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STATISTICAL ANALYSIS OF RADON CONCENTRATION IN UNDERGROUND GOLDMINE

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ABSTRACT

Radon concentrations and environmental factors were collected monthly over a period of one year in 10 different levels in an underground goldmine to determine the effect of environmental factors on radon concentration. The detectors were installed in batches within four quarters. The activity concentration within the year ranges from a minimum of 2 Bqm^{-3} to a maximum of 284Bqm^{-3} with a mean value of 58.51Bqm^{-3}. A positive relationship was observed between dry bulb temperature, relative humidity and radon concentration while a negative relationship was observed between barometric pressure, air quantity, wet bulb temperature and radon concentration and all the relationship was statistically insignificant but a principal component analysis deduced Barometric Pressure, Relative Humidity and Wet Bulb Temperature as the three main factors that influences the indoor radon concentration in the underground goldmine of which the wet bulb temperature was statistically significant at the 5% level of significance.

Keywords: Radon, Environmental factors, Radon Concentration, Correlation, Principal Component Analysis
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Introduction

The underground mine environment is complex and variable. Radon, after being exhaled, migrates along ventilation currents while it generates the solid decay products: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po (Cousins et al., 2011). These radionuclides attach to the aerosol particles in the air, forming what is termed attached radon progeny. The fraction of radon progeny that does not attach to the aerosol particle in the air is termed the unattached state. In both cases, concentrations of these radon decay products increase rapidly with time in air in the mine. If inhaled, both attached and unattached radon progenies may be deposited in the lung, especially in the upper respiratory tract, and irradiate the lung tissue as they decay. The entry of radioactive aerosol into the respiratory tract depends on their size; larger particles stop in the nasal cavity, while smaller aerosols reach the lungs (Planinic, Faj, Radolić, Šmit, & Faj, 1999). Epidemiological studies have revealed a strong correlation between lung cancer and exposure to radon (Yoon, Lee, Joo, & Kang, 2016). It was identified as a human lung carcinogen in 1986 by the World Health Organization – WHO. High concentration of radon is found in poorly ventilated structures and if the radon input from its sources is high, such as mines, caves, cellars, ancient tombs, and airtight houses. The inhaled radon passes from lungs into the blood and body tissues and may irradiate different soft tissue causing cancers such as lung cancer, kidney cancer and prostatic cancer. Radon has also been linked with melanoma and some childhood cancers. There is also a positive association between coronary heart disease and radon exposures where an elevated risk of mortality from coronary heart disease was observed among miners with accumulative radon exposure exceeding 1000 Working Level Month (WLM) (Bajwa & Virk, 1997; Hussein, 2008).

Materials and Methods

The radon gas measurement was done using radon samplers made up of LR-115 (type II strippable) cellulose nitrate detectors manufactured by Kodak Pathé in France and 25 cm PVC pipe with a diameter of 50 mm and an end cap. The detectors of area 2cm × 2cm were attached to a plastic dish with its sensitive side facing upwards and covered with a perforated plastic dish. The plastic dish with the radon detectors were installed at ten different locations of the Subika underground mine. The detectors were planted in batches within the four quarters. Each batch within the quarters was left within the sampling points for approximately four (4) weeks.

Forty (40) sampling points within the ten selected points were chosen within the project site using a non-probability quota sampling. A total number of 40 dishes containing 80 detectors were deployed at the points for each batch (month). In all a total number 320 detectors were deployed at the sampling points of which 20 of

them were crushed by the heavy-duty trucks underground, leaving at total of 300 detectors to be analysed at the Nuclear Track detection Laboratory of the Ghana Atomic Energy Commission.
After exposure for one (1) month, the detectors were removed from the dish. 200 grams of sodium hydroxide pellet was weighed in a beaker with an electronic balance and the solution prepared in a 2L volumetric flask using a magnetic stirrer at the Nuclear Track detection Laboratory of the Ghana Atomic Energy Commission. The detectors were then subjected to chemical etching in a 2.5 M analytical grade sodium hydroxide solution at (60 ±1) ºC, for two hours in a constant temperature water bath to enlarge the latent tracks produced by alpha particles from the decay of radon. After the etching, the detectors were washed with running cold water for 20 minutes to stop the etching process, then washed in distilled water for 15minutes. The detectors were then peeled whilst in the distilled water and air dried on a cardboard. After a few minutes of drying in air, the detectors were ready for track counting.

