STATISTICAL ANALYSIS OF RADIOLOGICAL AND METEOROLOGICAL PARAMETERS OF UNDERGROUND MINES IN OKE-OGUN, OYO STATE, USING MULTIVARIATE APPROACH.

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Abstract: In recent times, there are moves to boost the economy of Nigeria through intensive investment in solid minerals exploration. This may however be accompanied with increase in mining activities with the corresponding technological enhanced naturally occurring radioactive materials (TENORM) due to radiation from the ores, soil, rocks and radon that emanates from underground mine. Measurement of radon concentration and meteorological parameters in selected underground mines has been carried out using Radon Scout Plus. The radon concentration measured in the underground mines ranged between 49 - 225,000 Bq/m^3. The relative humidity, temperature and pressure measured ranged between 40% and 91%, 22^{0}C and 29 ^{0}C and 975 mmHg and 991 mmHg respectively. There is a weak and negatively weak correlation between radon concentration, relative humidity and pressure with values of 0.23 and -0.18 at 0.05 level of significance respectively. For the principal component analysis, the second and third components are strongly loaded on temperature (0.992) and radon concentration (0.99) which indicates a different source of the radon gas in the underground mine which was from the radionuclide in the rocks in the mine. For the cluster analysis, cluster I comprises of Temperature, relative humidity and pressure and all metrological parameters. Varying one of the parameters can result to change in the other. Cluster II comprises of radon concentrations and time both at same distance. The result of the study reveals that meteorological parameters measured in the underground mines affects radon concentration.
Keywords: Statistical Analysis, Multivariate Approach, Radiological, Meteorological, Parameters and Underground mines

Introduction

Artisan miners involve in underground mining are fully aware of the danger associated with the collapse of caves but are not fully of the danger of inhalation of radon gas that accumulates in caves. The concentration of radon in caves it can be as high as 7,100,000 Bq/m^3 (Gillmore *et al.,* 2001). Radon, a naturally occurring radioactive gas can decay into solid radioactive elements called radon progeny such as Polonium-218, Polonium-214, andLlead-214. Radon progeny attaches itself to dust and other particles and can be inhaled into the lungs where they give off radiation. Inhalation of radon and its decay progeny is responsible for half of the annual average effective dose received by humans due to natural sources of radiation (Gillmore *et al.*, 2001). Exposure to radon for a long period of time can lead to lung cancer. The aims of the study are to measure the radon concentrations and meteorological parameters in selected caves in Komu, Oke-Ogun and establish the relationship between them using multivariate approach. The simplicity of the univariate statistical analysis is obvious and likewise the fallacy of reduction can be apparent (Ashley and Lioyd, 1978). In order to avoid this problem, multivariate analysis such as Pearson's correlation and cluster analysis are used to explain the correlation amongst a large number of variables in terms of a small number of underlying factors without losing much information (Jackson, 1999 and Meglen, 1992). The multivariate treatment of environmental data is widely used to interpret relationships among variables so that the environmental system could be managed. The intention underlying the use of multivariate analysis is to achieve great efficiency of data compression from the original data and to gain some information useful in the interpretation of the environmental geochemical origin. The method can also help to simplify and organize large data sets to provide meaningful insight and can help to indicate natural associations between samples and/or variables (Wenning and Erickson, 1994) thus highlighting the information not available at first glance.

Principal components analysis is a variable-reduction technique that shares many similarities to exploratory factor analysis. Its aim is to reduce a larger set of variables into a smaller set of 'artificial' variables, called 'principal components', which account for most of the variance in the original variables.

For cluster analysis, aims at identification and classification of groups with similar characters in a new group of observation or object. Each observation or object with each cluster is the same but the clusters are dissimilar from each other. Similarity is a measure of distance between clusters relative to the largest distance between any two individual variables. A 100% similarity implies that the clusters were zero distance apart in their sample measurement while similarity of 0% means that the clusters area is disparate as the least similar region. To the best of the knowledge of the researcher, radon concentrations at these mines has never been measured before and the result of the study can serve as a preliminary study against which future measurement can be compared. The work will also contribute to the existing body of knowledge in this area of study.

