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Soil-Gas Radon Monitoring In Ibadan: Innovative Approach To Estimating Geological Fault Zones

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Abstract: *Radon gas, a leading cause of lung cancer, second only to cigarette smoking was investigated in Odo Ona, Ibadan, (which lies within Latitude 3˚50' 0' to Latitude 3˚55'0', and Longitude 7˚15'0' to Longitude 7˚25'0') a population of about 741 405 people. Four monitoring stations were randomly selected where soil gas radon were monitored using CR-39 solid state nuclear track detectors for about four months. Average soil-gas radon concentration from these sites which ranged from 531.9 Bq/m^3 to 9704.4 Bq/m^3 was significantly higher than the USEPA recommended action level. The monitoring stations were superimposed on the geological map of the area. The linear distances of the monitoring stations to the fault lines-major and minor were determined using ArcView GIS. Statistical correlation of the data using the SPSS revealed a direct relationship between Radon Concentration and the distances to the fault lines. This research reveals that the total radon concentration recorded at a particular monitoring station is not only a function of the distance or the number but a combination of the nature of the fault (whether major or minor), the number of faults close to the monitoring station and the distance of each fault to the measuring station. The results therefore, showed that average radon concentration for each station was directly proportional to proximity of, and size of fault lines. Hence, it can be concluded that radon concentration can serve an indirect probe for geological fault zones.*

Key Words: *Radon, Geological Faults, CR-39 Detectors, Etching.*

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I. Introduction

The subject of earthquakes which simply means a release of seismic waves from a particular region of the earth (called hypocenter) to certain kilometers and miles from the sources depending on the intensity thereby causing ground vibrations/roll have puzzled scientists until recently. In fact, it is not overstatement to declare that it is among the least understood concept of all natural disasters. The concept of plate tectonics, however, provides a coherent explanation for the existence of the major seismically active belts on earth. These are the boundary areas of relatively rigid crustal plates that move with respect to each other across the face of the globe. Although, plate tectonics and seismic history of a region tell us, in general, where to expect large earthquakes, they do not at present give specific information on time, exact location, or magnitude of any future earthquake. Such exact knowledge is, of course, required if effective warning systems, such as those for tornadoes, hurricanes and tidal waves are to be developed for earthquakes. The broad-scale success of the plate-tectonics concept has, in part, encouraged earth scientists in several nations to embark on serious efforts earthquake-prediction capability to a level that could provide a basis for public action. This is referred to as observation of precursory phenomena. Over the past two decades, a number of precursors have been identified. The precursors are of various kinds, such as ground deformation; changes in sea-level, tilt and strain, and changes in earth tidal strain, foreshocks, anomalous seismicity; changes in b-value, microseismicity, earthquake source mechanisms; hypocentral migration; changes in seismic wave velocities, geomagnetic field, telluric currents, resistivity, radon content, changes in ground level and so on. This research work however, focuses on radon content because it has been shown that among the terrestrial gases, radon has been the most favourite of earthquake predictors. Geochemical anomalies can provide life-saving, short-term earthquake predictions.

Segovia *et al*., in 1999, after some measurements carried out on hot springs, suggested there may be a correlation between Radon concentration and seismic activity. Radon measurements are performed for different applications. These range from exploration for resources such as uranium and hydrocarbon deposits to geothermal studies; earthquake prediction, including in between, tectonics and hydrogeology studies. Passive method has been used to measure the radon concentration in situ under natural conditions.

In Nigeria, the culture of building earthquake resistant structures is not given much attention. The advent of quarry sites without any consideration for the environmental impact worsens the situation. This calls for a veritable index for measuring ground vibrations and predicting earthquake through radon measurements since radon is the only ubiquitous radioactive noble gas that does not chemically react with its environment, be it rock or water. Its half life (3.83 days) is long enough that it can carry useful information on dynamic events. Several million earthquakes occur annually; thereby, thousands occur each day, although most are too small to be located. The problem, however, is in pinpointing the area where a strong shock will center and when it will occur. These justify the need for this research.

One of the techniques which bear considerable promise to predict an approaching earthquake is the measurement of excessive radon exhalation from the interior of the earth. This research work is, therefore, aimed at investigating radon anomaly for use in earthquake prediction and location of geological faults in Odo-ona Elewe, Ibadan, Nigeria where frequent earth tremors have been reported in the past few years.