The counting of tracks and the image acquisition was performed using a commercial scanner (Epson Perfection V600 Photo) having 4800`x9600-dpi resolution and 48-bit for colour and 16-bit for grey maximum depth coupled to a laptop. An important characteristic of the scanner is its double-lighting system. The films were inserted between two rigid transparent sheets on the scanner surface. This arrangement provides a reasonably uniform illumination of the films, reducing the formation of folds and/or bubbles. The negative acquisition of the film image was carried out using 24-bit colour depth and 4800-dpi resolution. This choice produces an image that allows discerning appropriately tracks without requiring too much memory. A square area (1x1) cm^2 inside the exposed surface of the film was acquired. ImageJ (Image Processing and Analysis in Java), a free digital image-processing software developed by the National Institutes of Health of the United States was used for the image processing and calculation of Radon concentration.

Data on some environmental factors such as Barometric Pressure, Relative Humidity, Dry Bulb temperature, Wet Bulb temperature and Air quantity were collected and analysed to determine its effect on radon concentration in the underground mine. The estimation of Radon concentrations is made by using the analytical expression of the multiple linear regression with the corresponding environmental variables at different levels in the underground goldmine.

Making use of the dedicated statistical package SPSS version 16.0 developed by IBM in New York, USA (Adjirackor, Darko, & Sam, 2017), the regression coefficients are determined by the least square method. The Multiple linear regression model assumes a linear relationship between the Indoor radon concentration as dependent variable and the environmental factors as predictor variables.

General model

$$y(t) = \beta 0 + \beta 1 X1(t) + \beta 2 X2(t) \ldots + \beta n Xn(t) + \varepsilon \qquad (1)$$

where
$y(t)$ - the value of the dependent variable
$X1(t), X2(t), \ldots Xn(t)$ - the current variable, value of the dependent variable at a time t given by the values of the independent variables at the same moment (the time corresponding to the value of the time series)
β_0 - regression constant
β_n - predictor coefficient $X_n(t)$
ε - time error

Specific Model

$$RC = \alpha + \beta 1BP + \beta 2WBT + \beta 3DBT + \beta 4RH + \beta 5AQ + \varepsilon \qquad (2)$$

Where RC = Radon Concentration (dependent variable) β1BP= Barometric Pressure (I.V) β2 WBT= Wet Bulb Temperature (I.V), β3DBT = Dry Bulb Temperature (I.V) β4 RH = Relative Humidity (I.V), β5 AQ = Air Quantity (I.V).

Hypothesis
H_{01}: There is a no correlation between barometric pressure and the radon concentration.
H_{02}: There is a no correlation between wet bulb temperature and the radon concentration.
H_{03}: There is a no correlation between dry bulb temperature and the radon concentration.
H_{04}: There is a no correlation between relative humidity and the radon concentration.
H_{05}: There is a no correlation between air quality and the radon concentration.

Results and Discussion

Table 1: Descriptive Statistics of Variables

Variables	Min-Max	Mean ±SD	Skewness	Kurtosis	Kolmogorov-Smirnov *P- values*
Radon Concentration	2.0-284.0	58.5±1.42	1.42	1.35	0.22
Barometric Pressure	99.5-102.5	101.1±0.9	-0.43	-1.02	0.24
Wet Bulb Temperature	24.6-32.0	28.4±1.6	-0.55	0.77	0.15
Dry Bulb Temperature	27.7-33.1	30.9±1.7	-0.79	-0.64	0.15
Relative Humidity	78.1-97.9	87.40±5.2	0.52	-0.67	0.14
Air Quantity	2.8-33.7	15.3±9.2	0.94	-0.25	0.23

The annual Radon concentration in the underground mine ranges from a minimum of 2 Bqm^{-3} to a maximum of 284 Bqm^{-3} with a mean concentration of 58.51Bqm^{-3}.The mean value of the measured Barometric pressure, Wet bulb temperature, Dry bulb temperature, Relative humidity and air quantity were 101.08 KPa, 28.36 ^{0}C, 30.89 ^{0}C, 87.40 %, 15.28 m^{3}/s, 15.24 mcal/cm^{2}s respectively as shown in table 1.