Materials and Methods

Description of the Study Location

The study locations are Komu, Sepenteri, Gbedu and Eluku villages in Itesiwaju, Saki East,Iwajowa and Saki Local governments respectively all in Oke-Ogun, Oyo State, Nigeria. Oke – Ogun (7°19'60" N and 4°4'0" E) is a populated place in Oyo State with a population of 174,152. It is located at an elevation of 188 meters above sea level (Oke-Ogun, Map).

In-Situ Measurement of Dose Rate in underground mines

Radon concentration was measured in the caves and open pits in selected mining sites using Radon plus Scout. It's measurement Range: 0 -10 M Bq/m³ and sensitivity of 1.8 cpm @ 1000 Bq/m³ (independent on the humidity) (Radon plus Scout Data sheet) .The instrument was placed away from pathway of workers and not close to the walls in the caves. It has internal Sensors for Relative humidity (0 -100%), Temperature (-20 - 40°C & Barometric pressure (800-1200 mba). The time for data collection is within the range of 70mins to 210mins.This was due to limited and hence the unequal number of data collected at the different underground mines.

Figure 1 : Radon Scout Plus

Estimated Radiological Parameters for the study

Annual Effective Dose.

According to the UNSCEAR, 1993 report, annual Effective Dose (***AED)*** (*mSv* y^{-1}) to the public due to exposure from ^{222}Rn and its progeny is estimated using the following equation (3):

$$AED = C_{Rn} \times F \times H \times T \times D \text{ ………………….(3)}$$

C_{Rn} is the ^{222}Rn concentration (Bqm^{-3}), F is an equilibrium factor (0.4), H is the occupancy factor (0.8),T is hours in a year (8,760 h y^{-1}) and D is the dose conversion factor (9.0 × 10^{-6} mSvBqm^{-3} h^{-1}), which is the effective dose received by adults per unit ^{222}Rn activity per unit of air volume.

The lung cancer cases per year per million people

The lung cancer cases per year per million person (CPPP), was obtained using the risk factor lung cancer induction of 18 X 10^{-6}mSv^{-1} and is given by the relation (4), (Mansour *et al.*,(2005), Abdullah *et al.*, (2013) and Ismail *et al*,(2010)):

$$CPPP = AEDE \times (18\times10^{-6}\ mSv^{-1}.y) \text{ ……………..….. ..(5)}$$

Statistical Analysis for the study

All the measured and estimated parameters for the study (radon concentrations, cancer case per million person and meteorological parameters) were subjected Multivariate analysis. Pearson correlation coefficient was used to establish their relationship between radon concentration and cancer case per million people. Principal component, cluster and factor analysis were used on the data from the underground mine in order to ascertain the similarities in the variables. The average linkage methods along with correlation coefficient distance were applied and the derived dendrograms shown in all the cases of consideration.

Results and Discussion

The section presents the result of the radon concentration and meteorological parameter measured in the underground mines and statistical relationship that exist between the parameters. Tables 1 and 2 presents the measured radon concentrations at the four selected underground mines and the metrological parameters for the study.

Table 1: Measurements of Radon concentrations (Bq/m^3) at the four underground Caves at KO I -IV mining sites

Radon Concentrations. at (Bq/m^3) KO I	Radon Concentrations at (Bq/m^3) KO II	Radon Concentrations at (Bq/m^3) KO III	Radon Concentrations at (Bq/m^3) KO IV
23289 ±1164.45	114±80.94	1004±240.94	304±136.80
63553±1906.59	55±55.00	1749±314.82	820±213.20
90498±1809.96	125±88.75	2421±363.15	2186±349.76
112295±2245.90	165±95.70	3388±440.44	1760±316.80
130871±2617.42	57±57.00	4635±509.85	2678±374.92
153301±3066.02	226±113.0	4536±498.96	2842±397.88
158197±3163.94	61±61.00	5246±524.60	3060±397.80
169454±3389.08	167±96.86	4754±522.94	3333±433.29
189180±3783.60	222±111.0	4841±532.51	2514±377.10
194426±3888.52	176±102.08	5792±579.20	3325±432.25
199617±3992.34	114±80.94	5027±502.70	2393±382.88
207869±4157.38	164±95.12	5847±584.70	3470±451.10
207432±4148.64	219±109.5	6284±565.56	3060±397.80
216339±4326.78	222±1111.0	5902±590.20	3415±443.50
216885±4337.70	219±109.5		2862±429.30
219454±4389.08	109±77.39		3157±419.41
217956±4359.12	219±109.5		3224±419.12
221093±4421.86	164±95.12		3770±452.40
219071±4381.42	223±111.5		2505±375.75
223115±4462.30	492±162.36		2842±397.88
224645±4492.90	437±152.95		2404±360.60
224973±4499.46	383±145.54		3005±390.65
220874±4417.48	492±162.36		2459±365.85
223661±4473.22	273±122.85		2640±422.40
	383±145.54		2404±360.60
			2186±349.76
			1257±263.97
			1967±334.39
Mean:187,163±366.30	**219±119.41**	**4388±483.61**	**2566.00±373.11**

