et al., 2014)

Trebinje sheet covers the southeastern part of Herzegovina, a smaller part of Dalmatia and a very small part of Montenegro. The area where the following schools are located: Elementary school Jovan Jovanovic Zmaj – Trebinje and Elementary Music School Trebinje represents the southwestern peripheral part of the urban core, Elementary school Vuk Karadzic Trebinje the western part of the urban core. Elementary school Vasilije Ostroski Trebinje is located about 600,00 m northeast of the city center.

The carbonate structure of almost the entire terrain, as well as the absence of forest or humus cover, caused a very good dispersion of the terrain. Orographically, Leotar stands out (1229 meters above the see level, north of the city of Trebinje) with Dinaric extension direction (northwest-southeast), with steep slopes, and sharp bilo.

Central and southwestern parts of the inner city core, as well as the northeastern and southwestern parts of the immediate and wider surroundings represent part of Trebinje field, located on the extreme southeastern edge of Popovo field depression, that is, the smaller units within this Lug – forest depression. The field is covered by alluvial deposits of the Trebisnjica River and deluvial deposits northeast of the city.

Most of the terrain is completely anhydrous. The constant water flow is Trebisnjica. Occasional streams have torrential character.

2. MATERIAL AND METHODS

2.1. Indoor radon concentrations measurements

Long-term measurements of radon concentration were performed with CR – 39 detector (Italy). This type of detector has been used in other studies so far (Stojanovska et al., 2016; Curguz et al., 2015). The detectors were placed for 12 months in the premises where children and teachers stay (classrooms and staff rooms). Measurements were performed in 4 schools and 13 premises. They were placed 30 cm from the ceiling and side walls, taking care that they are not above the heat source. The detectors were chemically developed within 1 hour in 6.25 normal NaOH solution at 98 ^{o}C. Once removed from the bathroom, the detectors were washed, first with distilled water and then with tap water and left for 30 minutes in 2% aqueous solution (distilled water) of acetic acid to stop further development of traces. The detectors were then rinsed again and left to dry. After drying of detectors, traces count was started (WHO (1996)). The counting was performed on the Politrack system (IT) at the National Institute of Health in Rome.

2.2. The Geological Characteristics of the sites

The geology of the wider surroundings of Trebinje R 1:25 000 was described, according to the interpreter of the Basic Geological Map R 1:100 000 for Trebinje sheet L 34-37 (Brkovic et al., 1976a; 1976b, Ciric et al,. 1978; Ciric 1980; Mojsilovic et al 1978, 1980)

The area where the city of Trebinje and its surroundings is situated represents the southeastern parts of the ***„High Karst Overthrust“***, i.e. *Ljubovo Anticlines*, a smaller tectonic structure separated within this geotectonic unit. The *„High Karst Overthrust“* is characterized by the general spreading of layers northwest-southeast, relatively slight general decline to the northeast, laying down of wrinkles to the southwest, banded arrangement of sediments and faults of different type, intensity and time of origin. The northern and northeastern parts of the wider surroundings represent the southwestern wing of the Leotar anticline, and the western, southwestern and southern parts of the wider surroundings represent the part of the northeastern wing of the Ljubovo anticline.

In addition to the longitudinal faults that separate individual tectonic units and along which the horizontal movements were performed with riding in the southwest direction, and through transverse and longitudinal faults. Three fault systems of different origin and intensity are observed. These are northwest-southeast fault (the oldest), the northeast-southwest faults (small length) and the faults of the general north-south direction (a system of parallel faults along which tectonic units split).

(1. Para-autochtone, 2-5. High Karst Nappe, 2. The Gromača anticline, 3. The Ljubovo anticline, 3a. The Leotar anticline, 4. The Lastva anticline, 4a.The Deluše-Bileća-Propastine anticline, 4b. The Zvijerina syncline, 4c. The Selište syncline, 4d. The Golobrdje anticline, 4e. The Sitnica Mt. Anticline, 4f. The Žukovica-Ivica-Gradina syncline, 4g. The Cerovi syncline, 4h. The Buduši-Moska syncline, 4i. The Košća Vlaka-Šobadina syncline, 4j. The Vidra syncline, 5. The Pustipuhe-Ljubinje syncline)

