ASSESSMENTS OF RADIOLOGICAL LEVELS AND ELEMENTAL CONCENTRATIONS IN SOILS FROM AWWAL AND BAGEGA GOLD MINING SITES IN KEBBI AND ZAMFARA STATES, NIGERIA

BY

GIRIGISU SHEHU

DEPARTMENT OF PHYSICS FACULTY OF SCIENCE
AHMADU BELLO UNIVERSITY, ZARIA

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GIRIGISU SHEHU

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DEPARTMENT OF PHYSICS
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NIGERIA

DECEMBER, 2012

DECLARATION

I declare that this work in the thesis titled 'Assessments of Radiological and Elemental Concentration in Soils from Awwal and Bagega Gold Mining Sites in Kebbi and Zamfara States, Nigeria' has been performed by me in the Department of Physics under the supervision of Professor I.G.E. Ibeanu and Dr. D.J. Adeyemo.

The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously printed for another degree or diploma at any university.

Girigisu Shehu

_____	_____	_____
Name of student	Signature	Date

CERTIFICATION

This thesis titled 'ASSESSMENTS OF RADIOLOGICAL AND ELEMENTAL CONCENTRATION IN SOILS FROM AWWAL AND BAGEGA GOLD MINING SITES IN KEBBI AND ZAMFARA STATES, NIGERIA' by Girigisu Shehu meets the regulations governing the award of the degree of Masters of Science of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and library presentation.

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Dr. D.J. Adeyemo	_____	_____
Member, Supervisory Committee	Signature	Date
Dr. Sadiq Umar	_____	_____
Head of Department	Signature	Date
Proffessor A.A. Joshua	_____	_____
Dean, Postgraduate school	Signature	Date

DEDICATION

This research work is dedicated to my late father, Alh. Saliu Girigisu, late mother Hajiya Zeenat, my wife, Medinat, and my children; Mahmud, Memunat, Suleiman, Zeenat and Alhassan.

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ABSTRACT

The research work was prompted by increase in artisanal gold mining activities in the zone; processes being carried out without protection against possible radiation and contamination hazards. Radiological Indices and Toxicological levels were assessed and compared. Three sets of detecting systems were deplored to execute the research work. Awwal results shows that ^{40}K activity is distinctly higher than ^{232} Th and it ranges between 2.89 and 1176.96 Bq kg $^{-1}$ with a mean activity of 425.96 ± 5.56 Bq kg $^{-1}$. ^{232} Th concentration ranges from 3.47 to 74.52 Bq Kg $^{-1}$ with a mean activity of 18.80 ± 1.21 Bq kg $^{-1}$. ^{226}Ra concentration ranges from 3.79 to 44.15 Bq kg $^{-1}$ with a mean activity of 23.85 ± 2.01 Bq kg $^{-1}$. The average outdoor gamma dose rates ranged from 8.89 to107.81 nGy h $^{-1}$ with a mean value of 34.26 nGy h $^{-1}$ which agrees well with the global average values. The effective dose rate ranged between 10.93 and 132.61μSv y $^{-1}$ with a mean value of 42.15 μSv y $^{-1}$ (= 0.042 mSvy^{-1}), which is just less than 0.07 mSv y $^{-1}$ given in UNSCEAR 1993 as the worldwide representative value. The result of the radium equivalent is found to be well below 250Bq/Kg; far below the maximum limit of 370Bq/kg set for radiation hazard. Bagega results revealed the ^{40}K activity ranges from 94.17 to 775.56 Bq kg $^{-1}$ with a mean activity of 370.79±7.98 Bq kg $^{-1}$. The ^{232} Th concentration ranges from 10.01 to 18.99 Bq Kg $^{-1}$ with a mean activity of 16.86 ± 0.94 Bq kg $^{-1}$. The ^{226}Ra concentration ranges from 0.76 to 47.06Bq kg $^{-1}$ with a mean activity of 18.3 ± 1.77 Bq kg $^{-1}$. The average outdoor gamma dose for soil ranged from 3.93 to 119.75 nGy h $^{-1}$ with a mean value of 27.25 nGy h $^{-1}$ which agrees well with the global average values. The effective dose rate ranged between 4.82 and 146.97μSv y $^{-1}$ with a mean value of 33.44 μSv y $^{-1}$, which is much less compare to 0.07 mSv y $^{-1}$ given in UNSCEAR as the worldwide representative value. From a radiological point of view, these values are low and do not imply any significant concerns on the health effects on the local population

outdoors, as the values are generally not significantly higher than the world average dose equivalents to individuals from soil. The elemental analysis revealed Lead(Pb) and silicon exists at very high concentrations. Both of them possess immediate and latent Hazards to health. Hence in view of the unprofessional practices of the miners, the miners, the villagers and its visitors are at risk if the trend is left unchecked.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 *Background to Research*

The development of natural resources worldwide involves the manipulation of the environment to arrive at specific objectives. Mineral resource is the most exploited natural resource and it involves extraction, grinding, ore concentration and dispersal of tailings (Ferreira da Silva *et al.*, 2004).These activities, which are carried out through mining processes, most often generate a lot of radiological hazards, chemical wastes and cause various degrees of damages and threats to plants, animals as well as human life. Mining can generate large concentrations of highly soluble inorganic matter, some of which are considered toxic (Mousa,1997).Generation of chemical waste as a result of mining activity occurs world-wide and may severely affect natural resources such as vegetation, streams and the ecosystem in general (Ramani, 2001). Radiological hazards are one of the least known effects which can be generated by these chemical wastes through contamination processes.

The composition and processing of ores also determine the nature of pollutants (Eppinger *et.al.*, 1999). After the precious metals which are usually derived from the ore are extracted, varying concentrations of other undesirable inorganic and radioactive parameters such as arsenic, copper, lead, zinc, iron, sulphate, cyanide, nitrate, calcium, and magnesium are usually passed into tailings. The tailings together with the sulphide-bearing mine waste rock are often exposed to the

weather, thereby resulting in the mobilization of metals and other chemical compounds related to ore processing into nearby water-bodies. Elevated concentrations of these elements in the water-bodies pose serious health hazards to host communities. According to changes in their physicochemical states and the prevailing chemical conditions, these metal contaminants migrate and threaten human health by contaminating soil, streams, groundwater, and food crops.

This research focuses on possible problems related to gold mining in the hills of Awwal, a settlement in Mahuta local government area of Kebbi State and Bagega/Sunke settlements in Anka local government of Zamfara State with particular focus on the possibilities of radiological and contamination hazards.

Gold mining can have devastating effects on nearby water resources. Long term effect include acid mine drainage, which raises acid level in rivers and streams, build up of high concentration of Radon gas and its decay products as well as contamination of soil and water by heavy metals resulting from Tailings. In Awwal mining exercise, the panning/sedimentation processes were carried out right in the middle of the stream-bed, which is, as at the study period, in its seasonal water-flow breaks.Water used for panning/sedimentation in these cases were obtained either from the bore-hole project near the stream-bed or from holes dug at various locations in the bed itself. Heavy metals associated with gold mining waste can dissolve and disperse into surrounding streams due to rain water percolating through the waste (Ferreira da Silva *et al*., 2004) or dispersed as particles through erosion processes. Impacts of goldmines can be environmentally detrimental and can constitute serious radiological hazards to exposed or contaminated individuals.



Plate1.1 *Sedimentation /Panning section. Note the panning process at lower right hand corner,*

Majority of people working in mines and those associated with various activities within the vicinity of the mines as well as those at the processing zones are largely unaware of health implications they are likely to be subjected to due to radiations from exposed rock surfaces, crushed and milled rocks and, generally, from pilled-up Tailings. The degree of ignorance exhibited by workers in small scale mining to the possibilities of their exposure to ionizing radiation shows in their attitudes in and around the mines. In Gari-awwal mines, as a case for consideration, workers that have gone deep into the belly of rocks (ahead of 20m in depth) by burrowing

with the aid of crude implements do spend some of their rest periods in these rocks. With this nature of implements, these workers in the caves are by no means always in very close proximity to freshly exposed radioactive rock surfaces over the work periods. These hours of rest and work all spent inside the belly of these rocks cumulatively put them to probable radiation exposure for close to a range of 8-12 hours per day.

The pathways of radiation exposure in small scale mining operations are numerous, ranging from exposure at the mining sites, milling sites to raised indoor radon levels in the make-shift shops where trading occurs in the mining area. Based on these exposure pathways and the level of ignorance of the workers, the research work becomes a necessity to investigate possibilities of raised radiation level, if it exists, and to quantify such level as indications of degree of radiological risk these workers are likely to be subjected to. The work also extends to identification of toxicology properties of the elements in a view of determining possibilities of contamination of the masses in the workplace.

1.2 The Study area

1.2.1 Locations of the study areas and accessibilities

Awwal is located on the southern part of kebbi State between longitudes 4°.45' and 4°.50' East of the prime meridian and latitudes 11°.35' and 11°.40' North of the equator. Awwal is a small settlement that shares boundaries with Maidanga in the North, Bula Maimi Eastwards, Kantu in the southern end and Fakku westwards. The settlement is remote and accessibility is facilitated by track routes. Easy transportation system in and out of the location occurs only on market days.

Accessibility by most of the track routes can further be limited by activation of the surrounding seasonal streams during raining seasons.

Bagega is a settlement on the North-Eastern part of Awwal, though in Zamfara State. It is located on the southern part of Anka, the Headquarters of Anka local government of Zamfara state. It exists on the longitude 6°.00' east of the prime meridian and latitudes 11°43' to 11°50' North of the equator. Bagega is a relatively bigger and more economically and socially active settlement when compared to Awwal. It is bounded in the North-East by Dankuka, westwards by Dorca, South-East by Bawa. It is relatively more accessible than Awwal, though subjected to poor drainage system due to the vast portions of clay terrain that makes up its landscape.

1.2.2 Topography

Zuru Emirate which generally encloses Awwal and the remaining chiefdoms has wide areas of flood lands of the Niger-River system. A notable feature of the hill is that it is a section of a range of hills dividing the area into two, running from Rijau (Niger State) to Danko. On both sides of the range of hills are vast lands connected by the River Ka valley. The area is also characterized by other hills of different heights which spread in the vast lands.

Figure 1.1 Regional map of the study areas showing neighboring settlements

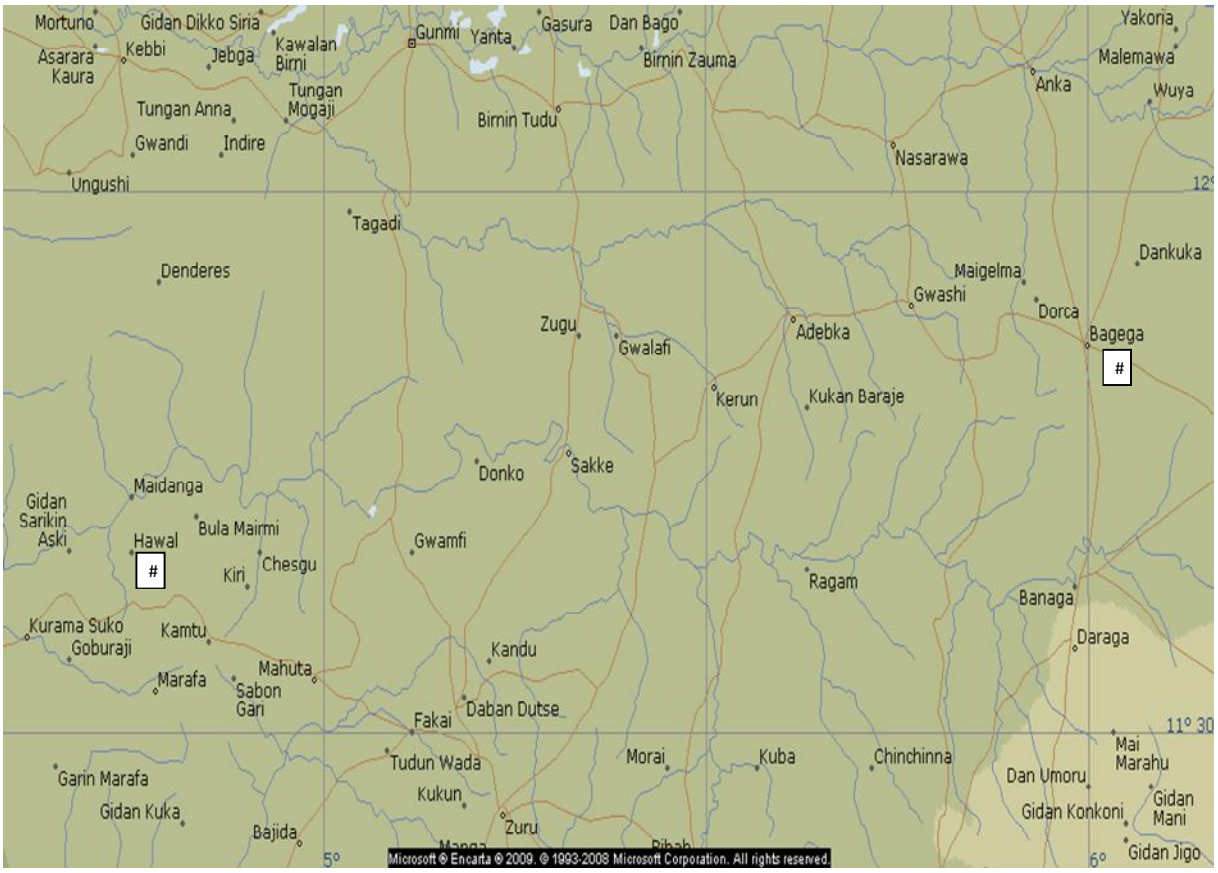


Figure 1.1 Regional map of the study areas showing neighboring settlements

The topography of Bagega is almost similar to that of Awwal except that it demonstrates more of flat terrain than Awwal; clear presence of clay landscapes that discourages easy run off of water in wet season is well noticed in this case.