II. Materials And Methods

Study area

The study area (Odo Ona area of Ibadan) lies within Latitude $3^{0}50^{'}0^{'}$ to Latitude $3^{0}55'0^{'}$, and Longitude $7^{0}15^{'}0^{'}$ to Longitude $7^{0}25'0'$ and spans four Local Governments regions namely- Ibadan North West, Ibadan South West, Ido and Oluyole Local Government Areas of Oyo State. The population distribution of the area of research is presented in table 1. The area account for about 13.259% (741405 inhabitants) of the total population.

Table 1: Population distribution at study area

Local Govt Area	Population	Male	Female
Ibadan North West	152834	75311	77523
Ibadan South West	282585	139515	143070
Ido	103261	51750	51511
Oluyole	202725	102220	100505

Location of Monitoring Stations:

Based on consultation with the dwellers in the region, four monitoring stations were randomly selected and their location noted using the GPS device. The geographical map of the study area showing measuring stations is shown in Figure 1.

a. Station 1- Odo Ona Elewe river with
   GPS Location. N 7.33837, E 3.85862
b. Station 2- with
   GPS Location N 7.39930, E3.87086.
c. Station 3- with
   GPS Location N 7.33160, E 3.84679.
d. Station 4- with
   GPS Location N 7.28410, E 3.85009.

Regional Geology of Ibadan

The study area (Ibadan) lies within the Precambrian basement complex of Nigeria. Several workers have described the general geology of the Nigerian basement complex while a number of unpublished reports on the geology of the basement complex is credited to the Geological Survey of Nigeria. However, Oyawoye (1972) classified rocks of the basement complex into four principal groups- older granites, migmatitic complex, metasedimentary series and miscellaneous rock type. However, the most acceptable and widely used description of the Nigerian Precambrian basement complex was developed by Ferre et al (1997). He divided the basement complex rocks into six groups, viz.

(1) Migmatite-Gneiss-Quartzite Complex
(2) Slightly Migmatized to Non-Migmatized Metasedimentary and Metaigneous rocks (Schist Belts).
(3) Charnokitic, Gabbroic and Dioritic Rocks
(4) Older Granite Suite
(5) Metamorphosed to unmetamorphosed calc-alkaline volcanics and hypabyssal rocks.
(6) Unmetamorphosed Dolerite Dykes, Basic Dykes and Syenite Dykes etc.

The migmatite-gneiss-quartzite complex is dominated by quartzo-feldspathic, biotite-hornblende bearing gneisses, schist and migmatites in which minerals such as garnet, silimanite, kyanite and staurolite suggest that they were metamorphosed under high grade amphibolite facies. These granitoids include charnockites, gabbros, dolerites and the older granites, which are Pan-African in age (750-500Ma). The diorites within the older granite suite and believed to have been formed as a result of subduction processes (Ferre et al., 1997).

The schist belts mostly consist of low to medium grade metasediments, and mafic-ultramafic bodies. Au, Fe, Ni, Cr ores are notably linked with these assemblage, and the belts are considered to be Proterozoic in age. Lithological, geochronological and multi-deformational attributes suggest that the Nigerian domain may have been part of an Archean continental proto-shield ranging from green-schist to low amphibolite metamorphic facies (Ferre et al., 1997).