A positively skewed data distribution of radon concentration, relative humidity and air quantity indicates that low values of data for the variables were recorded as compared to high values and a negatively skewed data distribution of barometric pressure, wet bulb temperature and dry bulb temperature indicates that high values of data for the variables were recorded as compared to low values. In addition, a platykurtic data distribution of radon concentration and wet bulb temperature indicates that the recorded values for the variables are scattered around the mean value and a leptokurtic data distribution of barometric pressure, dry bulb temperature, relative humidity and air quantity indicates that the recorded value for the variables is clustered around the mean value. However, the data for all the variables is normally distributed since the p-value in the Kolmogorov-Smirnov test as shown in table 1 is greater than the 5% level of significance ($P > 0.5$) thus; the representative values give a true reflection of the population.

Table 2: Output of Regression Coefficients^{a}

Model	Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	1097.466	915.779		1.198	0.239
Barometric Pressure	-9.579	9.177	-0.170	-1.044	0.304
Wet Bulb Temperature	-18.250	10.172	-0.619	-1.794	0.082
Dry Bulb Temperature	8.647	11.015	0.307	0.785	0.438
Relative Humidity	2.307	2.025	0.255	1.139	0.263
Air Quantity	-1.044	0.812	-0.202	-1.285	0.208
Wet Kata Temperature	-0.006	1.591	-0.001	-0.004	0.997

This table generated the specific regression equation as shown in equation 3.

$$\begin{aligned} RC = 1098 - 0.170BP - 0.619WBT + \\ 0.307DBT + 0.255RH - 0.202AQ - 0.001WKT \end{aligned} \qquad (3)$$

where RC - Radon Concentration, BP -Barometric Pressure, WBT -Wet Bulb Temperature, DBT -Dry Bulb Temperature, RH -Relative Humidity.

The regression coefficient for barometric pressure (B_1) = -0.170 depicts a negative correlation between barometric pressure and radon concentration and it implies that 1% increase in barometric pressure will decrease radon concentration by 17% holding WBT, DBT, RH, AQ constant as shown in table 2 and equation 3 but was statistically insignificant at the 5% level of significance ($P > 0.05$) hence, the null hypothesis is accepted. Increase in barometric pressure will cause a decrease in radon exhalation from porous rock in the underground mine environment, leading to a reduction of radon concentration (IAEA, 1992a; Sahu et al., 2016).

The regression coefficient for wet bulb temperature (B_2) = -0.619 depicts a negative correlation between wet bulb temperature and radon concentration and it implies that 1% increase in wet bulb temperature will decrease radon concentration by 61.9% holding BP, DBT, RH, AQ constant as shown in table 2 and equation 3 but was statistically insignificant at the 5% level of significance ($P > 0.05$) hence the null hypothesis is accepted.

A wet bulb thermometer measures the extent of cooling as moisture dries from a surface (evaporative cooling). At this point the underground mine experiences some coolness due to ventilation and warmer air which causes significant increase in the wet bulb temperature flows naturally out of the underground mine, carrying radon into the atmosphere. This results in a significant decrease in the activity concentration of radon inside the underground mine (Fijałkowska-Lichwa & Przylibski, 2011).

The regression coefficient for Dry bulb temperature (B_3) = 0.307 depicts a positive correlation between Dry bulb temperature and radon concentration and it implies that 1% increase in dry bulb temperature will increase radon concentration by 30.7% holding BP, WBT, RH, AQ constant as shown in table 2 and equation 3 but was statistically insignificant at the 5% level of significance ($P > 0.05$) hence the null hypothesis is accepted.

The dry-bulb temperature is an indicator of heat content. The underground mine is a warm environment and the moisture content in the underground mine increases at high temperatures. The increase in radon concentration could be due to the increase in moisture content when temperatures are high since exhalation rate of porous rocks increases with increase in moisture content (IAEA, 1992a; Sahu et al., 2016)

The regression coefficient of Relative Humidity (B_4) = 0.255 depicts a positive correlation between Relative Humidity and Radon Concentration and it implies that 1% increase in Relative Humidity will increase radon concentration by 25.5% holding BP, DBT, WBT, AQ constant as shown in table 19 and equation 42 but was statistically insignificant at the 5% level of significance ($P > 0.05$) hence the null hypothesis is accepted. Humidity also refers to the degree of moisture or water vapour found in the atmosphere, when air contains moisture, it is said to be humid. Conditions such depth of workings, machinery and work-related activities also contribute to high temperatures in the underground mine and hot places like the underground mine tend to be more humid than cool places because heat causes water to evaporate faster. The increase in radon concentration could be due to the increase in amount of water present in the pore space (moisture content) since exhalation rate of porous rocks increases with increase in moisture content (IAEA, 1992a; Sahu et al., 2016)

The regression coefficient for Air Quantity (B_5) = -0.202 depicts a negative correlation between Air Quantity and Radon Concentration and it implies that 1% increase in Air Quantity will decrease radon concentration by 20.2% holding BP, DBT, RH, WBT constant as shown in table 2 and equation 3 but was statistically insignificant at the 5% level of significance ($P > 0.05$) hence the null hypothesis is accepted.