Table 2: Measured Metrological Parameter--*+s Time t(s), Temperature, (T^0C), relative humidity (%) and Pressure, P_R (mmHg)) at the Four Underground mines for the study

KOI				KOII				KO III				KO IV			
t (s)	T (^{0}c)	R_H (%)	P_R (mmHg)	t (s)	T (^{o}c)	R_H (%)	P_R (mmHg)	t (s)	T (^{0}C)	R_H (%)	P_R (mmHg)	T (s)	T (^{0}C)	R_H (%)	P_R (mmHg)
10	26.5	55	988	10	26.0	40	990	10	26.5	47	987	10	24.0	61	988
20	26.0	61	988	20	24.5	48	990	20	26.5	54	987	20	25.5	66	988
30	26.0	66	988	30	24.0	54	990	30	26.0	59	987	30	26.0	69	988
40	26.0	69	988	40	23.5	58	990	40	26.0	63	986	40	26.0	72	988
50	26.0	71	989	50	23.5	61	990	50	26.0	67	986	50	26.5	74	988
60	26.0	73	989	60	23.5	63	989	60	26.0	72	986	60	26.5	76	988
70	26.0	75	988	70	23.0	65	989	70	26.0	74	986	70	26.5	77	988
80	25.5	76	988	80	23.0	67	989	80	26.0	77	986	80	26.5	78	988
90	25.5	77	988	90	23.0	69	988	90	26.0	78	986	90	27.0	79	988
100	25.5	78	988	100	23.0	70	989	100	26.0	80	986	100	27.0	80	988
110	25.5	79	988	110	22.5	71	988	110	26.0	80	985	110	27.0	81	988
120	25.5	80	988	120	22.5	73	988	120	26.0	81	986	120	27.5	83	988
130	25.5	80	988	130	22.5	73	988	130	26.0	82	986	130	27.5	83	988
140	25.5	81	987	140	22.5	76	988	140	26.0	83	985	140	27.5	84	988
150	25.5	82	987	150	22.5	77	988					150	27.5	84	988
160	25.5	82	987	160	22.5	78	988					160	27.5	85	988
170	25.5	83	987	170	22.5	78	987					170	28.0	85	988
180	25.5	83	987	180	22.5	78	987					180	28.0	85	988
190	25.5	84	986	190	22.5	79	987					190	28.0	86	987
200	25.5	84	986	200	22.5	80	987					200	28.0	86	987
210	25.5	85	986	210	22.5	80	987					210	28.0	87	987
220	25.5	85	985	220	22.5	81	987					220	27.5	87	987
230	25.5	85	985	230	22.5	81	986					230	27.5	87	987
240	25.5	85	985	240	22.5	82	986					240	27.5	88	987
				250	22.5	82	986					250	27.5	89	987
												260	27.5	89	987
												270	27.5	90	986
												280	27.5	90	986

Results of the statistical analysis of meteorological parameters measured for KO I- IV underground mines

The result of the correlation that exists between radon concentrations measured in the underground mines and measured meteorological parameters. As shown in the Table 3 below, there are weak, negative and strong positive correlation between radon concentration and meteorological parameters measured at the site. There is a weak correlation with a value of 0.23 at 0.05 level of significance between radon concentration and relative humidity. This may be explained by the fact that the underlying rocks from where radon gas is released is water logged and radon being soluble in water is released in the mine with water vapor thereby contributing to the level of humidity in the mine. As the radon concentration increases under the mine, the relative humidity also increases. In the atmosphere, radon and its daughters can exist in two states, either as attached or unattached to particulate matter.