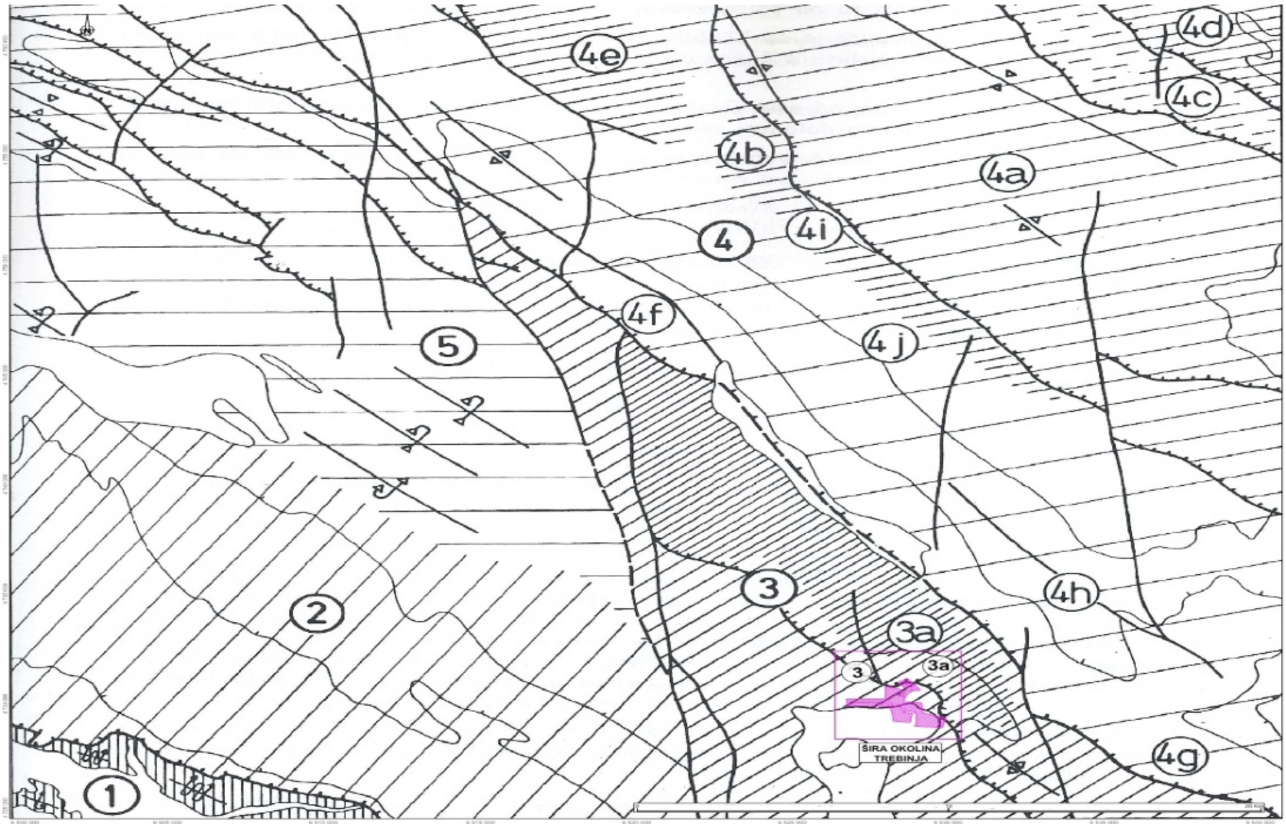

Figure 1. *Generalized tectonic map of Trebinje sheet*

2.3. Lithostratigraphic structure of the terrain

The following lithostratigraphic units are registered in the area of Trebinje sheet:

Triassic (T) formations are present in the sediments of the Upper Triassic, within which the following are distinguished: *Carnian layer* (T_3^1) – thin-plate limestones, dolomites and subordinately marls with coal; *Noric andi Rhaetian layer*(T_3^{2+3}) – massive, less often banked dolomites, subordinate dolomitic limestones in the form of lenses within the dolomites.

Lower Jurassic - Lias (J_1) deposits were discovered as a narrow belt in the coastal part and in the area of Lastva anticline. They are represented by layered to banked limestones with a cryptocrystalline structure and dolomites with a fine crystalline structure, which are easily decomposed.

Middle Jurassic - Dogger (J_2) – is built of limestones lying normally over the Lias sediments. The limestones are layered and massive, with interlayers of dolomite and predominantly pseudo oolitic structures in the lower horizons, and oolitic structures in the higher horizons.