Air Quantity is the product of air velocity within a particular area of interest. An increase in air velocity tends to increase the ventilation rate thereby cooling the underground mine allowing warm air to move out which reduces the radon concentration in the underground mine. Air velocity alone is not so much significant, but, its combination with wet-bulb temperature produce reliable results in hot and humid mine environment. (Neingo & Tholana, 2016).

Table 3: Multicollinearity of Independent Variables

Collinearity Statistics	
Tolerance	VIF
0.854	1.171
0.190	5.255
0.148	6.746
0.452	2.210
0.919	1.088

a. Dependent Variable: Radon Concentration

Table 4: Collinearity Diagnostics of variables

Model Dimension	Eigenvalue	Condition Index	(Constant)	Barometric Pressure	Wet Bulb Temperature	Dry Bulb Temperature	Relative Humidity	Air Quantity
1	6.671	1.000	0.00	0.00	0.00	0.00	0.00	0.00
2	0.230	5.381	0.00	0.00	0.00	0.00	0.00	0.88
3	0.093	8.477	0.00	0.00	0.00	0.00	0.00	0.09
4	0.005	38.255	0.00	0.00	0.01	0.03	0.22	0.01
5	0.001	67.113	0.01	0.01	0.16	0.00	0.10	0.01

a. Dependent Variable: Radon Concentration

The tolerance value of less than 0.10 indicates a multicollinearity problem (O'Brien & Robert, 2007). In the above table the tolerance values of all independent variables are 0.854, 0.190, 0.148, 0.452 and 0.919 as shown in table 3 are less the 0.10 which shows all the independent variables have multicollinearity problem.

The reciprocal of the tolerance is known as the Variance Inflation Factor (VIF). The VIF of 5 and above indicates a multicollinearity problem (O'Brien & Robert, 2007). In table 3 the VIF values of independent variables are 1.171, 5.255, 6.746, 2.210, 1.088 and 1.444 indicates two of out of the six the independent variables have issues of multicollinearity indicating a high correlation between dry and wet bulb temperature.

Eigen values close to 0 indicate dimensions which explain little variance (Agarwal, S., & Adjirackor, T. 2016). In table 4 eigen values of 0.230, 0.093, 0.005, 0.001, and 0.00 are close to zero which shows little variance among the independent variables which indicates a possibility of high correlations among the independent variables which is also an issue of multicollinearity.

The condition index summarizes findings thus, a condition index over 15 indicate a possible multicollinearity problem and a condition index over 30 suggests a serious multicollinearity problem (Agarwal, S., & Adjirackor, T. 2016). In table 4, two out of the five independent variables have a multicollinearity problem indicating a high correlation between dry bulb temperature and relative humidity. The statistical insignificance of the independent variables on the radon concentration in underground mine could be due to the issue of multicollinearity among some of the independent variables, hence the need for a principal component analysis and factor analysis to deduce the actual variables influencing radon concentration in the underground mine.

Cluster, Factor and Principal Component Analysis

Cluster Analysis was used to determine components (variables) that are significant at a particular level (cluster) in the underground mine. Principal Component Analysis (PCA) and Factor Analysis are used to determine the factors or Components that will significantly influence the radon concentration.