1.2.3 Climate

The climate of Awwal and Bagega is characterized by two distinct seasons; rainy and dry seasons. The rainy season starts in April and end September. The peak of the rainfall is in July/August. Temperatures vary between 30°C and 35°C.The coldest temperatures are experienced during the harmattan periods when

temperatures drop as low as 18°C.During the harmattan, the winds are cold, dry, dusty and strong. The hot season starts in March and ends in May.

1.2.4 Vegetation

Awwal and its environs have typical Sudan savannah vegetation characterized by short stunted trees with communities of grasses. What remains of the natural vegetation today are mainly economic trees such as sheer butter, locust bean. Another major characteristic of the vegetation in the area is the derived vegetation as a result of re-growth on fallow farmlands.

1.3 *Statement of the problem*

Collapse of mining cave is a major mining problem known to mine workers, however the awareness of possibilities of exposure to ionizing radiation and relative degree of its absorption to human body being factor of time, distance and shielding are information that most mine workers are oblivious of.

Additional integrating problem is often generated by contamination of the mining area and its environs by tailings and acid mine drainage (AMD). There are two angles to hazards from these contaminants: radiological and toxicological. To a very great extent, local miners are ignorant of these stated sources of health problems.

Mining operation at Awwal village has generated a lot of survival related activities such as petty trading, hard and conventional drug peddling and prostitution, developments which exposes people in these groups to radiations from exposed radioactive rock surface, milling processes, mine tailings and raised indoor radon levels all of which cumulatively are of grave danger to their health.



Plate 1.2 A typical Gold-panning arrangement showing pot-holes in the bed of the stream where water is obtained for the process.

The pathway of the seasonal stream, [Plate 1.2], where panning and sedimentation takes place is a potential source of radiation hazards for all users of the stream for agricultural and domestic purposes due to possibility of exposure by contamination from radionuclides in tailings or in dissolved stream water as well as by ones taken up by plants.

The seemingly non-existence of government impact in terms of provision of social services to the area, education of communal people about risks to health of the mining operation as well as other related matters that require government participation has serious integrating effects on possibilities of radiation absorption by these communal people.

1.4 *Aims and Objectives*

The research is aimed at investigating possibilities of radiation exposure and contamination in Awwal and Bagega mining operations with the following objectives in mind.

To investigate the rate of radiation exposure of selected miners in view of their closeness to the exposed rock surfaces in the project area via the use of the under listed detectors;

(i)Rados (ii)FH40F2

To collect soil sample of the study areas and evaluate concentration level, of elements of interest contained.

To collect tailing sample and evaluate concentration level, of elements of interest, present in them.

To compare the obtainable data on radiation levels of the two study areas (Bagega and Mahuta) and relate them to their common geological setting.

To make comparison between the data obtainable of the concentration levels of the two study areas.

To estimate hazard indices associated with mining operations in the study areas.

To compare the levels of radiation exposure of workers at the two mine settings to internationally acceptable “safe” limit for occupational exposures based on obtained readings.

1.5 *Significance of the study*

The outcome of this investigation may help health workers in the geographical location in tracing history of recently prevalent health cases and consequently be in better position to respond to them appropriately,

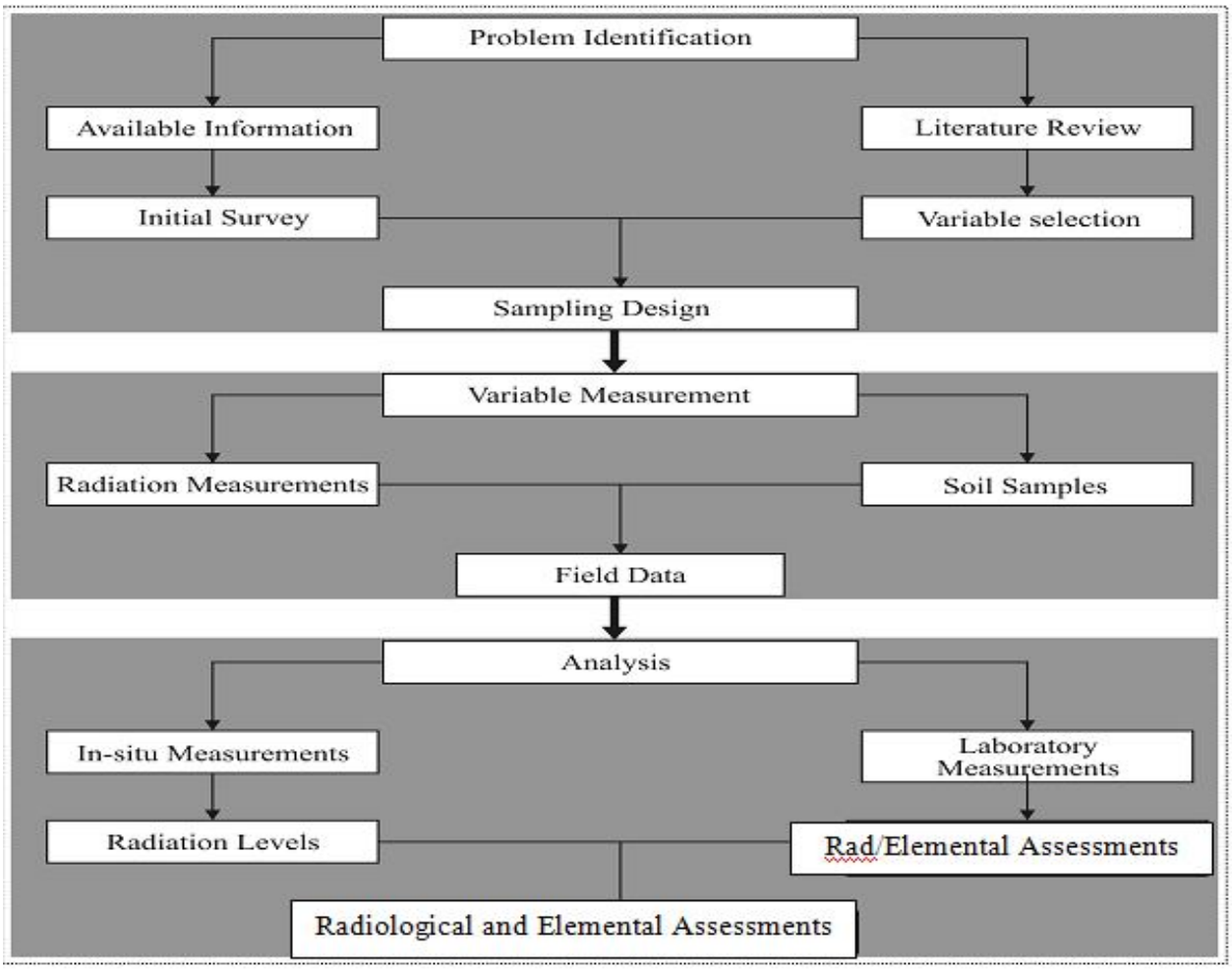
The work and its result is aimed at stimulating the state and federal government into action on educating the endangered settlers, workers and other related groups of people in the area, of environmental and most importantly radiological and toxicological risks involved by the mining exercise.

The study outcome will help workers, having been educated, to know how to combat anticipated problems as well as adopting protective measures.

1.6 *Research Approach*

The research was conducted in a three-phase approach as described below

Figure 1.2. Research approach



1.6.1 Preliminary Work

This was the first phase of the research. It spanned through literature review, conduct of initial sets of surveys of the site on which research is to be carried out. Available information was studied to identify pathways of radiation exposure and to bring to forefront a number of events/issues that surround it. Detailed review of various researches was carried out on the biological and medical implications of radiation absorption resulting from chemical reactions generated by physical processes of interaction of radiation with matter (-the biomolecules).

1.6.2 Field Work

The second phase was the measurement of environmental variables. The preliminary surveys conducted in first phase gave direction to areas at which radiation readings were taken along with which soil/rock samples were collected. Radiation readings were taken at selected relatively separated mine caves as well as taking of soil samples. Similar procedures were taken up at milling and sedimentation units.

1.6.3 Sample Size and Level of Confidence

The confidence interval provides a range that is highly likely (often 95% or 99%) to contain the true population quantity, or parameter that is being estimated. The confidence level determines the level of assurance.

The chosen size of samples for this work is based on the relation which connects the three quantities, (confidence level, confidence interval and sample size), together;

$$(1-p)^n \geq 1-c$$

Where,

P= Probability

C= Confidence Level

N= Number of samples

With a chosen probability, p= 5% (representing 0.05 value), confidence level placed at 90%(representing 0.9 value), then minimum size of samples to be collected was determined by the process below;

$(1-p)^n \geq 1-c$

$$(1 - 0.05)^n \geq 1 - 0.9$$

$$(0.95)^n \geq 0.1$$

$$log(0.95)^n \geq log(0.1)$$

$$nlog(0.95) \geq log(0.1)$$

$$n \geq \frac{\log (0.1)}{\log (0.95)}$$

$$n \geq \frac{-1}{-0.0223}$$

$$n \geq 44.8$$

This gives $n \geq 45$

Thus a minimum of 45 samples is required to be collected to meet the level of confidence chosen.

1.6.4 Analytical Methods

The final phase is to be occupied by the analysis of in-situ measurements taken in the field, two-method laboratory Analysis of samples collected for radiological and concentration levels of the elements.

The in-situ measurements are to be analyzed to determine whether the level of radiation absorption by the workers is significant or not significant in terms of possibility of development of health problems by making comparisons to internationally accepted safe level for occupational exposure.

The laboratory work is to consist of the analysis of the samples using Gamma ray and x-ray fluorescence spectrometry. The In-situ results shall be compared to the

Gamma ray radiation results to determine level of correlation between the two sets of radiological analysis.



Plate 1.3 (a) A typical trench layout mine and (b) A typical well-layout of mine setting

1.7 Gold occurrence in Nigeria

Gold occurs in primary, alluvial or eluvial forms and can be found at:

- Okolom/Kogi State, with grades from 1.0-36g/ton
- Dogondaji/Kogi State with grade values from 1.0-75g/ ton
- Waya/Kebbi State, with grade values 0.4 g/ton to 11g/ton
- Iperindo/Osun State, as primary gold
- Other major Gold occurrences in Ogun, Adamawa, Edo, Kwara, Niger, Kaduna and Zamfara states.

Gold in Nigeria is found in alluvial and eluvial placers as well as in primary veins from several parts of schist belts in the northwest and southwest of Nigeria as

enlisted above. There are also a number of smaller occurrences beyond these major areas. Below is a Nigerian map showing major groupings of gold occurrence.

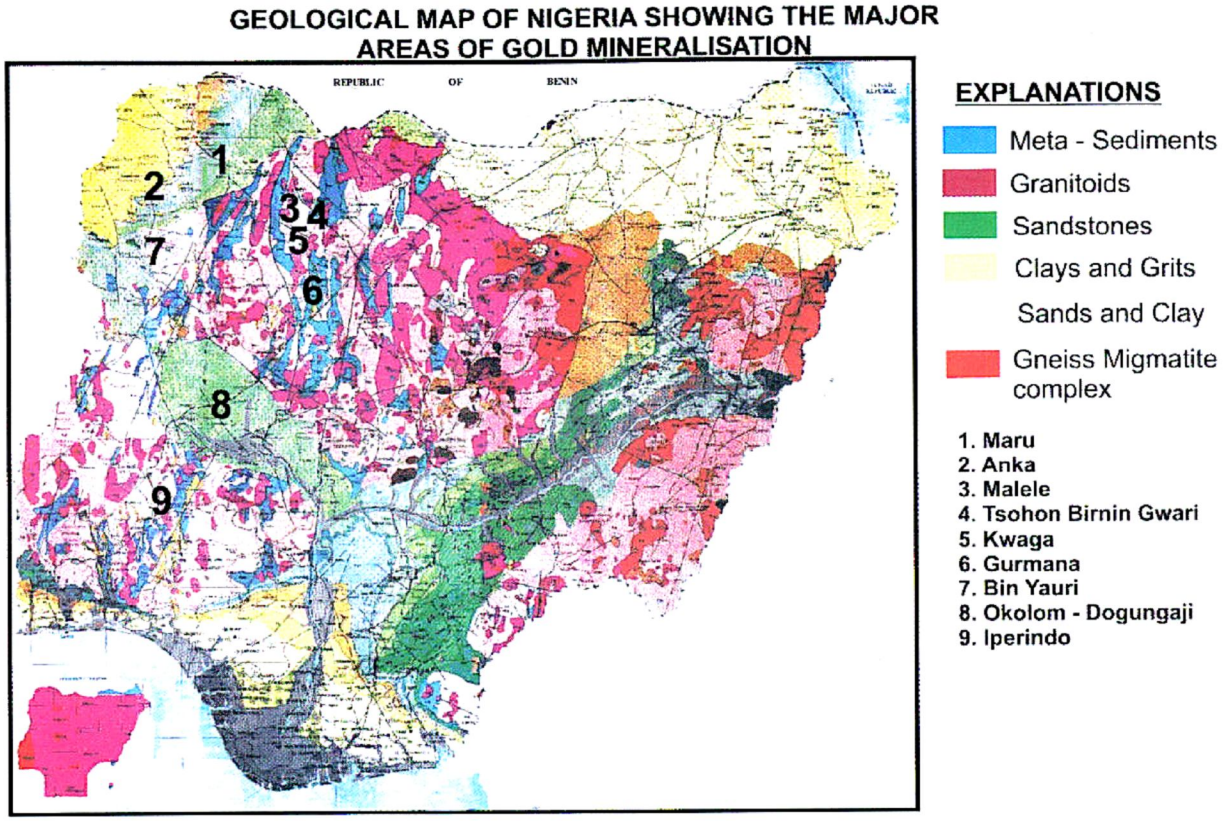


Figure 1.3 Geological map of Nigeria

Source; Mining Journal, Nigeria, 2006.