The upper Jurassic – Malm (J_3) is isolated in the Lastva, Ljubovo and Gromaca anticlines. There are two packages:

– Lower *Oxford-Kimmeridge* ($J_3^{1,2}$) built of well-bedded (in lower horizons) to massive (in higher horizons) limestones;

– Upper *Kimmeridgian-Tithonian* ($J_3^{2,3}$) dolomites and layered limestones.

Lower Cretaceous limestones and dolomites of the Lower Cretaceous were developed in the Gromaca, Ljubovo, Leotar and Lastva anticlines, and the smaller secondary Deluse anticline. Lower Cretaceous deposits are divided into three packages:

– Massive to banked dolomites and layered banked, cracked limestones Valangian -Barremian (${}^1K_1$);

– Thin-plate (marly and butuminous) and layered limestones *alb-apt* (${}^2K_1$);

– Layered limestones with rare interlayers of dolomites *apt-cenoman* ($K_{1,2}$).

Upper Cretaceous limestones and dolomites of the Upper Cretaceous are the most distributed in the terrain of the Trebinje sheet. They were continuously deposited and all three packages were separated.

Cenomanian (K_2^1) is represented by dolomites and a series of oolitic and cryptocrystalline limestones.

Turonian (K_2^2) limestones and dolomites of this package have a dominant distribution in this area. Where possible, they were separated into three packages:

– *Plate dolomites with interlayers of limestone* (${}^1K_2^2$)*;*

– *Limestones and dolomites with chandrodonts* (${}^2K_2^2$)*;*

– *Limestones with rudists* (${}^3K_2^2$)*.*

1. Elementary School Jovan Jovanovic Zmaj Trebinje is situated in the south western part of the urban city center. The terrain structure of the immediate location includes alluvial deposits (al) deposited over the limestone and dolomite packages with chondrodonta (${}^2K_2^2$) – Middle Turonian.

2. Elementary School Vasilije Ostroski Trebinje is situated north of the urban city center. The terrain of the immediate location includes deluvial deposits deposited over the Lower Cretaceous Valangian -Barremian (${}^1K_1$) massive, scarce banked dolomites with smaller lenses or layers of gray-bluish and brown dolomite limestone in the lower horizons.

3. Elementary School Vuk Karadzic in Trebinje is situated in the eastern part of the urban city center. The terrain structure of the immediate location includes alluvial deposits (al) deposited over the limestone and dolomite packages with chondrodonta (${}^2K_2^2$) – Middle Turonian.

4. Elementary School Trebinje is situated in the southwestern part of the city. The terrain structure of the immediate location includes alluvial deposits deposited over the limestone and dolomite packages with chondrodonta (${}^2K_2^2$) – Middle Turonian.

3. RESULTS AND DISCUSSION

Table 1 shows descriptive statistics of the measurement results in four schools. The minimum measured value was 75 Bq/m^3 and the maximum value was 4 244 Bq/m^3, which is 10 times more than the recommended 90/143/ Euratom (Council of the European Union – 400 Bq/m^3) WHO (1996).