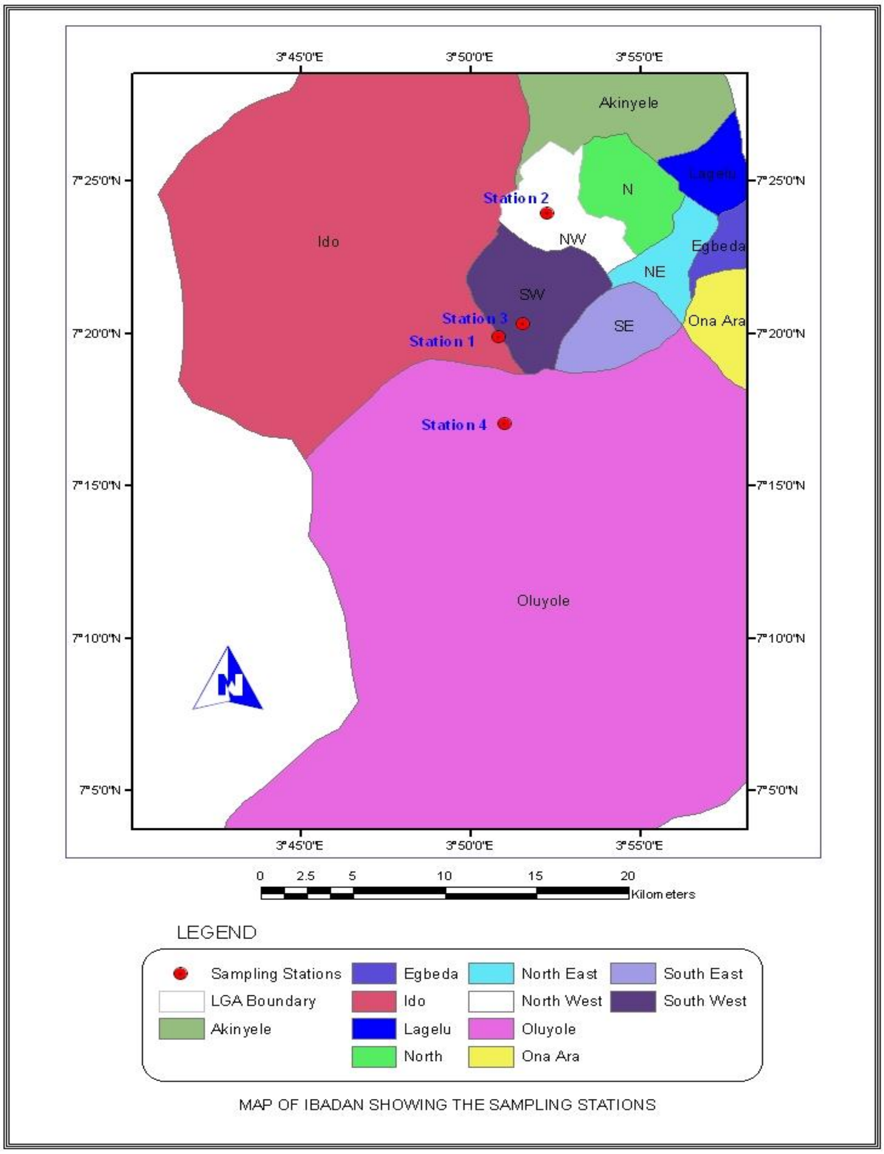

Fig. 1: The Geographical Map of the Study Area Showing Measured Stations.

Local Geology of the Study Area

The major rock types in Ibadan include; quartzite/quartz schist pegmatite banded gnesis, granite gneiss, migrated gneiss and augends with minor intrusions of dolerite, aplite, quartz veins and pegmatite. Particularly in odo-ona elewe/kekere region, of Oluyole local government, grant guises, pegmatite and quartile are predominant. The sampling stations are shown on the geological map in Fig. 2.

Quartzite

Quartzite form prominent topographic features around Asipa, Oke-Aremo, premirre hill, Mokola-Oremeji ridge, the ridge between the Polytechnic and University of Ibadan Campuses, and likewise the area of investigation, Odo-Ona. They generally lack schistocity except in Mokola area where they are schistose. Most of the exposed quartzite are highly weathered with dull luster while the fresh samples are shining with vitreous luster. Darkening of the quartzite was due to precipitation of ferric oxide (Fe_20_3) from the unstable hydroxide.

The major observed structures are faults and joints. Quartzite ridges in Ibadan are trend in NNW-SSE direction and they are essentially composed of tightly interlocking medium grains of quartz. The grains exhibit granoblastic texture, often whitish of grayish in colour. This is shown in Fig. 2. This rock represents a quartz-rich zone within a mass gneissose rock. It consists essentially of interlocking of medium to coarse grained anhedral quartz grains which show some tendency parallel elongation. Scattered within the mass of quartz are occasional subhedral laths of colourless muscovite which exhibit strong birefringence. Also present are rare, very find zircon grains.