1.8 Geological Background

Jibiril (Jibiril, 2009) in his paper quoted Whicker and his team that the natural environmental radioactivity in a location and its associated external exposure due to gamma radiation depend primarily on its geological and geographical conditions. It is related to the composition of each litho-logically separated area and the content of the rock from which the soil originates (Whicker, 1983; Wollenberg and Smith, 1990).

In Nigeria, half of its land area of 923,768 km^2 is underlain by crystalline rocks or basement complex and the remaining half, by sedimentary rocks. The basement complex is of Precambrian age and composed primarily of metamorphic and igneous rocks such as granites, gneisses and migmatites (Rahaman, 1988). There are also extensive occurrences of schist, phyllites, quartzite and marble. Two groups of granites can be distinguished in the geological setting of Nigeria.

The two study areas fall within a vast, geologically well noted zone called Bin yauri in the north-west of Nigeria. Primary gold mineralization in the schist belt commonly occurs in quartz veins within several lithologies. Both Awwal and Bagega falls to the Bin Yauri deposit of Zuru and Anka schist belts of north-western Nigeria. They both are of vein-type quartz-sulphide-carbonate gold mineralization hosted by a brittle fault zone. The fault zone cuts hornfels that occurs between a granodiorite batholit and politic metasedimentary rocks of the schist belt(figure 1.4.).

1.8.1 Gold Mineralization in Anka zone (Zamfara State)

In this area, which boarders around Bagega, there are a number of old gold workings, such as Kamfani Kwali, Jameson, Daki Hamsin, Cooper, Rafin Gero, Kekule, Babiyi, Zuzurfa, Magelma, Mairakuma, Sunke and Kuba, hosted by schists, phyllites and quartzites of the Anka schist belt. The zone is a small unit of the Bin Yauri. The most prominent of these sites is the Kamfani Kwali where about five shafts and adits were sunk by the colonial operators in the 1930s-1940s. Gold mineralization in this area is apparently related to sub-regional NNE-SSW fault structures that are subsidiary to the transcurrent Anka fault system (Garba and

Akande, 1992). Individual veins or reefs seldom exceed 0.5 km of strike length as indicated by the extent of past workings, and are concordant with the host rock foliation. In the Anka area there is a total lack of exposure of the gold-quartz veins or their altered wall rocks, except in the Zuzurfa old mine, where altered phyllites and quartzites are left behind by past miners. The mineralized wallrocks show metal values in the following range: Cu = 647-5410 *ppm*, Pb = 7550-22600 *ppm*, Ag = 1.5-8.6 *ppm*, and Au = 123-6320 *ppm*.(Garba and Akande, 1992).

1.8.2 Gold Mineralization in Zuru Zone (Kebbi State)

The zuru gold mineralization encloses Awwal mining exercises. Gold-sulphide-carbornate quartz veins occur in a brittle fault zone cutting fine-grained metamorphic rock composed of silicate minerals and formed through the action of heat and pressure on shale at the contact of a Pan-African granodiorite intruding phyllites and tourmalinites of Yelwa-Zuru schist belt in northwestern Nigeria. The brittle fault is a NW-SE trending subsidiary structure of the transcurrent Anka fault (fig.4). Gold occurs associated with pyrite, chalcopyrite, galena, and minor sphalerite, magnetite and bismuth telluride in a gangue of mainly quartz with some carbonates, sericite, chlorite and tourmaline. The gold veins are surrounded by a narrow zone of hydrothermal alteration in which a chlorite-tourmaline-pyrite-carbonates association overprints a dominantly sericitic fabric of the hornfels wall rocks. Past mine records, reconnaissance exploration and studies have shown gold grades in the range 5-15 ppm. (Garba and Akande, 1992)

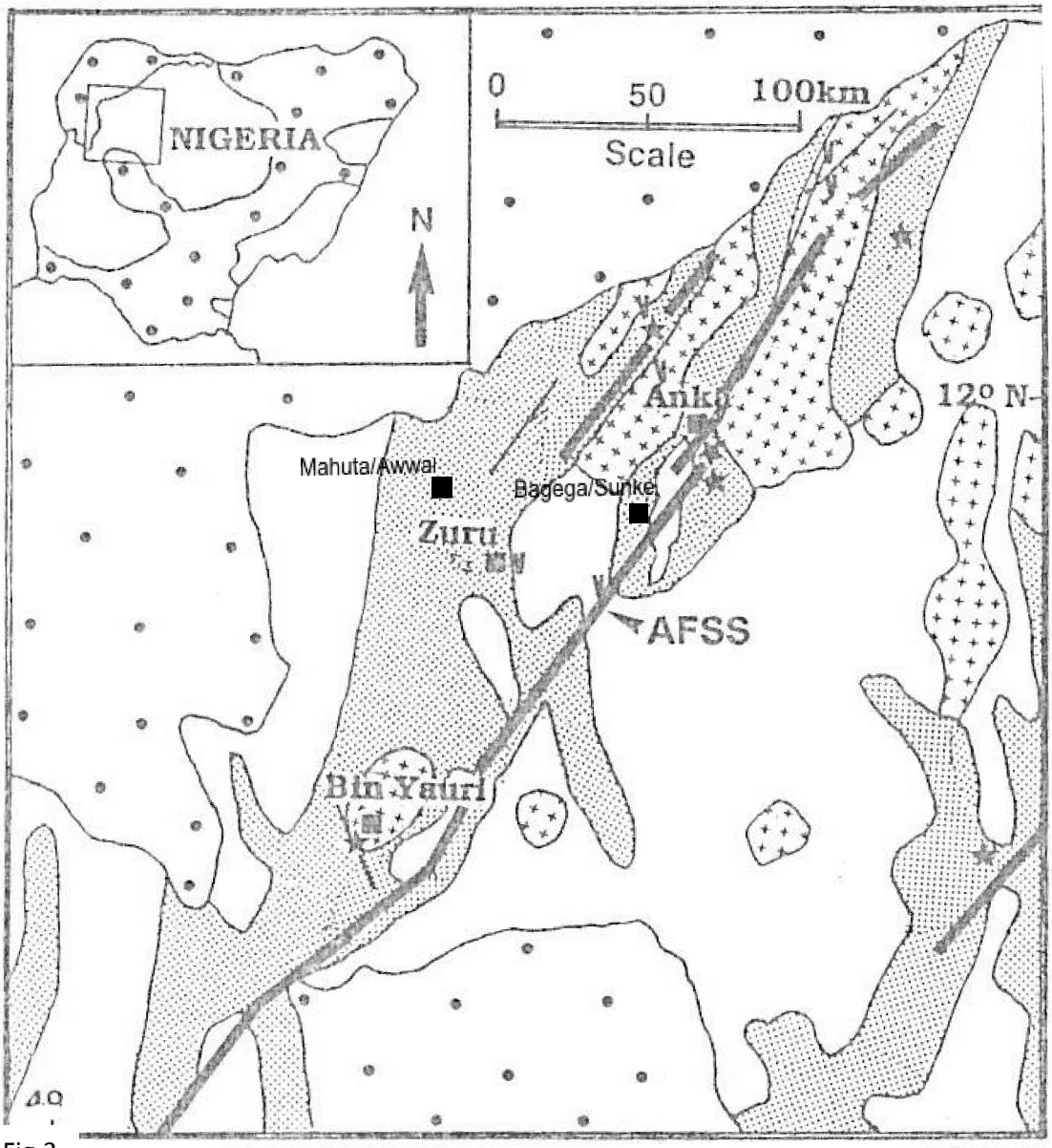


Fig.3

Fig. 1.4 Regional geological setting of the Bin Yauri gold mineralization. Sediments, Pan-African Volcanics, Pan-African granites, Schist belts, Dahomeyan basement, —— Major fault systems, AFSS Anka Fault/Shear System, —— Minor faults. ★ Old gold mines □ New Gold Mine locations under radiation assessments

(Adopted and modified from Garba 1992)

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Living organisms are exposed to numerous natural and man-made agents that interact with molecules, cells, and tissues, causing reversible deviations from homeostatic equilibrium (GRPC, 1977). These agents are thus deleterious. Many aspects of aging and many diseases are thought to stem from these exogenous and endogenous deleterious agents acting on key components of cells within the body. (GRPC, 1977). One of the natural and exogenous deleterious agents is Ionizing radiation and the possible proliferation of its release due to human activities into the environment is the concern of this work with a particular focus on radiation and contamination issues about mining in Awwal, kebbi state and Bagega in Zamfara state. Estimation of the radiation dose distribution is important in assessing health risk to a population and serve as the reference in documenting changes to environmental radioactivity in soil due to anthropogenic activities. Natural environmental radioactivity arises mainly from primordial radionuclides, such as ^{40}K, and the radionuclides from the ^{232}Th and ^{238}U series and their decay products, which occur at trace levels in all ground formations. Gamma radiation emitted from those naturally occurring radioisotopes, also called terrestrial background radiation, represents the main external source of irradiation of the human body. Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world (UNSCEAR,

2000). The specific levels of terrestrial environmental radiation are related to the geological composition of each litho logically separated area, and to the content thorium (Th), uranium(U) and potassium(K) of the rock from which the soils originate in each area. In terms of natural radioactivity, it is well known, for instance, that igneous rocks of granitic composition are strongly enriched in Th and U (on an average 15 ppm (parts per million) of Th and 5 ppm of U), compared with rocks of basaltic or ultramatic composition (<1 ppm of U) (Menager *et.al* 1993). For that reason, higher radiation levels are associated with igneous rocks and lower levels with sedimentary rocks. There are exceptions, however, as some shales and phosphate rocks have relatively high content of those radionuclides (UNSCEAR, 2000).

With this background information, the review in this work is focused broadly on some selected past works on the physical, the biological and related medical issues on radiation absorption in attempts to justify the core concept of study which gave birth to the research: Radiation biophysics as the intersection of biology and radiation physics. To structure the review, radon, heavy metals from mine tailings and acid mine drainage are viewed as main sources of radioactive materials in artisanal mining, while air, water and soil treated as pathways of these radioactive materials into human body. Mechanisms of radiation damage, repair processes, cell cycle and its deregulation are necessary inputs to this review as means of giving a generalized background of the research works. Ultimately, regulatory guides for radiation exposure and toxic benchmarks need be inculcated to serve as guides for the measurements. These issues have been organized into themes in the schematic

representation below (Figure 2.1). Some of the sections of the themes overlap on each other due to the necessity for brief analysis of the relations between them; nevertheless, the objectives of each of these sections remain clarified.