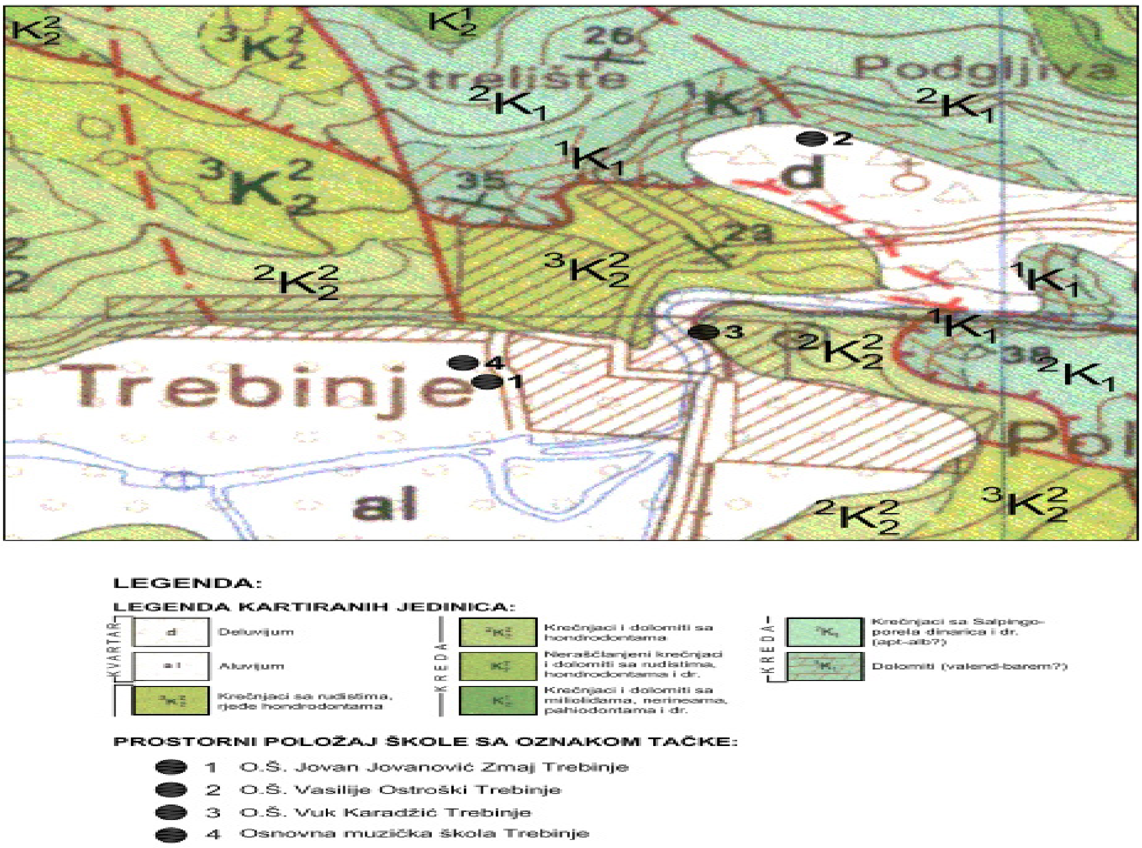

Figure 2. *Generalized tectonic map of Trebinje sheet*

Table 1. *Descriptive measurement statistics in 4 schools*

Statistic	Rn
Minimum (Bq/m3)	75
Maximum (Bq/m3)	4244
Median (Bq/m3)	472
Arithmetic mean(AM) (Bq/m3)	978
Standard deviation (SD) (Bq/m3)	1193
Geometric mean (GM)	511
Geometric standard deviation (GSD)	3,41

What is characteristic for the area of the City of Trebinje is that in each building, at least in one room, the concentration of radon was above the recommended level (OS Jovan Jovanovic Zmaj 4244 Bq/m3, OS Vasilije Ostroski 1 447 Bq/m^3, OS Vuk Karadzic 1 193 Bq/m^3 and 1 126 Bq/m^3, Elementary Music School 1920 Bq/m^3) sl.3. The results are significantly different from previous research in Italy, Serbia, Macedonia and the Republic of Srpska (schools) (Bochicchio, F. et al.2014, Bossew, P et al. 2014, Carpentieri, C et al. 2011, Stojanovska, Z, et al. 2014, Curguz, Z., et al. 2015)

4. CONCLUSION

This paper links the high indoor radon concentrations to the geological substrates beneath the measurement facilities. When analyzing the geology of the measured area, the dominance of limestone and dolomite packages with chondrodonta ($^2K_2^2$) – Middle Turonian is observed, as well as high karst overthrust and faults of different types give answers about high radon concentrations in all schools. It is known that radon concentrations vary from room to room in the same building, which was also determined in other studies (3). This phenomenon is also confirmed in this paper where we have a very pronounced variability of concentrations. This phenomenon requires the measurement of radon concentrations in each of the premises of the facility in order to properly demonstrate the risk of the geogenic potential of the area. The results of these measurements indicate the need to analyze radionuclides of the materials from which the facilities were built to determine their impact in total concentrations. All data from this research should be taken into account during the construction of such and similar facilities in the area of the city of Trebinje.