Migmatite Gneiss

Migmatites are the most widespread group of rocks in the Basement Complex. They form the ground mass in which all other rocks seem to occur. The gneisses are strongly foliated with a general strike of NNW-SSE direction. They exhibit alternating leucocratic and melanocratic bands, of equal dimensions, angular to sub angular in shape. The bands vary in width from fraction of an inch to about two inches and commonly have thick dark band. Observed minor structures on the banded gneiss included folds, pinch and swell structure, concordant and discordant quartz veins. This is a gneissose rock made up mainly of irregular bands and aggregations of coarse grained, quartz and zones composed of interlocking, fine grained, subhedral feldspar grains. Plagioclase is present in minor amounts but most of the feldspar present is alkaline in character and displays prominent cross-hat hatched twining. Irregular, discontinuous stringers of fine grained ferromagnesian minerals present traverse the rock. Strongly pleochroic brown biotite and green hornblende are the predominant types present; they are accompanied by occasional fine subhedral grains of pink garnet. There are occasional highly altered laths of a highly altered clinopyroxene-possibly hedenbergite. Very fine, subhedral zircon and sphene grains are present in accessory amount.

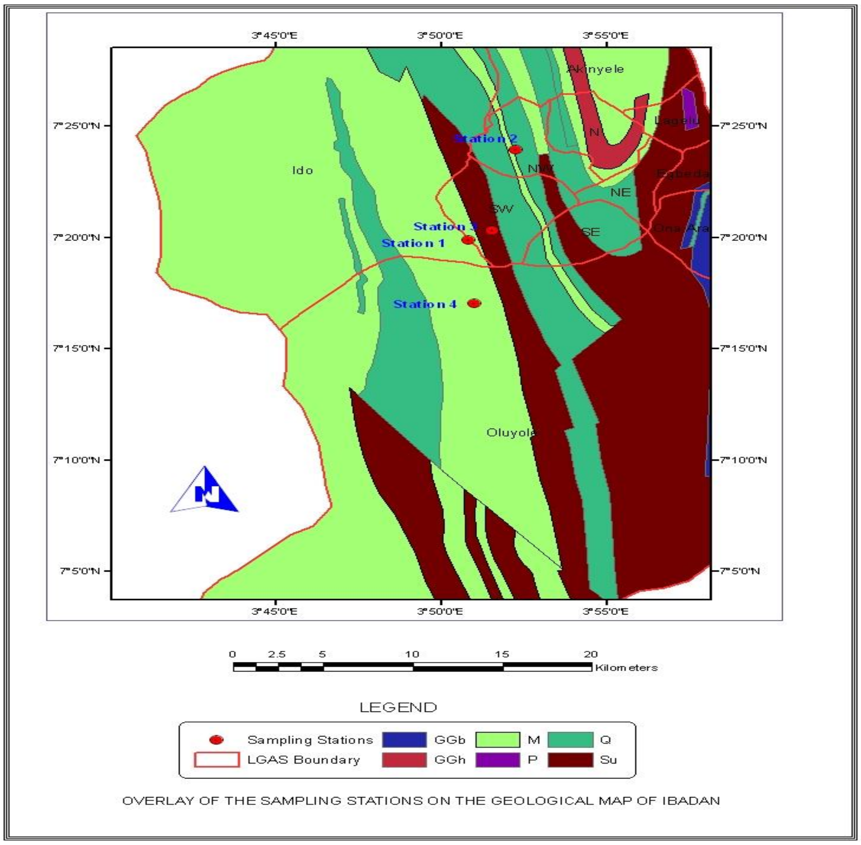

Fig. 2: Overlay of the Sampling Stations on the Geological Map of the Study Area.

Granite Gneiss

A distinctive characteristic of this rock type of the (eye-like) clothe structure resulting from flowage of micaceous Mineral around less developed crystals of quartz and feldspar. They are coarse grained, angular to sub angular in shape and brownish in colour due to its high feldspar content. The rock is segmented into large boulders by a well-developed joint system. The general strike is NNW-SSE direction. This is a fine to medium grained granitic rock made up of varying amounts of quartz, and alkaline feldspar together with subordinate amount of plagioclase and biotic. The quartz and feldspar form an interlocking mosaic of interlocking fine to occasionally medium anhedral of subhedral grains. Irregular stringers of very finely granular quartz and feldspare traverse the rock, suggesting that it has been subjected to a minor post-crystallization cataclastic event. Biotite is scattered throughout in subordinate amounts; it is a variety strongly pleochroic in shades of pale to dark brown which occurs in irregular clusters of the laths. Opaque grains probably composed of iron oxides, are present in accessory amounts. Also present are occasional anhedral carbonate grains.