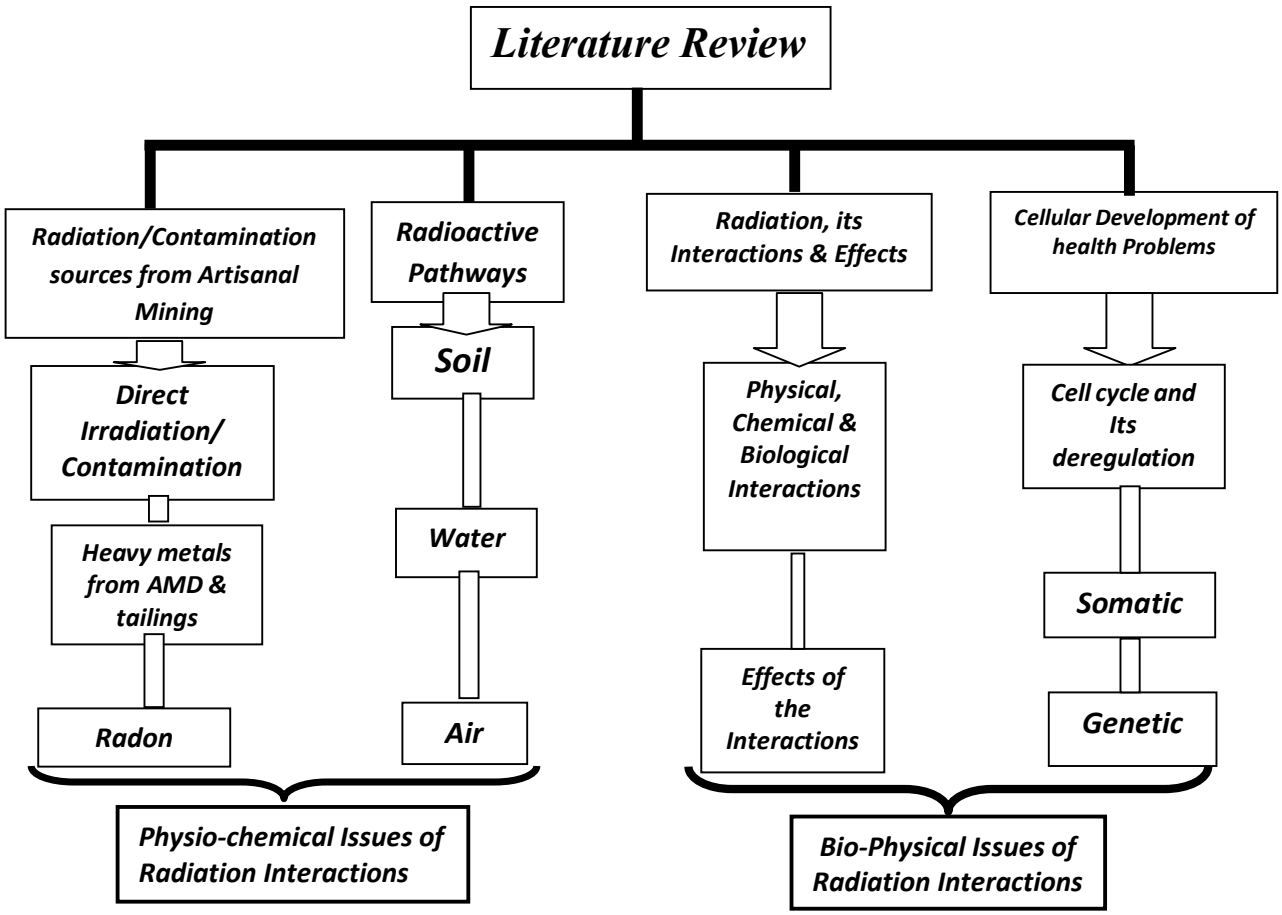


Figure 2.1 Scheme of the review of related literature

2.1 Natural Radioactivity of Radionuclide of Interest

Nuclear radiation is a result of radioactive decay of energetically unstable nuclei. The decay is accomplished by emissions of charged particles and/or electromagnetic rays. Radionuclide can occur naturally or can be by man-made.

Natural radionuclides in the environment are of two general classes; The Cosmogenic and the primordial.

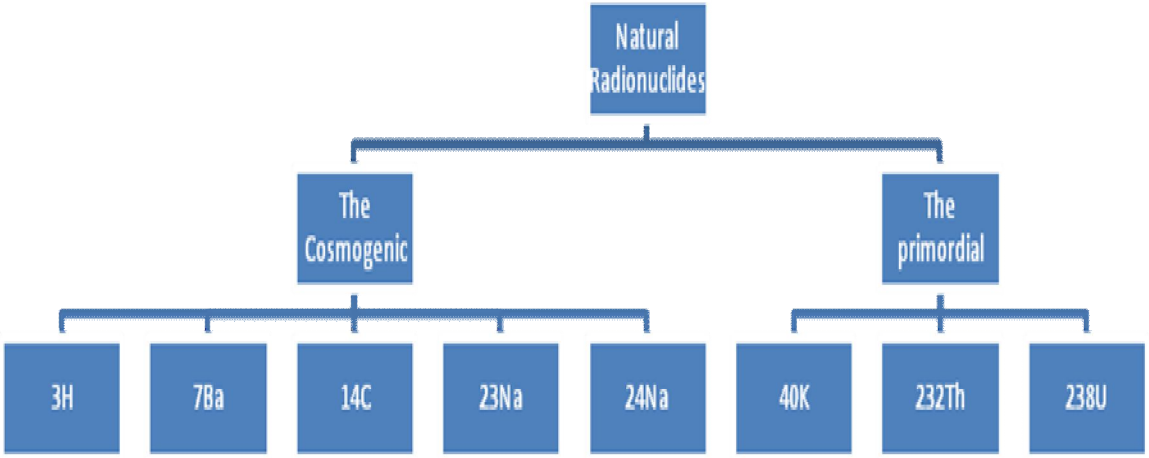


Figure 2.2 Classification of natural radionuclides

The radionuclides specified above are not the exhaustive; however they are the major contributors to either class. The cosmogenic radionuclides are produced by the interactions of the cosmic rays with target atoms in the atmosphere.

The major portion of human exposure from naturally occurring radionuclides results from ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th, all of which are of primordial origin. This observation calls for necessity of review of some of the past works on them;

Oyedele and his team measured activity of these radionuclides stated. Activity concentrations of the naturally occurring ^{238}U, ^{232}Th and ^{40}K in soil samples collected from four major towns across the northern region of Namibia were determined using gamma-ray spectrometry with the objective of providing baseline data on the radiation level in the region. The average concentrations of radionuclides in the towns vary from 7.5 ± 2.3 to 14.2 ± 3.3 Bq kg^{-1} for ^{238}U, 5.8 ± 2.6 to 24.9 ± 6.1 Bq kg^{-1} for ^{232}Th and 52.1 ± 28.7 to 380.1 ± 112.9 Bq kg^{-1} for ^{40}K.

These concentrations were used to calculate the mean absorbed dose rate and the mean annual effective dose in the region. The low value of 21 ± 16 μSv obtained for the mean annual effective dose indicates that the region has normal background radiation. (Oyedele *et.al.* 2008). A related work was carried out by Ajayi (2004), in which Four radionuclides (^{137}Cs, ^{238}U, ^{232}Th and ^{40}K) were analyzed in soil samples collected from Aramoko-Ekiti, South West Nigeria by a sensitive gamma-ray spectroscopic system consisting of a 7.6 cm × 7.6 cm Nal(TI) scintillation detector interfaced with Canberra series 10 plus multichannel analyzer. Results obtained show that the radionuclides are present in varying concentrations in the soil, except ^{137}Cs which was not detectable. The absorbed dose rates in the air of the location due to these radionuclide are within the UNSCEAR recommended world average value. Ademola (2008), in his research works on exposure to high background radiation level in the tin mining area of Jos Plateau, Nigeria, measured the radioactivity of samples of tin tailings collected from a mining site in Jos. The activity concentrations of the samples were measured using a gamma-ray spectrometer with a hyper-pure germanium detector. *In situ* dose rates at the site were also measured using a pre-calibrated survey meter. Potassium-40 was not detected in any of the studied samples. The activity concentrations of ^{238}U and ^{232}Th ranged from 17.1 × 10^2 to 16.6 × 10^3 Bq kg^{-1} and from 52.9 × 10^2 to 47.5 × 10^3 Bq kg^{-1}, with mean values of 72.2 × 10^2 and 16.8 × 10^3 Bq kg^{-1}, respectively. The absorbed dose rates were between 4.0 and 36.3 μGy h^{-1}, with a mean value of 13.5 μGy h^{-1}, which is much higher than the world average of 0.06 μGy h^{-1} for soil. The calculated effective dose rates varied between 2.8 and 25.4 μSv h^{-1}, with a

mean value of 9.4 μSv h^{-1}, whereas the effective dose rates obtained for the *in situ* measurement varied between 6.0 and 28.0 μSv h^{-1}. An extension of Radioactivity measurements of radionuclide from human exploitation of natural resources was carried out using gamma-ray spectroscopy to determine the radionuclide concentrations in soil samples in the premises of the Warri Refining and Petrochemical Company located in the Niger Delta region of Nigeria and also in communities around it. The radionuclide contents of the crude oil and petroleum additives were also similarly determined. Results indicate that on the premises used by the company, the ranges of activity concentrations of ^{40}K, ^{226}Ra and ^{228}Th in the soil samples were 261.3–932.3 Bq kg^{-1},<4.2–23.0 Bq kg^{-1} and<5.1–10.2 Bq kg^{-1}, respectively. For the 13 villages studied, activity concentrations ranged from <17.2–766.3 Bq kg^{-1},<4.2–104.7 Bq kg^{-1} and<5.1–13.7 Bq kg^{-1}, respectively, for ^{40}K, ^{226}Ra and ^{228}Th. The lowest radionuclide concentrations were found in the crude oil relative to the petroleum additives. The highest outdoor effective dose rate obtained in the study was 47.5 μSv y^{-1} for the villages and 35.2 μSv y^{-1} within the company premises. These values are less than the world average outdoor value of 70 μSv y^{-1} given by UNSCEAR. Overall, the researchers, (Jibiril *et al*., 2008), concluded that the long duration of refining activities does not seem to have affected radionuclide concentrations in the environment. Their measurements also showed that the observed radiation dose rates did not vary significantly from the previously determined Warri City outdoor gamma radiation dose rates, for which the probability of occurrence of any health effects of radiation was judged low. The

measurements, therefore, are interpreted to represent baseline radiometric data for future reference and research in the area.

In another related gold mining radiation investigation by Darko and his team (Darko *et.al.*, 2005),preliminary studies were conducted into the occupational radiation exposure to NORMS from surface and underground mining operations in a gold mine in the Ashanti Region of Ghana. The result revealed annual effective dose estimated to be 0.26 ± 0.11 mSv for surface mining and 1.83 ± 0.56 mSv for the underground mines using the ICRP dose calculation method. The team concluded that the results obtained are found to be within the allowable limit of 20 mSv per annum for occupational exposure control recommended by the ICRP.

2.2 Heavy Metals as Pollutants from Mining

Heavy metals are natural components of the Earth's crust. They cannot be degraded or destroyed. To a small extent they enter our bodies via food, drinking water and air. Heavy metals are dangerous because they tend to bio-accumulate (*Kilic, 2009)*. The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic or poisonous even at low concentration (Lenntech, 2004). "Heavy metals" is a general collective term, which applies to the group of metals and metalloids with atomic density greater than 4 g/cm^3 , or 5 times or more, greater than water (Garbarino *et al.*, 1995,Hawkes, 1997). However, being a heavy metal has little to do with density but concerns chemical properties. Heavy metals include lead (Pb), cadmium (Cd), zinc (Zn), mercury (Hg), arsenic (As), silver (Ag) chromium (Cr), copper (Cu) iron (Fe), and the platinum group elements. Many of these metals enter the environment and remain environmental problems due to

pollution properties. Most of these environmental pollutants also occur naturally through natural weathering processes, however, published reports also indicate that, mainly mining and smelting plants release metals from the bed-rock (Walker and Sibly, 2001).

Heavy metals are referred to interchangeably as trace elements depending on the field of study or context in which it is being discussed. In this works, the toxic properties of the metals is the factor of key interest and thus the toxicologist refer to heavy metals/trace elements as those elements distributed into the environment by industrial processes that are detrimental to human health or the environment. This definition is not based on abundance in the environment, or density or metallic properties, but solely on the adverse effects of the element in the environment.(Evalyn,2004).

2.3 Heavy Metal Poisoning and Bio-toxicity

The bio-toxic effects of heavy metals refer to the harmful effects of heavy metals to the body when consumed above the bio-recommended limits. Although individual metals exhibit specific signs of their toxicity, the following have been reported as general signs associated with cadmium, lead, arsenic, mercury, zinc, copper and aluminium poisoning: gastrointestinal (GI) disorders, diarrhea, stomatitis, tremor, hemoglobinuria causing a rust–red colour to stool, ataxia, paralysis, vomiting and convulsion, depression, and pneumonia when volatile vapours and fumes are inhaled (McCluggage, 1991). The nature of effects could be toxic (acute, chronic or sub-chronic), neurotoxic, carcinogenic, mutagenic or teratongenic.

Lead is the most significant toxin of the heavy metals, and the inorganic forms are absorbed through ingestion by food and water, and inhalation (Ferner, 2001). A notably serious effect of lead toxicity is its teratongenic effect. Lead poisoning also causes inhibition of the synthesis of haemoglobin; dysfunctions in the kidneys, joints and reproductive systems, cardiovascular system and acute and chronic damage to the central nervous system (CNS) and peripheral nervous system (PNS) (Ogwuebgu and Muhanga, 2005). Other effects include damage to the gastrointestinal tract (GIT) and urinary tract resulting in bloody urine, neurological disorder and can cause severe and permanent brain damage. While inorganic forms of lead, typically affect the CNS, PNS, GIT and other biosystems, organic forms predominantly affect the CNS (McCluggage, 1991; INECAR, 2000; Ferner, 2001; Lenntech, 2004). Lead affects children by leading to the poor development of the grey matter of the brain, thereby resulting in poor intelligence quotient (IQ) (Udedi, 2003). Its absorption in the body is enhanced by Ca and Zn deficiencies. Acute and chronic effects of lead result in psychosis.

As with lead and mercury, arsenic toxicity symptoms depend on the chemical form ingested (Ferner, 2001). Arsenic acts to coagulate protein, forms complexes with coenzymes and inhibits the production of adenosine triphosphate (ATP) during respiration (INECAR, 2000). It is possibly carcinogenic in compounds of all its oxidation states and high-level exposure can cause death (Ogwuegbu and Ijioma, 2003; USDOL, 2004).