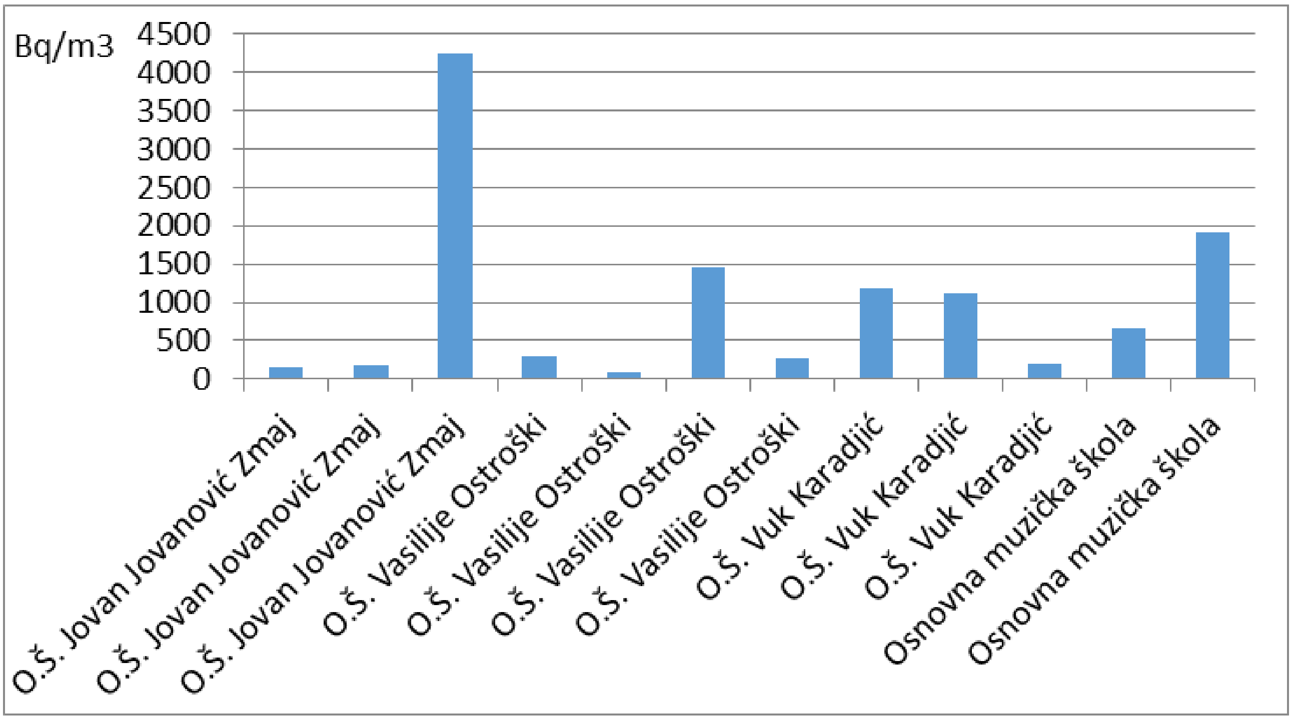

Figure 3. *Measurement plot*

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УТИЦАЈ ГЕОЛОШКИХ ПАРАМЕТАРА НА УНУТРАШЊЕ КОНЦЕНТРАЦИЈЕ РАДОНА У ТРЕБИЊУ

Сажетак: Рад се бави анализом резултата концентрације радона у затвореном простору измјерених у четири школе у Требињу, узимајући у обзир њихову геолошку подлогу и њене карактеристике. Извршено је 13 мјерења и резултати су показали опсег од 75 Bq/m^3 до 4244 Bq/m^3. Неке од концентрација радона у затвореном простору биле су веома високе, до 15 пута веће од препоручених, достижући ниво од 300 Bq/m^3.

У свакој од четири школе постоје мјеста са високим геогеним потенцијалом и 38% резултата показује концентрацију већу од 1100 Bq/m^3, што додатно карактерише ово подручје као подручје приоритета за радон. Са геолошке тачке гледишта, геолошки лист Требиње представља дио мезозојског и палеогеног комплекса који граде вањски дио Динарида. Постоје и различите варијанте подручја калцијум-карбоната и доломита са спорадичном појавом пешчара (пескари) и лапорца (лапорци) акумулираних на крају палеогенског периода тако да је литолошки садржај прилично једноставан.

Главни дио терена представљају седименти настали из мезозојских и палеогених структура који се јављају уз већу дислокацију у уским низовима.

Кључне речи: радон, концентрација радона, детектори Цр–39, кречњак, доломит, дислокације.

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