Pegmatites

They are coarse grained and mostly occur as intrusions (veins) in the major rock types in Ibadan. Their contacts with the host rock are sharp or gradational and intrude concordantly and discordantly to the host rock. They appear pinkish in colour due to the presence of alkali feldspars and quartz. In certain part of the study area, they are massive in extent and appear to be the major rock type.

Results of the identification of rocks and petrography descriptions of rocks in Odo-Ona Area of Ibadan reveal that they are from a zone of Alkali Granites or Granitic Gneisses.

Experimental method

The method that has been applied here is track etch technique using CR-39 detectors. The choice of CR-39 as the Solid State Nuclear Tract Detectors (SSNTD) used for this research is its excellent sensitivity over a wide range of particle energies, and its good chemical and electrochemical properties. For α-particle measurement, CR-39 detectors are sensitive over the range 0.1-40 MeV which makes them an excellent choice for these types of measurements. The CR-39 detectors and cups used for this research work were kindly donated. The detectors of 1 cm^2 area were already fixed in the cups and the cups were sealed in a radon tight foil. The foils were only removed at the sites and consequently, for the CR-39 detectors to be exposed to radon. The cups were 4.7 cm in height and 6.3 cm in diameter.

A P.V.C. pipe with upper and lower sides open was placed inside the hole of 70 cm deep below the earth surface. The cup was placed within the P.V.C. pipe in the hole. Silica gel was placed in the hole surrounding the cup to absorb moisture there. This is showed in Fig. 3. The upper end of the P.V.C. pipe that was almost in the level of the upper ground surface was covered with a lid. The arrangement reduced the effect of external meteorological effect on radon flow.

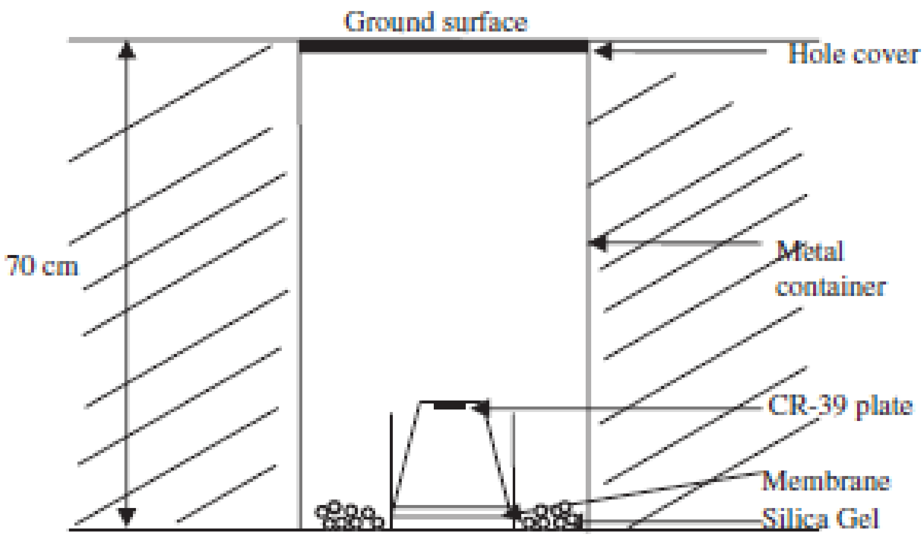

Fig. 3: The experimental set-up during the measurement of radon concentration.

Each CR-39 alpha-track detector was exposed for 4 days (96 h) in such an undisturbed condition. On completion of the exposure time, the detector was removed and another detector was placed in the same manner. After exposure, 38 CR-39 detectors that were deployed to the four Monitoring stations were taken to the Radiation and Health Physics laboratory at the Department of Physics, University of Ibadan for chemical etching and analysis.