Metal leaching is a naturally occurring process. Under certain conditions if the trace elements in the original media are in anomalously high concentrations they may

have a negative impact on the receiving environment. Metal leaching is generally associated with acid mine drainage (AMD), however it can occur under non AMD conditions.

Concentrations of trace elements in soil are important to soil scientists not only for environmental purposes, such as quantifying contamination, but also to help solve problems associated with human and plant toxicity. The elements typically studied are Ag, Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Sb, Se, Si, Sr, Th, Ti, V, and Zn. These elements are usually described in terms of their total content and availability. In soil, trace element retention is dependent on several soil characteristics, as well as parent material. Soil characteristics include pH, cat-ion exchange capacity (CEC), particle size distribution, organic matter content, and oxide content. These characteristics cause trace elements to either accumulate in the soil, or leave the soil for other components of the environment. When parent materials have high trace element concentrations, the soils that develop over them have high or even higher trace element concentrations (Evalyn I. A., 2004).

In Evalyn's(2004) result, he concluded that "average concentrations of Si, K, Ba, Pb, and U are highest in soils formed over felsic parent materials. Average concentrations of these elements decrease when comparing felsic to intermediate to mafic derived soils. Conversely, Ti, V, Cr, Mn, Co, Ni, Cu, and Zn average concentrations are highest in soils formed over mafic parent materials and average concentrations of these elements decrease when comparing mafic to intermediate to felsic derived soils. Concentrations of Cd and Hg are too close to the instrument detection limits to make any conclusions on concentration differences".

A related elemental analysis conducted by Kodom and his members was aimed to investigate the extent of heavy metal pollution in the surface soils at "Suame-Magazine" industrial area of Kumasi, and to verify any significant industrial impact. According to Kodom(Kodom, 2008), Concentrations of nine (9) heavy metals (Zn, Pb, Cr, Cu, Co, Ni, Cd, Hg, and As) were qualitatively and quantitatively measured and examined from six (6) sampling sites, using X-ray Fluorescence (XRF) analysis. Four (4) out of the six (6) sampling sites were selected from areas of high industrial impact due to the chemical and metallurgical activities highly embarked on at the area. Whereas, the other two (2) were residential communities relatively of low industrial activity selected in close proximity to the previous region. The results from locations of high industrial impact showed that, the mean concentration of zinc present in the soil ranges from 189.2- 908.6 $mgkg^{-1}$, lead values were in the range of 133.7- 571.3 mgkg-^{1}, Chromium concentration varies from 91.3 - 545.8 $mgkg^{-1}$, the concentration of copper ranged from 62.9 - 334.6 $mgkg^{-1}$, concentration values for cobalt, nickel, cadmium, mercury, and arsenic were respectively in the range 38.6 - 81.9 $mgkg^{-1}$, 12.4 - 30.9 $mgkg^{-1}$, 6.9 - 13.2 $mgkg^{-1}$, 5.5 - 10.4 $mgkg^{-1}$ and 2.3 - 18.6 $mgkg^{-1}$. Apart from nickel and arsenic, all the heavy metals recorded values extremely high above their respective threshold limit values (TLVs). However, comparing these concentrations with those obtained from locations of low industrial activity, relatively very low heavy metals were recorded, with chromium, cadmium and mercury being the heavy metals which were recorded in enhanced levels far above their TLVs. Considering all the heavy metals obtained at the study area, Zn, Pb and

Cr dominated in all the investigated zones of high industrial impact. This is attributed to the indiscriminate disposal of industrial waste as well as anthropogenic point source contamination. The extremely high contents of the heavy metals generally recorded at the study area are terribly alarming in terms of environmental pollution. Therefore, the inhabitants (mostly children) and the numerous workers, who reside and work at such polluted environment, are at serious risk of heavy metal toxicity and awareness needs to be created as such.

2.4 *Silica Dust and Silicosis*

Silicosis is a debilitating respiratory disease caused by inhalation of fine crystalline silica dust that is retained in the lungs.(Ziskind, *et. al, 1976*) The amount of dust inhaled, the percentage of free or uncombined silica in the dust, the size of the dust particles, and the length of exposure all affect the onset of silicosis. The inhaled dust deposited in the bronchioles and alveoli reacts within the lung tissue to form silicotic nodules. The nodules appear on chest radiograms as discrete, rounded opacities or shadows. The presence of silicotic nodules and a history of occupational exposure to silica dust are necessary for a positive diagnosis of silicosis. The earliest symptom of silicosis is shortness of breath. As the disease progresses, the silicotic nodules coalesce and form a continuous mass of fibrotic tissue, called progressive massive fibrosis.

Silicosis manifests itself in different ways depending on exposure conditions and individual variations. Researchers have described three forms of the disease. They differ primarily in the length of exposure before the onset of symptoms of the

disease and the rate at which the disease then progresses. The common or simple form of silicosis has been recognized as an occupational disease since antiquity. It may take 20 or more years of exposure before a chest radiogram is positive for silicosis. Usually there is little or no respiratory impairment associated with the early stages of simple silicosis. The silica content of the dust to which workers developing simple silicosis are exposed is often less than 30%.

Accelerated and acute silicosis develop after shorter exposures to respirable silica dust at high concentrations. Accelerated silicosis differs from simple silicosis mainly in the time from first exposure to silica dust until silicotic nodules appear on a chest radiogram. In accelerated silicosis the exposure varies between 5-15 years, the progression of disease development is faster, and often there is progressive massive fibrosis.

Acute silicosis, also termed silicoproteinosis, develops after 1-3 years of exposure and progresses even faster than accelerated silicosis. There is a rapid loss of pulmonary function, invariably followed by death. A distinctive feature in acute silicosis is the presence of a surfactant-like liquid in the alveoli. On a chest radiogram there are few silicotic nodules, and they are rather diffuse.

No effective medical treatment is available for silicosis.

2.5 Mine Tailings

Mine waste consists of two types: mine tailings, which consist of fine-grained mineral materials, sludges produced by ore treatment processes (i.e., concentration,

flotation, and cyanidation), and slag generated by pyro-metallurgical operations (calcinations); and Waste rock, which consists of the host rock (gangue) that is discarded in the preparation phase (i.e., crushing and grinding) and generally contains no commercially valuable ore.

In gold mining, 99% of the rock material removed from the ground consists of tailings and waste rock, normally stored in ponds that may cover several hectares or waste rock piles (hills) that can reach as much as 100 m in height.(PHAC,2008).

2.6 Radon

When radon decays, it releases a "large" atomic alpha particle and the atom is transmuted into polonium. An alpha particle is essentially a helium atom stripped of its electrons. It is at this point that the real hazards associated with radon are encountered. For it is not the radon which is responsible for the health problems, but rather the short lived radon daughters (SLRDs) and their decay products, such as the alpha particles. The radon may be thought of merely a source and a vehicle for the SLRDs.(Connell, 2006).

There are several different kinds (isotopes) of naturally occurring radon. Of these, radon 222 which has a half life of 3.8 days has radioactive properties that pose hazards to health.

Once the radon atom decays, it subsequently undergoes four rapid decays starting with polonium 218 which decays into lead 214, which decays into bismuth 214, which decays into polonium 214. Each of these daughters has a half life of less than 30 minutes (the polonium 214 has a half life of only 0.00016 seconds). Furthermore, the daughters are electrically charged.

During each of the decay, at least one of three types of ionizing radiation is emitted by the SLRDs: alpha, beta and gamma. The alpha particle is easily stopped by a single piece of paper or layer of clothing. Since the alpha particle is large and easily stopped, the alpha particle transfers virtually all of its energy to the material which has stopped the particle. Beta has less probability of being stopped and imparts less energy into the stopping material. The gamma radiation is similar to X-rays and has an even lower probability of being stopped.

Since the radon is airborne, these daughters have a high probability of being airborne. Inhaled progeny of radon are the most important source of irradiation of the human respiratory tract. Epidemiological studies of underground miners of uranium and other minerals have provided reasonably firm estimates of the risk of lung cancer associated with exposure to radon progeny.(Yu, Lau & Nikezic, 2008)

If the daughters are inside the lung when they decay, the lining of the lung wall becomes the stopping material. Since the alveolar cells of the lung wall do not have a significant protective coating, an alpha particle can collide with the live cell, imparting an enormous amount of energy to the cell, possibly disrupting the DNA within the cell. This is the interaction which is thought to initiate the cancers associated with the SLRDs.

Connell (2006) further asserted that 'when a daughter is airborne, it has an electrical charge associated with and it has a higher probability to adhere to other airborne particulates and dust'. Radon-222 is one of the decay products in the radioactive series that originates with Uranium. It contributes a significant portion of terrestrial

radiation to a great percentage. On average two thirds of the dose people receive from terrestrial sources comes from the gas, radon-222.(Bafandeh, 2004).

2.7 Contamination and Irradiation

There are two broad types of damage that internal radioactive materials may produce: first, the radiation produced may be expected to exhibit the usual sort of either direct or indirect destructiveness. Second, many radioactive species are heavy metals, and are therefore chemically toxic, even at extremely low concentrations.

Piccard (2005), in his submission on radiation damage and Dose measurement made assertions about graph of the rate of removal of a substance (in moles/sec) versus the concentration (in moles/l) of that substance within the relevant tissue (perhaps the circulating blood). Such a graph, according to him, will typically exhibit a portion passing linearly through the origin and in theory may exhibit at high concentration a leveling off, or saturation. On the other hand, if the concentration is low, the rate of removal will decline as the concentration is reduced, hence the graph will head downward at a decreasing slope, flattening out. The mathematics is exactly parallel to that of radioactive decay: during this final phase of removal, the concentration will decline exponentially with time.(Piccard, 2005)

This exponential removal law applies to any chemical species at low concentration. In view of his assertion, when dealing with radioactive decay of a contaminant, it is necessary to consider the "removal" by decay in two ways. First, after it decays it is no longer the original substance, so there is less of that material present. Thus, the

concentration of the original material will decline faster if it decays and is being removed by the body, than it would if it were decaying in vitro. Second, the damage done to the body results only from the decay that occurs within the body. Provided that the original concentration is so low that the removal is following an exponential law, the amount of material that will be excreted prior to its decay can be determined by elementary calculus. In that case, the effect is to produce an exponential reduction in concentration with time, with an overall "effective half-life" calculated from the "biological half-life" and the "radioactive half-life," as follows:

Let

The biological half-life, T_b, has decay constant of λ_b

The radioactive half-life, T_r, has decay constant of λ_r

The effective half-life, T_e, has decay constant of λ_e

Then, the relationship between them is given by,

$$\lambda_e = \lambda_b + \lambda_r \quad \text{.....Eq. 2.1}$$

Now, by exponential law, half-life, $\mathbf{T = \frac{0.693}{\lambda}}$ giving, $\boldsymbol{\lambda = \frac{0.693}{T}}$ **.....Eq.2.2**

Consequently, substitution of the decay constants for the three decay modes gives

$$\frac{0.693}{T_e} = \frac{0.693}{T_b} + \frac{0.693}{T_r} \quad \text{.....Eq. 2.3}$$

It then follows that,

$$\cancel{\frac{0.693}{T_e}} = \cancel{0.693}\left\{\frac{1}{T_b} + \frac{1}{T_r}\right\}$$

Resulting in,

$$\frac{1}{T_e} = \frac{1}{T_b} + \frac{1}{T_r} \quad \text{.....Eq. 2.4}$$

This equation implies that the total rate of removal is the sum of the rates of removal by biological action and by radioactive decay.

2.8 Pathways of Radioactive Material into Human Body

In the words of Ibeanu (1999), the presence of both artificial and natural radioactivity in the environment has led to various sources of radiation exposure. She developed her assertion further that 'to effectively evaluate radiation exposure impact, knowledge of environmental transfer mechanism becomes of paramount importance'. These transfer mechanisms include the environmental elements and the pathways.

Radioactive materials both natural and man-made can find their way into human body through different environmental sources. For exposure to occur, an exposure pathway must exist. Exposure pathway is characterized as complete or potential. The five elements of a completed exposure pathway are;

1. A source of chemical or radioactive contamination,

2. A media [e.g. Ground water, surface water, air] through which contaminants are transported from on-site to off-site locations.

3. A point of exposure or place where human exposure is likely to occur.

4. A route of human exposure e.g. eating and breathing

5. An exposed population.

A potential pathway exist when one of the elements is missing, but available information indicate that human exposure is likely to occur via that pathway.

2.8.1 Water pathways (Ingestion)

Radionuclides can come in contact with water in several ways. They may be deposited from air. They may also be released to the water from the ground through erosion, seepage, or human activities such as mining. Some radionuclides that reach either groundwater or surface water will move with the water. Others will be deposited on the surrounding soil or rocks. One important factor affecting their movement is how thoroughly they dissolve in water [solubility].

Another factor affecting movement is the radionuclides ability to adhere to the surfaces of rocks or soil through which the water flows.

Exposure by the ingestion pathway occurs when someone swallows radioactive materials. Alpha and beta emitting radionuclides are of most concern for ingested radioactive materials. They release large amounts of energy directly to tissue, causing DNA and other cell damage.

Ingested radionuclides can expose the entire digestive system. Some radionuclides can also be absorbed and expose the kidneys and other organs, as well as the bones. Radionuclides that are eliminated by the body fairly quickly are of limited concern. These radionuclides have a short biological half-life.(EPA, 2007).