Table 3: Pearson Correlation Coefficient Values of Radon Concentration and Meteorological Parameters Measured For KO I - IV Underground Mine

Variables	Radon Conc. (Bq/kg)	Time (mins)	Temperature (^{0}C)	Relative Humidity (%)	Pressure (mBar)
Radon (Bq/kg)	1				
Time (mins)	0.17	1			
Temperature (^{0}C)	0.55	0.88	1		
Relative Humidity (%)	0.23	0.83	-0.15	1	
Pressure (mBar)	-0.18	-0.54	0.15	-0.54	1

Radon daughters through their ionized state and chemical reactivity are usually found in attached state in the atmosphere and combine with suspended water vapor in the pit. Hence, the higher the relative humidity, the higher the radon concentration level in the pit. Time which is also a function of temperature has a weak correlation between radon concentrations. The rate at which the gas is being released from the pockets of trapped radon gas in the underlying rocks in the underground mine is not affected by temperature. Similarly, there is a negative weak correlation with the value -.178 between radon concentration and pressure. The pressure build-up in the mine as a result of multi-factorial factors like the breathing rate of workers digging under the mine, the difference in environmental pressure under the mine, the number of artisan miners at a time under the underground mine and the atmospheric pressure and the high relative humidity in the mine does not affect the release of trapped radon gas from the rocks. As the temperature inside the underground mine increases as a result of the work activities and the temperature difference between inside the pit and the immediate environmental atmospheric air temperature increases, the relative humidity drops, hence there exists a negative correlation with a value of - 0.152.

The high humid environment under the mine correlates negatively with the pressure inside the pit also explains the fact that the source of the high humidity is not the pressure in the environment which by ventilation no matter how small is related to the atmospheric pressure outside the underground mine. There is a positive correlation between time and relative humidity but weak positive correlation between time and temperature. Nature explains that.

The work by Fernandez *et al.* (2013), reported an anomalous record for Radon indoor air of the Galdar cave to be mainly caused by the seasonal increase in vapor condensation within the porous system of the rock surfaces inside the cave. This leads to water adsorption of the porous rock surfaces and the isolation of the cave's atmosphere due to a reduction of air-filled porosity of the surface layers of host-rock on the walls and ceiling. The highest radon concentration coincides with the period of high relative humidity (summer), and consequently with the highest rate of effective condensation of water on the inner rock surfaces (mainly the cave's ceiling).The properties of the host rock's pore structure, and particularly water condensation behavior, reveal a relative humidity threshold for the cave air is about 70% -75%, from which the amount of water adsorbed by the porous surface system significantly increases.

Table4: Pearson Correlation values for Radon concentration and Lung cancer case per million persons (CPPP) for the mining sites

Parameters	Radon Concentration (Bq/m^3)	Cancer Case per million Person
Radon Con. Pearson Correlation	1	0.988**
Cancer case per million person	0.988**	1

** **Correlation Significant at 0.01 levels (2-tail)**

A strong positive correlation (0.998 at 0.01 level of significance) exists between radon concentration and lung cancer per million people. The health implication of this is that as the radon concentration increases, the probability of lung cancer per million persons is also significance

Table 5 : Variables and Components Matrix for parameters for Underground Mines

Variables	Factor 1	Factor 2	Factor 3
Relative Humidity (%)	0.898	0.992	0.025
Temperature (^0C)	0.090	0.992	0.025
Time (mins)	0.932	-0.097	0.024
Pressure (mbarr)	-0.756	-0.106	-0.107
Radon Con. (Bq/m^3)	0.118	0.025	0.99
Eigen Value	0.403	0.993	0.926
% of variance explained	45.386	20.882	20.204
Cumulative %	45.386	20.882	86.473

The result of factor loading and three components were extracted with Eigen value > 0.9. The first component was loaded heavenly on relative humidity (0.898) and time (0.932). This indicates the source of these parameters as meteorological. There is a positive correlation between relative humidity and temperature which is a function of time. For the first component, the principal component increase with time, relative humidity and pressure. The second component is strongly loaded on temperature (0.992). For the second, the principal component seems to be balance with relative humidity and temperature. This indicates a strong correlation between the two parameters. The third component is strongly loaded on radon concentration (0.99) which indicates a different source of the radon gas in the underground mine which was from the radionuclide in the rocks in the mine. The variables that make up each component fall close to each other in the 3-dimensional sample space.