Table5: Cluster Analysis

Level	Cluster	RC (Bq/m^3	BP X1 (kPa)	WBT X2 (^{0}C)	DBT X3 (^{0}C)	RH X4 %	AQ X5 (m^3/s)
800	1	39.14	**101.70**	**29.88**	32.00	86.95	23.78
810	2	64.75	101.60	26.23	29.03	84.80	19.13
840	3	63.76	101.20	28.18	31.83	84.10	12.50
880	4	**78.00**	100.70	29.33	**32.38**	84.28	8.98
790	5	56.11	101.68	29.50	31.15	89.98	10.98
820	6	77.08	101.50	28.30	30.83	85.35	12.10
960	7	51.54	100.33	27.90	29.23	**94.53**	10.98
1000 YOD	8	77.13	100.50	27.78	31.38	88.13	8.98
920	9	59.42	100.40	29.10	31.38	87.05	16.38
1000 SKY DEC	10	77.43	100.63	27.05	29.93	89.03	**32.33**

The following variables were observed at each level in the underground goldmine: Wet bulb temperature (˚C), Dry bulb temperature (˚C), Relative humidity (%), Barometric pressure (kPa), Air quantity (m^3/s) and Radon concentration (Bqm^{-3}). Additionally, a multivariate statistical analysis was performed. A cluster analysis (CA) was applied by using the 10 different levels in the underground goldmine forming 10 groups. The groups differ in their variables as shown in Table 5, and one can observe the centroids of each variable in each group. This analysis indicates group 4 recorded the highest radon concentration, Dry bulb temperature which explains the positive relationship between the variables. Group 1 recorded the highest barometric pressure and wet bulb temperature, and these two variables have a negative relationship with radon concentration. Group 7 recorded the highest relative humidity and Group 10 recorded the highest Air quantity since it's the first level after the reference level which makes it closer to the entrance of the underground mine as compared to the other levels.

Table 6: Principal Component Analysis

Component Number	Eigen Value	% Of variance	Cumulative %
1	2.09	34.90	34.90
2	1.37	22.75	57.65
3	1.05	17.51	75.16
4	0.82	13.66	88.81
5	0.67	11.19	100

A principal component analysis and factor analysis was performed to determine the associations between the analysed variables and estimate the possible origins of the radon concentrations in the indoor environments of the underground goldmine. The first three components of this principal component analysis obtained an eigenvalue above 1 were extracted and represent 75.16% of the variability in the observed data (Table 6).

Table 7: Weight of Each Component

	Components		
Variables	1	2	3
WBT	0.889		
DBT	0.877		
BP		0.861	
RH			0.890
AQ			-0.507

Table 7 presents the weights for each component variable. In it, one can observe that for component 1, wet bulb temperature and dry bulb temperature have the highest weights, 0.889 and 0.887, respectively; the greatest weights for component 2 correspond to barometric pressure with a value of 0.861 while the greatest weight for component 3 corresponds to relative humidity. The negative values are considered to carry negligible weights.

Table 8: Factor Analysis

	Components		
Variables	1	2	3
BP	0.170	0.720	0.050
WBT	0.469	0.210	0.237
DBT	0.410	-0.015	-0.248
RH	-0.030	0.110	0.737
AQ	-0.175	0.173	0.418
WKT	-0.227	0.468	0.001

Source: Field data 2019

The purpose of the Factor Analysis (FA) was to strengthen the Principal Component Analysis (PCA) results and obtain several factors to explain most of the variability in the environmental factors (Wet bulb temperature (˚C), Dry bulb temperature (˚C), Relative humidity (%), Barometric pressure (kPa), Air quantity (m^3/s)).

As shown in table 8 three environmental factors were found to represent 75.16% of the variability in the original data. The FA explains the greater factors the influences the radon concentration in the underground mine. It was observed that the wet bulb temperature has the greatest weight in factor 1 with values of 0.469, the greatest weight for factor 2 correspond to Barometric pressure with a value of 0.720 while the greatest weight for factor 3 with a value of 0.737 correspond to Relative humidity as shown in table 8. These findings allow us to infer that component 1, or factor 1, is influenced by environmental conditions relating to wet bulb temperature. In contrast, component 2, or factor 2, favors barometric pressure. On the other hand, component 3 or factor 3 favors relative humidity. These results also explain that wet bulb temperature, barometric pressure and relative humidity are the main environmental factors that influences radon concentration in the underground goldmine.

Table 9: PCA Regression Coefficients

Model	Unstandardized Coefficients		Standardized Coefficient	t	P-value
	B	Std Error	Beta		
Constant	64.425	7.169		8.987	0.000
Wet Bulb Temps	-14.479	7.260	-0.303	-1.1994	0.045
Barometric pressure	-10.229	7.260	-0.214	-1.409	0.167
Relative Humidity	8.193	7.260	0.172	1.129	0.267

a. Dependent Variable: RC

The principal component regression was modelled to ascertain the significance of the main factors that has influence on the radon concentration in the underground goldmine. Table 9 shows a significant negative relationship between wet bulb temperatures and radon concentration at the 5% level of significance ($P < 0.5$). Thus, a unit increase in the wet bulb temperature will cause a decrease of 30.3% in the radon concentration in the underground mine.