2.8.2 Soil Pathways (via food chain)

A number of interrelated pathways that link the source term [radionuclide] to the food consumed by the people do exist. The main source terms affecting the food

chain are the airborne effluent that are deposited on the ground or directly on crops and animal fodder and liquid effluents that are in water use for irrigation of crop and animal husbandry. Radionuclides in soil can get into the food chain through plants. Plants are capable of absorbing radionuclides from water in soil in the same way as other minerals are absorbed. When animals drink water some of the radionuclides in the water remain in their bodies. These plants and animals eventually become food for people thus providing a pathway for radionuclide to move through the environment to people.

2.8.3 Air Pathways (via inhalation)

Air exposure pathways include contaminants released directly to air as particulate or gaseous emissions, and direct radiation [e.g. x-rays, gamma rays, energetic beta particles, neutrons]. They also include those released to air from re-suspension of particulates deposited on the ground surface.

Radionuclide can be released into the air by human activities. They can also be created in the atmosphere by natural processes such as the interaction of cosmic radiation with nitrogen to produce radioactive carbon 14. Radionuclide can be removed from the air in several ways. Particles settle out of the atmosphere if air current cannot keep them suspended. Rain and snow can remove them.

2.8.4 Special Consideration of Women and children

Women and children may sometimes be affected differently than the general population by contaminants in the environment. Both are smaller than the population average and are affected by smaller quantities of the contaminants (ATSDR, 2007). The effect of hormonal variations, pregnancy, and lactation can

change the way a woman's body responds to some substances. Exposure during pregnancy and lactation can expose the fetus or infant if contaminants cross the placenta or get into the mother's milk. Depending upon the stage of pregnancy, exposure of the fetus could result in death [miscarriage or stillbirth] or birth defects. If the mother is exposed during lactation, her milk may concentrate certain contaminants, increasing the exposure to her infant.

A developing young person (whether fetus, infant or child), has unique vulnerabilities. Some exposures would affect children more than adults because of their lower body weight and higher ingestion dose or amount taken into the body compared to their body weight. Because children are shorter, their breathing zones are closer to the ground, and thus closer to soil contaminants and low-lying layers in the air. Different behavioral characteristics, which include more of hand-to-mouth behavior, increase the ingestion of soil or dust contaminants.

Furthermore, children's metabolic pathways are less developed than those of adults, especially in the first months after birth. Hence some chemicals that are not toxic to adults are highly toxic to infants.

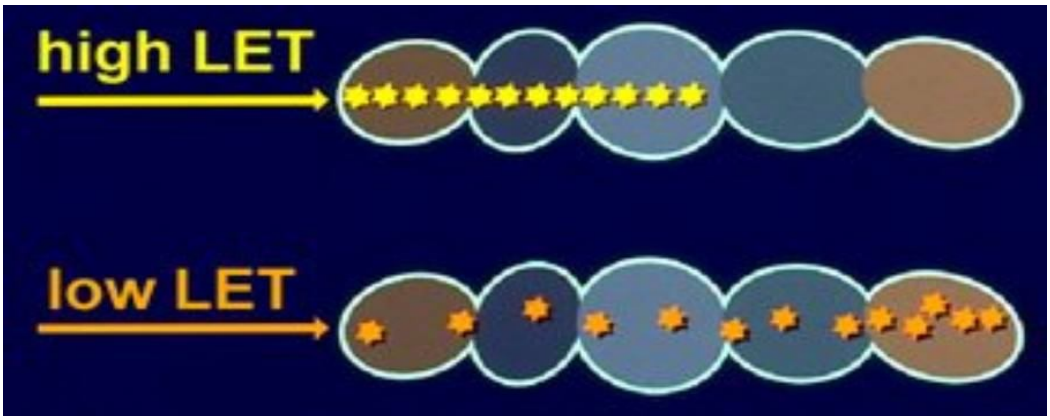
Children grow and develop rapidly in their first months and years of the development. Some organs systems, especially the nervous and respiratory systems may experience permanent damage if exposed to high concentrations of certain contaminants during this period. Because of rapid growth and development, a child's genetic materials [deoxyribonucleic acid or DNA] is more likely to be exposed than later in life, making it more vulnerable to damage.

2.9 Ionizing Radiation

Ionizing radiation consists of subatomic particles or electromagnetic waves that are energetic enough to detach electrons from atoms or molecules, thereby ionizing them. The occurrence of ionization depends on the energy of the impinging individual particles or waves, and not on their number. An intense flood of particles or waves will not cause ionization if these particles or waves do not carry enough energy to be ionizing. (Wales, 2009). Radiation affects people by depositing energy in body tissue, which can cause cell damage or cell death. In some cases there may be no noticeable effect. In other cases, the cell may survive but become abnormal, either temporarily or permanently. Additionally, an abnormal cell may become malignant. Both large and small doses of radiation can cause cellular damage. The extent of the damage depends upon the total amount of energy absorbed, the time period and dose rate of the exposure, and the particular organs exposed.

When ionizing radiation impinges on biological systems, energy is transferred into the system according to fundamental physical principles. How energy is transferred from ionizing radiation to tissue is described by the concept of LET (linear energy transfer). Energy from ionizing radiation is transferred to living tissue in a straight line path called LET, which is expressed in units of keV/cm. The Less penetrating radiations such as particulate radiation, photoelectrons, alpha particles, and beta radiation are high LET radiations.

Figure 2.3 Mode of transfer of Ionizing radiation



Source: IAEA-WHO (Module VIII-a),2008

The chaotic state induced within a living cell when it is exposed to ionizing radiation has been graphically described by Dr. Karl Z. Morgan as a 'madman loose in a library '.(Karl, 1975). The result of cell exposure to these microscopic explosions with the resultant sudden influx of random energy and ionization may be either cell death or cell alteration. The alteration which can be temporary or permanent can leave the cell unable to reproduce (or replace) itself. One source of radiation is the nuclei of unstable atoms. As these radioactive atoms (also referred to as radionuclide or radioisotopes) seek to become more stable, their nuclei eject particles and high-energy waves. This process is known as radioactive decay.

Ionizing radiation is classified as a potent carcinogen (Ames, 1991) .When interacting with living cells; it causes a variety of changes depending on exposed and absorbed dose, duration of exposure and interval after exposure, and susceptibility of tissues to ionizing radiation. The sensitivity of cells to ionizing radiation depends especially on the rate of differentiation and accompanying factors of the tissue as well as on the efficiency of the intrinsic antioxidative defense systems (Wallace, 1998)

Ionizing radiation damages biological tissues by exciting or ionizing their atoms and molecules (Bacg and Alexandra, 1966). Additional indirect damage is caused by the formation of free radicals in water (known as water radiolysis), which makes up 75%-80% of the mass of living systems.

The primary products of water radiolysis are the hydroxyl radical, hydrogen radical and hydrated electron; hydroperoxy radicals and hydrogen peroxide are also formed in the presence of oxygen. The production of lysosomal enzymes and biological mediators, such as histamine and prostaglandins, is another biological response to radiation exposure (Donlon, 1988).

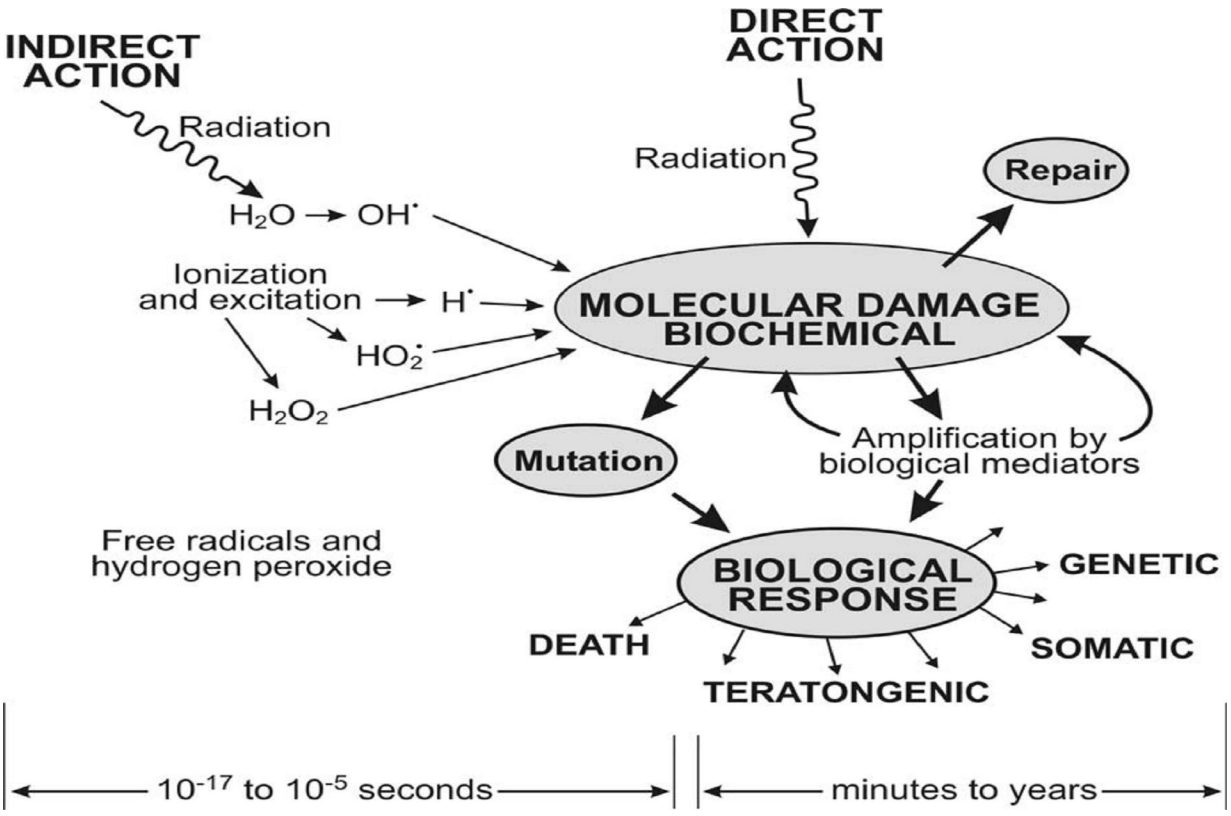


Figure 2.4 ***Physical and Biological responses to ionizing Radiation***.
Source;UNSCEAR 1993

The interaction of ionizing radiation with living cells induces a variety of reaction products and a complex chain reaction in which many macromolecules and their degradation products participate.(Magorzata *et.al*, 2000). Interactions of ionizing radiation with DNA consist of the direct ionization of DNA (direct effect) (Steenken, 1989) and its reaction with surrounding water molecules (the indirect effect), followed by DNA destruction by the induced radicals ($^{\bullet}OH$, $e^{-\bullet}$ and, to much lesser extent, $H^{\bullet}$). A wide variety of biochemical consequences of radiation-induced damage to DNA (Becker and Sevilla, 1993) occurs because of free-radical attack (Breen and Murphy, 1995).

2.9.1 Direct Actions

Excitation occurs if alpha or beta particles or gamma photons transfer sufficient energy to remove one of the electrons from an inner to an outer orbital shell.

Ionization occurs if alpha or beta particles or gamma photons transfer sufficient energy to remove one of the electrons from the target atom. Each ionization event produces an ion pair consisting of a free electron and the positively charged remainder of the atom.

For direct action, damage occurs as a result of ionization of atoms on key molecules in the biological system. This causes inactivation or functional alteration of the molecule.

Absorption of energy sufficient to remove an electron (called ionization) can result in bond breaks. Excitation of atoms in key molecules can also occur resulting in bond breaks.

Direct effect is the predominant cause of damage in reactions involving high LET radiation, such as alpha particles, neutrons and heavy ions. The complex molecules making up living organisms are composed of long strands of atoms forming proteins, carbohydrates and fats. They are held together by chemical bonds involving shared electrons. If the ionizing radiation displaces one of the electrons in a chemical bond, it can cause the chain of atoms to break apart, splitting the long molecule into fragments, or changing its shape by elongation.(Bertell,2001).This is an `ungluing' of the complex chemical bonds so carefully structured to support and perpetuate life. The gradual breakdown of these molecular bonds destroys the templates used by the body to make DNA and RNA or causes abnormal cell division.

2.9.2 Indirect Action (***Generation of free radicals***)

Indirect actio*n* is predominant with low LET radiation such as X and gamma rays. It involves the transfer of energy to an atom with a subsequent "decay" to a free radical species (Fig,2.4). Indirect action, thus, involves the production of reactive free radicals whose toxic damage to the key molecule has biological effect.

2.10 *Radiation Damage*

Radiation injury to living cells is, to a large extent, due to oxidative stress (Ward,1988). Reactive oxygen species (ROS) and free radicals induced by partial reduction of oxygen (O_2) react with cellular macromolecules (i.e., nucleic acids, lipids, proteins, and carbohydrates) and damage them. The molecule most often reported to be damaged by ionizing radiation is DNA. Hydroxyl radicals ($^{\bullet}OH$),

considered the most damaging of all free radicals generated in organisms, are often responsible for DNA damage caused by ionizing radiation.(Magorzata *et.al*, 2000).