Method of Analysis

The solid state nuclear track detectors were etched in 6.25M NaOH solution for 2 hrs at 90°C. The temperature was carefully maintained at constant value. The detectors were first washed under running water and then in distilled water. This was done to stop the activity of the etchant. The tracks in the plates formed due to alpha particles were counted by a semi-automatic inage analysis system consisting of a CCD camera, a personal computer and an optical microscope. The alpha tracks were analysed using the Image J software from which their respective radon concentrations were determined.

III. Results

At the commencement of the experiment there was a problem of moisture accumulation over the membrane. This was overcome by placing silica gel in the shallow borehole and the problem was greatly reduced. There was no significant change in the atmospheric pressure (753 ± 1 mm of Hg) during the period of investigation. The radon concentrations determined in Bq/m^3.

IV. Discussions

Odo Ona Monitoring Station

The deduced Radon concentration ranges from BDL to 848 Bq/m^3. The average Radon concentration for the monitoring Station within the period of investigation is 531.9 Bq/m^3. The standard deviation is 278.9 Bq/m^3. Peak radon anomaly 848 Bq/m^3 was recorded on 21st day of investigation.

Orita Challenge Monitoring Station

The deduced Radon concentration ranges from 424 to 2120 Bq/m^3. The average Radon concentration for the monitoring Station within the period of investigation is 970.4 Bq/m^3. The standard deviation is 677.1 Bq/m^3. Peak radon anomaly 2120 Bq/m^3 was recorded on the 9th day of investigation

Asipa Monitoring Station

The deduced Radon concentration ranges from 424 to 2120 Bq/m^3. The average Radon concentration for the monitoring Station within the period of investigation is 904.4 Bq/m^3. The standard deviation is 522.7 Bq/m^3. Peak radon anomaly 2120 Bq/m^3 was recorded on 29th day of investigation.

Ratcon Quarry Monitoring Station

The deduced Radon concentration ranges from 424 to 1696 Bq/m^3. The average Radon concentration for the monitoring Station within the period of investigation is 781.9 Bq/m^3. The standard deviation is 448.2 Bq/m^3. Peak radon anomaly 1696 Bq/m^3 was recorded on 13th day of Investigation.

From the rmean radon concentration in each of the regions under investigation had the following ranking:

Orita Monitoring station	Highest (970.4 Bq/m^3)
Asipa Monitoring station	Very High (904.4 Bq/m^3)
Ratcon Quarry Monitoring station	High (781.9 Bq/m^3)
Odo Ona Monitoring station	Fairly High (531.9 Bq/m^3)

The discovery confirms that Radon concentration levels are based not on artificial activities of quarries that periodically but regularly blasts causing ground vibrations but are rather caused by the tectonic nature of the lithosphere regions under investigation. It therefore, shows a correlation between the seismicity which is a product of earthquakes and radon concentration.

A Juxtapose of the linear distances of the fault line(s) to each measuring station with respective radon concentration from the latter is presented in Table 2.

Table 2: Linear distances of the fault line(s) to each measuring station

	Radon Conc. (Bq/m^3)	Distance from Major Fault line (m)	Distance from Minor Fault line (m)
Orita Monitoring station (S2)	970.4	1142.6, 1744.0	234.4
Asipa Monitoring station (S3)	904.4	-	432.1, 601.3, 642.0
Ratcon Quarry Monitoring Station (S4)	781.9	-	808.2, 887.7, 1530.9
Odo Ona Monitoring station (S1)	531.9	982.4	-

Major fault lines are deeper and cover a very wide area while minor fault cover a very small area. For Orita Monitoring station (S2), there are two major fault lines at distances 1142.6 m and 1744.0 m and one minor fault line at linear distance 234.4 m respectively as indicated in Table 2 with an average radon concentration of 970.4 Bq/m^3. There are three minor fault lines close to Asipa monitoring station (S3) at distances 432.1 m, 601.3 m, and 642.0 m, respectively. The average radon concentration for this station is 904.4 Bq/m^3. Three minor faults at 808.2 m, 887.6 m and 1530 m respectively are measured on the map (Fig. 4) from the Ratcon Quarry monitoring station (S2) with an average radon concentration of 781.9 Bq/m^3. Only one major fault line was observed at 982.4 m from Odo Ona monitoring station (S1) whose average radon concentration is 970.4 Bq/m^3.