The reason been that a wet bulb thermometer measures the extent of cooling as moisture dries from a surface (evaporative cooling). At this point the underground mine experiences some coolness due to ventilation and warmer air which causes significant increase in the wet bulb temperature flows naturally out of the underground mine, carrying radon into the atmosphere. This results in a significant decrease in the activity concentration of radon inside the underground mine (Fijałkowska-Lichwa & Przylibski, 2011).

The statistical significance between temperature and radon concentration is due to a good ventilation system and it also signals that, it is a variable that must be of interest to the environmental health and safety department of the mine. It must be closely monitored to inform if ventilation rate has to be increased to reduce radon concentration in the underground mine.

Relative humidity exhibited a positive correlation with radon concentration but was statistically insignificant at the 5% level of significance ($P > 0.05$). Thus, a unit increase in Relative Humidity will cause an increase of 17.2% in the radon concentration and vice versa in the underground mine.

The increase in relative humidity could be due to the increase in moisture content when temperatures are high and since exhalation rate of porous rocks increases with increase in moisture content thereby increasing the radon concentration (IAEA, 1992a; Sahu et al., 2016).

The statistical insignificance of the Relative Humidity on radon concentration might be because the rocks type in the underground mine has low exhalation rate since rock types have different exhalation rate. or it could also be due to a good ventilation system in the underground mine since indoor humidity is influenced by ventilation rates. Ventilation usually reduces indoor moisture levels (Flannigan and Morey, 2009) thereby cooling down the warm environment and decreasing radon concentration as warm air rises and escapes to the atmosphere through the ventilation system.

Barometric pressure also exhibited a negative correlation with radon concentration but was statistically insignificant at the 5% level of significance ($P > 0.05$). Thus, a unit increase in Barometric pressure will cause a decrease of 21.1% in the radon concentration underground.

This is because an increase in barometric pressure will cause a decrease in radon exhalation from porous rocks in the underground mine environment, leading to a reduction of radon concentration (IAEA, 1992a; Sahu et al., 2016).

The statistical insignificance of barometric pressure and relative humidity could also be due to the low emanation of radium from solid like rocks and low diffusing rate of radon gas in solid grains in the underground mine or a good ventilation system. When ventilation rate increases, convection mechanism resulting from pressure gradient would cause the depletion of radon from indoor environment (Flannigan and Morey, 2009).

The result of the positive correlation between indoor radon concentration and indoor humidity agrees with the results of some researchers, Kearfott et al. (1992), Blaauboer and Smetsers (1997) and (Alonso et al., 2013). However, the results were contrary to the results described by Yu et al. (1999) who found the decline in radon gas concentrations could be associated with a rise in relative humidity.

The results for temperature and barometric pressure was different from Xie, Liao, Wang, and Kearfott (2017) who detected that that indoor barometric pressure and temperature are generally constant with the average values of 97,000Pa and 23^0C, respectively. Indoor radon concentrations have no apparent correlation with indoor barometric pressure and indoor temperature. This difference could be due to the factors associated with different indoor environment thus, homes and underground mines.

Conclusion

Temperature, Barometric pressure and Relative Humidity and its changes have a critical impact on ventilation conditions in the underground workings of deep mines. Changes in pressure are particularly important because they are responsible for the transient states of ventilation conditions; therefore, assessing the scale of pressure change is essential. Keeping an eye on the barometer is critical during mining operations because situations in which the barometric pressure either rises too high or drops too low can create serious safety risks. The statistical insignificance and low values of radon concentration could be because ventilation at the underground goldmine is adequate, but a statistical significance of temperature signals that it is a variable that must be of interest to the environmental health and safety department of the mine. It must be closely monitored to inform if ventilation rate must be increased to reduce radon concentration in the underground mine. As mine atmospheres contain varying amounts of moisture that can be present at varying temperatures due to the prevailing conditions encountered, it then follows that their presence can have important effects on a person's safety and their ability to perform hard work.

Recommendation

Continuous monitoring of indoor radon and environmental parameters is important to evaluate temporal variations of indoor radon and the influence of environmental factors. The other influencing factors apart from environmental factors should be considered more carefully to help understand the behavior of indoor radon in the underground environment.

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