Much study of radiation damage is organized around the concept of "free radicals," Free radicals can be defined as covalently bound groups of atoms (or single atoms) which have at least one unpaired electron, and which are free to move within the sample. Their presence in an irradiated specimen is demonstrated by electron paramagnetic resonance (Piccard, 2005).

The radical (OH^{+}) is electrophilic and highly reactive. Since the predominant molecule in biological systems is water, it is usually the intermediary of the radical formation and propagation.

The water molecule absorbs energy and disassociates into two radicals with unshared electrons in the valence shell. The transfer of the free radical to a biological molecule can be sufficiently damaging to cause bond breakage or inactivation of key functions. In addition, the organic peroxy free radical can transfer the radical from molecule to molecule causing damage at each encounter. Thus, a cumulative effect can occur, greater than a single ionization or broken bond. The lifetimes of simple free radicals are very short, on the order of 10^{-10} sec. While generally highly reactive, they do not exist long enough to migrate from the site of formation to the cell nucleus. However, the oxygen derived species such as hydroperoxy free radical does not readily recombine into neutral forms. These more stable forms have a lifetime long enough to migrate to the nucleus where serious damage can occur.

Ionizing radiation is a well-established carcinogen due to the resulting oxidative damage (Halliwell, 1991), and the molecule most often reported to be damaged by this physical agent is DNA.

If DNA repair mechanisms, which are induced after exposure to ionizing radiation, are inefficient, the damaged DNA strands that are copied during replication lead to mutagenesis and carcinogenesis (Halliwell, 1991). The damaging effects of ionizing radiation lead to cell death and are associated with an increased risk for numerous genetically determined diseases (Sankaranarayanan, 1999).

Among other indices of DNA damage caused by ionizing radiation are chromosome aberrations and micronuclei formation; these are apparent when irradiated cells are observed microscopically (Vijayalaxmi *et.al* 1995).

Radiation damage can cause the cell to produce a slightly different hormone or enzyme than it was originally designed to produce, still leaving it able to reproduce other cells capable of generating this same altered hormone or enzyme. In time there may be millions of such altered cells. This latter mechanism, called *biological magnification*, can cause some of the chronic diseases and changes we usually associate with old age. One very specific mutation which can occur within the cell is the destruction of cell's mechanism for resting which normally causes it to cease reproductive activities after cell division. This inability to rest results in a runaway proliferation of cells in one place, which, if not destroyed, will form a tumor, either benign or malignant.

If the radiation damage occurs in germ cells, the sperm or the ovum, it can cause defective offspring. The defective offspring will in turn produce defective sperm or ova, and the genetic 'mistake' will be passed on to succeeding generations, reducing their quality of life until the family line terminates in sterilization and/or death.(Muller,1964)

2.11 Tripartite Modes of Radiation Interaction with Bio-Molecules

2.11.1 The Physical processes

Ionizing radiation interacts with matter through either the electron cloud or the nucleus. This is true for both charged particles [alpha and beta particles] and for uncharged radiation [neutrons, gamma and X-rays]. Their modes of interaction, range in matter and penetrating ability differ considerably. However, both the various particles [alpha [α], beta [β] and radiation (gamma [γ], X-rays) and neutrons emitted during nucleus transformation are ionizing in the sense that they can impact enough localized energy of the electrons in atoms and molecules on their path to separate them from the parent atom or molecule.

Charged particles because they are electrically charged, interact continuously with the electrically charged electrons and nuclei in atoms. In the collision with atomic electrons, they impact energy to the atom and excite it to a higher energy state. If the energy of the charged particles is sufficiently high, one or more electrons may be detached from the atom, i.e. the atom is ionized. In every ionization event, a small amount of energy is transferred from the particle to the atom being ionized, so that the energy of the moving particle is decreased. Thus charged particles are said to be directly ionizing.

*Uncharged radiations(neutrons, gamma and x-rays);(i)*are indirectly ionizing.(ii)While x-rays and gamma rays generates fast recoil electrons on their absorption into matter, neutron produces fast recoil protons, alpha particles and heavier nuclear fragments.(iii)They lose energy at discreet locations giving rise to secondary radiations, which subsequently cause excitations and ionizations.(iv)x-ray and gamma ray possess both external and internal radiation hazards.

2.11.2 The Chemical Processes;

Chemical changes produced by radiation in living tissues can be observed from the effect on water molecules since about 75% of any mammalian cell is composed of water .The initial changes produced by radiation on water are the creation of ionized and excited molecules. During this physical stage, H_2O^+, H_20* and sub-excitation electrons are formed in local track regions. This stage is followed by a pre-chemical stage from about 10^{-15} to 10^{-12} seconds, during which the primary species produced by the radiation induce secondary species such as hydronium ions,H_3O^+,hydroxyl radicals, OH, or hydrated electrons, $e^-_{aq.}$

At room temperature, a water molecule can move an average distance of about 1 - 2 ´, in about 10^{-12} seconds. This time lapse after the passage of a charged particle marks the beginning of ordinary diffusion controlled chemical reactions that take place within and around the particle's path.

When radiation reacts with matter in the human body, energy is transferred from the radiation to the medium in small amounts. These transfers occur in very short time and are spatially distributed in a continuous fashion in the medium along the track of the radiation .Within about 10^{-15} seconds, the radiation displaces electrons from

the atoms in the cell and a large number of positive ions and free electrons are formed. Within about 10^{-12} seconds, these positive ions and free electrons react with neutral molecules forming two kinds of extremely dangerous products-free radicals and peroxides. These products are very reactive and attack any molecule in their vicinity. They can move rapidly in the medium a distance from the site of production to cause further chemical changes in the molecules of the medium before they are inactivated in times of the order of 10^{-6} seconds or less. (fig. 2.5)

Within 10^{-6} seconds, the free radicals and peroxides attack, amongst others, the vitally important complex molecules in the cell. They can, for example, attach themselves to a molecule, or cause molecules to break up. The molecules attacked by a free radical can become a free radical itself, thus setting in motion a chain reaction. By these processes, essential molecules are destroyed and rendered function-less or even poisonous to the functioning of the cell. In this way, essential life-functions of the cell may be suppressed and genetic material may be damaged. These physical processes of excitation or ionization which eventually lead to chemical and biological effects in living systems last for a period of about 10^{-15} s.

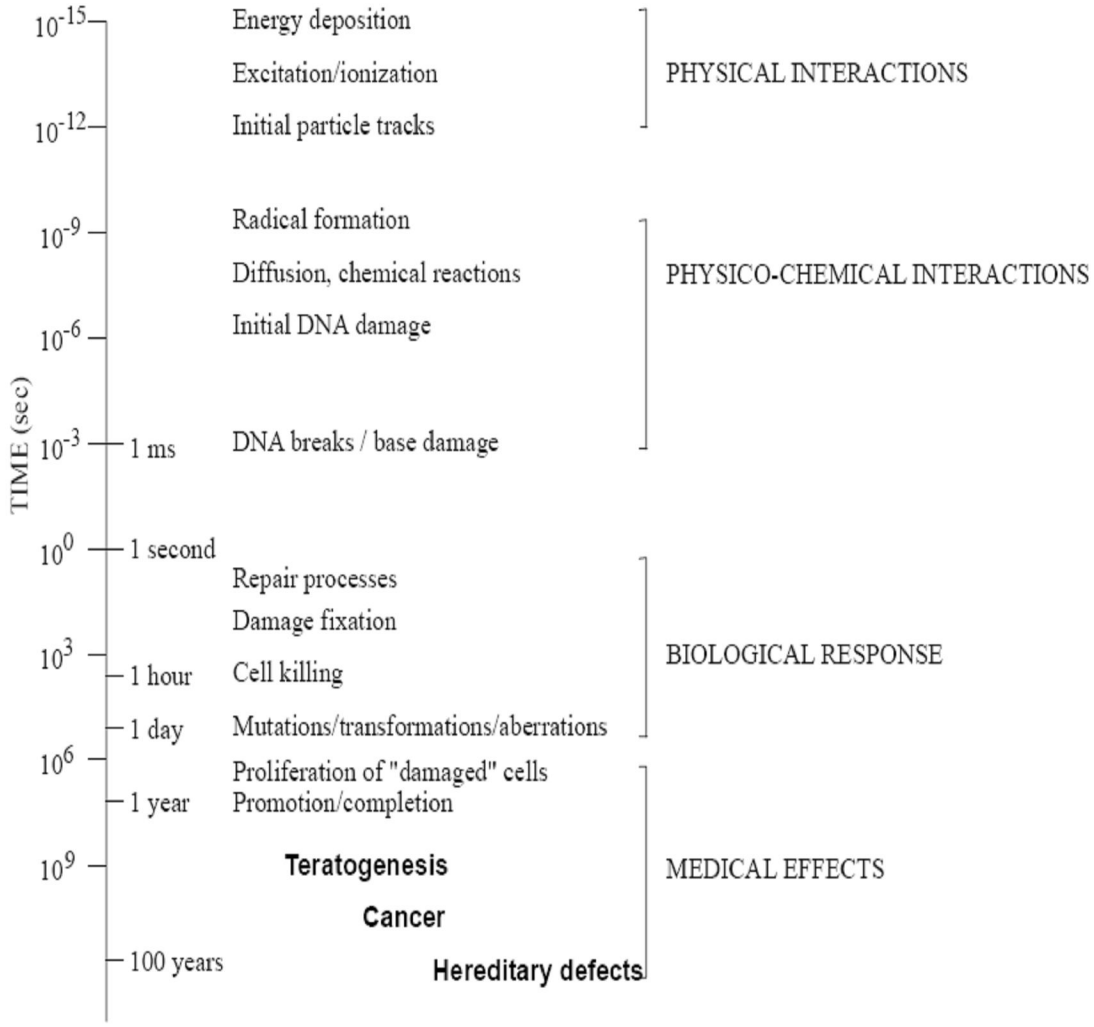


Figure 2.5. ***Scheme of events leading to stochastic radiation effects***.
Source. UNSCEAR, 1993 Annex H

2.11.3. The Biological End-points

Biological effects of ionizing radiation in humans, due to physical and chemical processes, occur immediately following the passage of radiation through living matter. According to UNSCEAR reports, these processes will involve successive changes at the molecular, cellular, tissue and whole organism levels. For acute whole-body exposures above a few gray from radiation of low linear energy transfer (LET), damage occurs principally as a result of cell killing. This can give

rise to organ and tissue damage and, in extreme cases, death. These effects, termed early or deterministic, occur principally above a threshold dose that must be exceeded before they are manifested as clinical damage.[UNSCEAR,1993 ;UNSCEAR,1982].

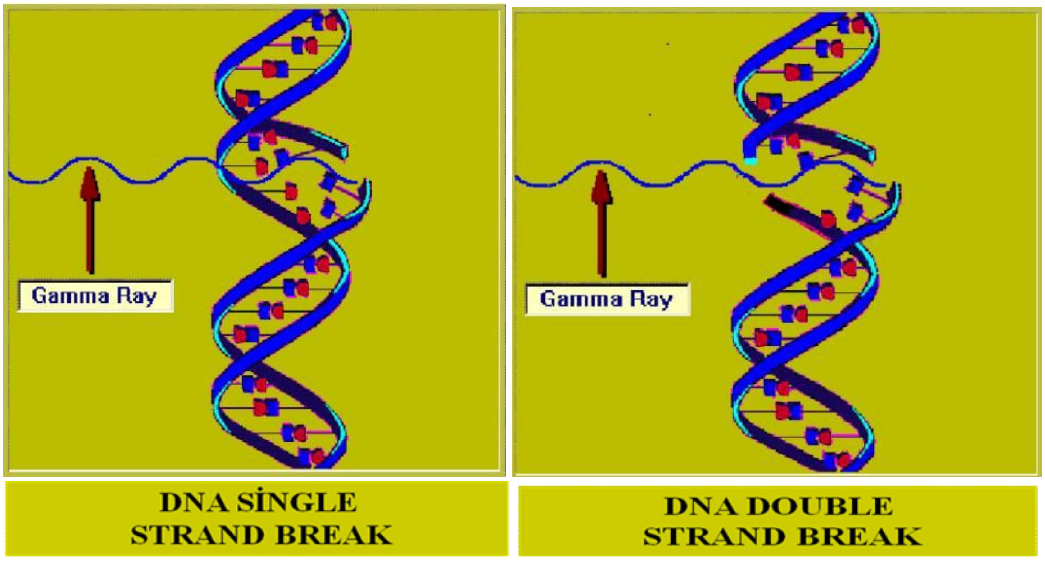
A second type of damage can occur at later times after exposure. This damage consists primarily of damage to the nuclear material in the cell, causing radiation-induced cancer to develop in a proportion of exposed persons or hereditary disease in their descendants. Although the probability of both cancer and hereditary disease increases with radiation dose, it is generally considered that their severity does not. The probability of a radiation-induced cancer or harmful genetic effects is related to the total amount of radiation accumulated by an individual. Based on current scientific evidence, any exposure to radiation can be harmful; however, at very low exposures, the estimated increases in risk are very small. For this reason, cancer rates in populations receiving very low doses of excess radiation (doses of radiation above background) may be similar to the rates for average populations.(EPA,2007)

These second types of damage are termed stochastic effects and were reviewed in the UNSCEAR 1977, 1988, and 1994 Reports [UNSCEAR, 1977; UNSCEAR, 1988; UNSCEAR, 1994]. For the majority of situations in which human beings are exposed to ionizing radiation in the home, in the natural environment, and in many places of work, the principal concern is the consequence of exposure to low doses and low dose rates. For the purposes of radiation protection, the establishment of the expected incidence of cancer or hereditary disease following radiation exposure is presently based on the hypothesis that the frequency of their induction increases

proportionally with radiation dose. A linear, no-threshold dose-response relationship has generally been adopted by national and international bodies for assessing the risks resulting from exposures to low doses of ionizing radiation (ICRP, 1991; UNSCEAR, 1988). This hypothesis implies that the risk of cancer increases (linearly) with increasing exposure and that there is no threshold, i.e. no dose below which there is absolutely no risk. The linear dose-response model suggests that any increase in dose, no matter how small, results in an incremental increase in risk. The linear no-threshold model (LNT) hypothesis is accepted by the Nuclear Regulatory Commission (NRC) and the EPA and its validity have been reaffirmed by a National Academy of Sciences Committee. (UNSCEAR, 1988)

Damage to DNA, which carries the genetic information in chromosomes in the cell nucleus, is considered to be the main initiating event by which radiation damage to cells results in the development of cancer and hereditary disease (UNSCEAR, 1993). Either one or both strands of the DNA helix in cells maybe damaged or broken, resulting in cell death, damage to chromosomes, or mutational events.