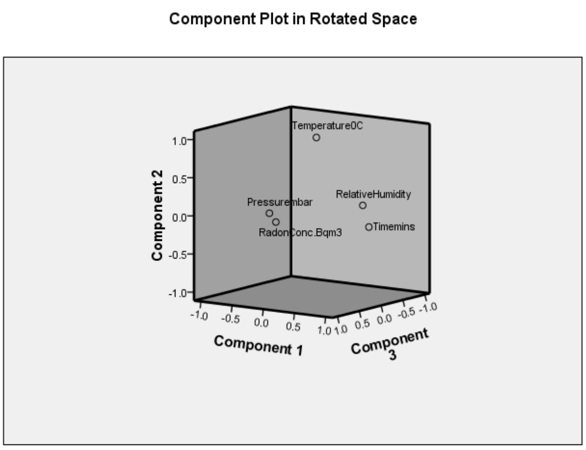

Figure 3: Graphical representation of factors 1 (45.386%), factor 2 (20.882%) and factor 3 (20.204 %)

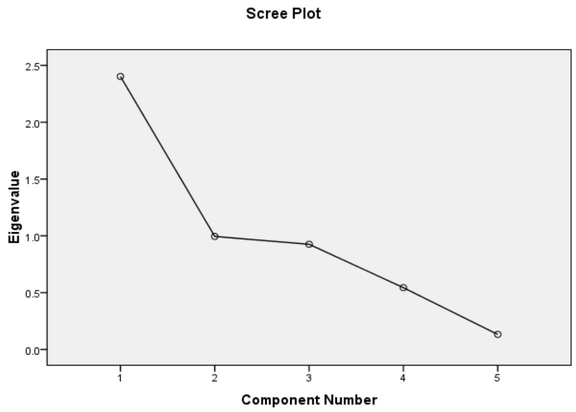

Figure 4: Eigen value against component number for Underground mines

HIERARCHICAL CLUSTER ANALYSIS

Dendrogram using Single Linkage Rescaled Distance Cluster Combine

Label Numb +---------+---------+---------+---------+---------+

Temperature 3 -+ ……………………………….Cluster 1
Relative 4 -+
Time (mins) 2 -+---+
Pressure 5 -+ Cluster 2
Radon (Con) 1 --+

Figure 4: Dendrogram showing cluster formation between radon concentrations and meteorological parameters for Underground Mines

There are two clusters. Cluster 1 comprises of Temperature, relative humidity and pressure and all metrological parameters. Varying or change in one of the parameters can result to change in the other. Cluster 2 comprises of radon Concentration and time both at same distance .Radon concentration is known to vary with temperature which is a function of time.

Conclusion

Measurement of radon concentration and meteorological parameters in selected underground mines in Komu, Oke-Ogun has been carried out. The radon concentration measured in the underground mines ranged between (49 -225,000) Bq/m^3 with the upper limit value beyond the safe limit. The relative humidity, temperature and pressure measured ranged between (40-91) %, (22-29) ^{0}C and (975-991) mmHg respectively. There is a weak and negatively weak correlation between radon concentration, relative humidity and pressure with values of 0.23 and -0.18 at 0.05 level of significance respectively. The second and third components are strongly loaded on temperature (0.992) and radon concentration (0.99) which indicates a different source of the radon gas in the underground mine which was from the radionuclide in the rocks in the mine. For the cluster analysis, cluster 1 comprises of Temperature, relative humidity and pressure and all metrological parameters. Varying or change in one of the parameters can result to change in the other. Cluster 2 comprises of radon Concentration and time both at same distance. The result of the study reveals that meteorological parameters measured in the underground mines affects radon concentration

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