An instructive pattern could be deduced from the result tabulated in the table 2. As the mean radon concentration increases with respect to the monitoring stations, average distance of each station to a fault line increases. That is, the closer the distance from a fault line to a measuring station, the higher the radon concentration there.

Each fault line accumulates radon gas. S2 (Orita) has the highest value of radon concentration because it is situated close to two major faults and a minor fault. Although, radon concentration measured at a monitoring station should be relative to the distances from the station, major fault lines will accumulate more radon gas and the net count will be higher though farther than minor faults. S1(Odo Ona) should literally have the highest radon concentration following this line of thought but the number of fault lines close to other monitoring stations makes the total radon concentration measured at other monitoring stations exceed that of S1. This implies that the number of fault lines close to the monitoring station is also a vital parameter which influences radon concentration in an area of investigation.

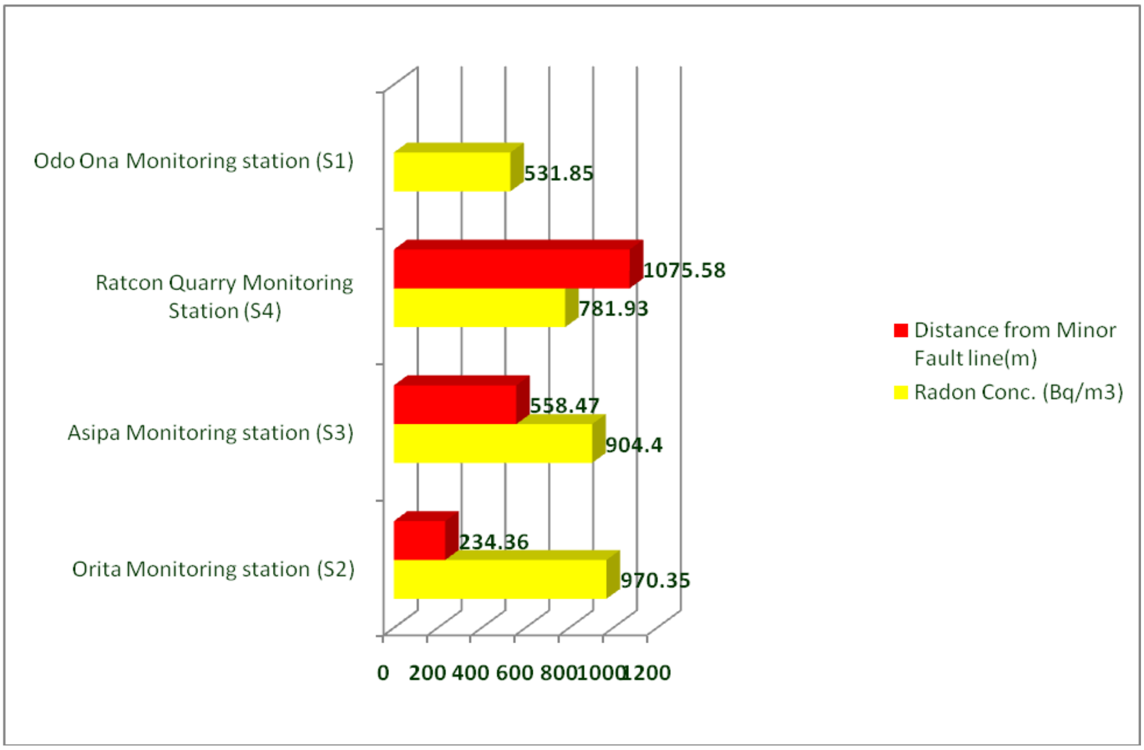

Fig.4: Variation in distances from minor fault lines with radon concentrations at the stations**.**

V. Conclusion

Radon concentration levels in Odo-ona area indicates occurrence of small foreshocks along this region. Radon concentration is higher in Odo-ona Elewe area of Ibadan than other areas of study (Asipa, Orita, Ratcon) which shows that Odo-ona area is close to a fault zone. Increase in radon concentration is influenced by the quarry activities in the extreme region of Odo-ona (Ratcon).

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