Figure 2.6 *Damage to DNA strands*



Source; IAEA-WHO (Module VIII-a),2008

Single-strand damage may be reconstituted rapidly in an error-free fashion by cellular repair processes since the enzyme systems involved will, for all these lesions, have the benefit of the DNA base sequence on the undamaged strand acting as a template on which to recopy the damaged or discontinuous code. Single ionizing tracks of radiation will induce a preponderance of such single-strand damage as a result of energy loss events occurring in close proximity to a single DNA strand in the double helix. A cluster of such events within the diameter of the DNA duplex (about 2 nm) has, however, a finite probability of simultaneously inducing coincident damage to both strands. In support of this, an approximately linear dose response for double-strand break induction by low-LET radiation has been observed (Jenner, *et al*.1993) confirming that breakage of both strands of the duplex maybe achieved by the traversal of a single ionizing track and does not require multiple-track action.

A fraction of radiation-induced double-strand damage will be repaired efficiently and correctly, but error-free repair of all such damage, even after low-dose exposure, is not anticipated. Unlike damage to a single strand of the DNA duplex, a proportion of double-strand lesions will result in the loss of DNA coding from both strands. Such losses are inherently difficult to repair correctly, and it is believed that misrepair of such DNA double-strand lesions is the critical factor underlying the principal hallmarks of stable mutations induced by ionizing radiation of various qualities (Thacker,1992;Thacker,1986). Double-strand DNA losses may in principle be repaired correctly by DNA repair recombination, but such damage may be subject to error-prone repair, which can result in the formation of gene and chromosomal mutations that are known to characterize malignant development (Chadwick, *et.al.* 1994).

2.12 Overview of the analytical set-ups

There are two aspects to radiation detection: counting and spectroscopy. A counter detects the presence of radiation and can be sensitive to individual ionization events. Measuring the rate of events in a counter gives information about the intensity of the radiation. In spectroscopy, it is the energy of the radiation quanta that is of interest. The energy of the x-rays or gamma rays being emitted by a given sample corresponds to the energy level difference in the nuclear transition that was responsible for the emission of those rays.

If a sufficiently distinctive measurement of this energy can be made, it could indicate the presence of a specific isotope in the sample. These functions can be carried out by gamma ray and XRF detectors. A ray must first interact in the

detector before it can be detected. For this particular research work two methods of analysis were implored; the Gamma ray spectrometry and the x-ray fluorescence spectrometry.

2.12 (a) (i) Background on Gamma ray spectrometry Application

The use of gamma spectrometry in the analysis of bulk samples requires that the emitted characteristic gamma rays from the samples be assessed either directly or indirectly to quantify the amount of the particular radionuclide/element of interest. In the use of gamma spectrometry, the gamma spectra from natural (un-irradiated) samples are measured in order to determine the bulk uranium, thorium and potassium content of the sample. For these studies, the measuring device commonly implored is usually Nal(TI) detector.

According to Ibeanu (1999), gamma spectrometry is a widely used analytical technique that has seen many applications in natural environmental studies. The method has been documented to have various advantages such as the cheapness, speed of analysis, relative ease of sample preparations and the simplicity of the procedures of data reduction.

2.12 (a) (ii) Instrumentation

The instruments for measuring gamma radiation convert photon energies into an electrical current. The most widely used instruments are solid state detectors and scintillation counters out of which NaI(Tl) gains very wide acceptance.

In a gamma spectrometer, the characteristic photon energy is measured and used to quantify the different radionuclides. This is done by recording the count rate in distinct energy windows specified for the gamma radiation energy of particular

nuclide. For this work, below is a simplified block diagram of experimental set-up of NaI(Tl) gamma spectrometry used. The detector assembly is enclosed in a 6.0 cm thick of lead shield supported internally by line-ups of cadmium and copper sheets. The lead shield minimizes the effects of background radiation, while the inner sheets absorb the fluorescent x-rays and scattered photons. Figure 3.1 shows a simplified NaI (Tl) detector assembly of the Experimental set-up.

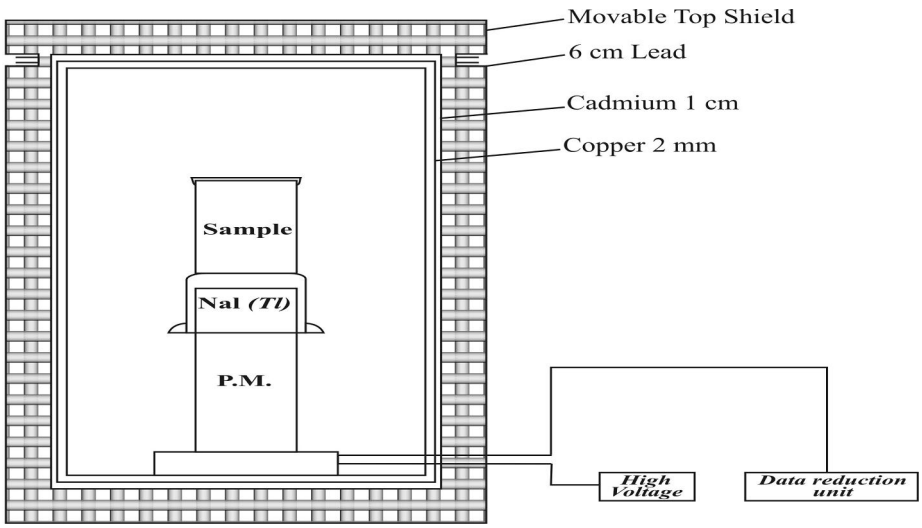


Figure 3.1 A simplified NaI(Tl) detector Assembly of the Experimental set-up.

The assembly consists of a 7.62cm by7.62cm Na(Tl) detector optically coupled to a photomultiplier tube (PMT).The stated set-up is then incorporated with NIM Bin consisting of preamplifier, amplifier and MCA system.

The backbone of the gamma spectrometry is the analysis of one of the physical properties of most radionuclides undergoing decay; emitted gamma rays. As stated by Ibeanu (1999), the principles involved in this method has been described extensively by Adams and Gasparinr(1970) and Durane(1986).The detection of radionuclides by gamma spectrometry depends on the interaction of the photons

with the detecting materials. For efficient conversion of the gamma energies, detector materials with the characteristic of effective absorption of the incident gamma energies (i.e. good scintillation properties) are used. In these materials, the photon energies are converted to lower energy photons, which then undergo further conversion into electrical pulses via a photomultiplier tube (PMT). The intensity of each pulse is proportional to the quantity of the nuclide characterized by the particular gamma energy. The most commonly used scintillation materials are the high density Tl-activated sodium iodide, Nal(Tl).This has the advantage of possessing high atomic number, which increases the probability of interaction. This high probability of photon interaction increases the conversion efficiency of the detector which ultimately results in relatively high photo peak efficiency of the detector.

2.12 (b)(i) Background on X-ray Fluorescence Spectrometry Application

The working principle of XRF involves the excitation of inner shell electron by incident photon in the x-ray region. A source X-ray strikes an inner shell electron. If at high enough (above absorption edge of element), it is ejected from the atom. Higher energy electrons cascade to fill vacancy, giving off characteristic fluorescent X-rays. The energy difference between the two shell levels is given off by the atom in the form of electromagnetic radiation called x-rays. The x-rays spectrum acquired during the above process reveals a number of characteristic peaks. The energy of the peaks leads to the identification of the element present in the analysis- this is the measure of the qualitative analysis. The intensity of the peak gives the elemental concentration referred to as the quantitative analysis.

2.12 (b)*(ii) Instrumentation*

Generally, the voltage determines which elements can be excited. More power results in lower detection limits. Anode selection determines optimal source excitation. Several radiation sources are capable of exciting material to produce x-ray fluorescence suitable for material analysis.

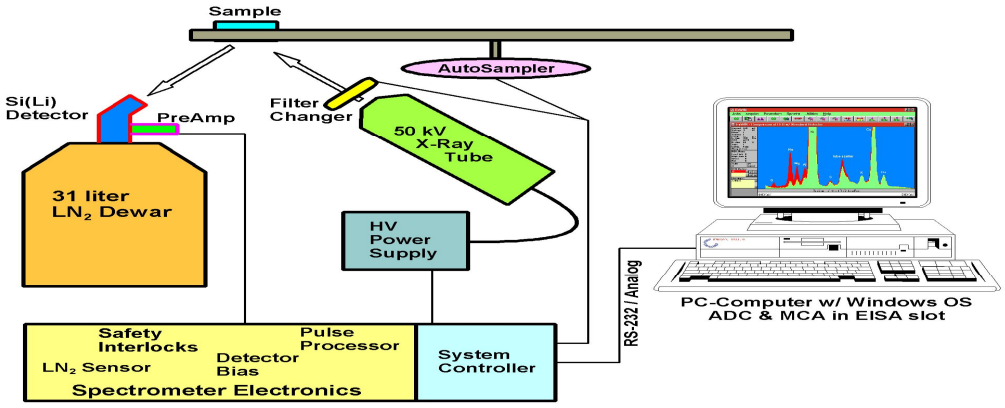


Fig.3.2 Typical XRF arrangement used in the experiment.

2.12 (b)(iii) Procedure for Analysis of samples

Mini Pal is a compact energy dispersive x-ray spectrometer designed for the elemental analysis of a wide range of samples. The system is controlled by a computer running the dedicated Mini pal analytical software.

The Mini pal 4 version in use is PW4030 x-ray spectrometer, which is energy dispersive microprocessor controlled analytical instrument designed for the detection and measurement of elements in a sample (solids, powders and liquids) from sodium to uranium. The sample for analysis is weighed and grounded in an agate mortar and a binder (PVC dissolved in Toluene) is added to the sample, carefully mixed and pressed in a hydraulic press into a pellet.

The pellet is loaded in the sample chamber of the spectrometer and voltage (30kV max.) and a current (1mA max.) is applied to produce the x-rays to excite the sample for a preset time (of 30minutes is this case). The spectrum from the sample is now analyzed to determine the concentration of the elements in the sample.

2.13 Regulatory Guides and Concepts for Exposure

In attempt to set baseline data for the works being undertaken, it is a necessity to highlight major regulatory limits as it affects;

2.13.1 Dose Limits

(i) Occupational exposure

International Atomic Energy Agency (IAEA) specifies dose limits for occupational exposure of any worker not to exceed limits as follows.

(a)An effective dose of 20 mSv per year averaged over five consecutive years.

(b) An effective dose of 50mSv in any single year.

(c) An equivalent dose to the lens of the eye of 150mSv in a year; and

(d)An equivalent dose to the extremities (hand and feet) or the skin of 500mSv in a year.

(ii) Public Exposure

The estimated dose average to relevant critical groups of members of the public shall not exceed an effective dose of 1mSv in a year,

In special circumstances, an effective dose of up to 5 mSv in a single year provided that the average dose over five consecutive years does not exceed 1mSv per year;

An equivalent dose to the lens of the eye of 15mSv in a year;

An equivalent dose to the skin of 50mSv in a year.

2.13.2 Radiological Assessments

SCK and WIV (Gillard et al., 1988) put up absorbed dose rates benchmark resulting from the average values of their spectrometric analyses of the soil samples. The work was collaborated by UNSCEAR leading to Table 2.1

Table 2.1 External exposure rates calculated from the average radionuclide concentrations in soil in Belgium *(and worldwide)*

Primordial Radionuclide	Concentration in soil Bq/kg	Dose coefficient nGy/h / (Bq/kg)	Absorbed dose rate nGy/h
^{40}K	380 *(420)*	0.0417	16 *(18)*
^{226}Ra	26 *(33)*	0.462	12 *(15)*
^{232}Th	27 *(45)*	0.604	16 *(27)*
Total absorbed dose rate outdoors from soil measurements:			= 44 *(60)*

Source; unscear_naturel (2000)

The three components of the external radiation field make approximately equal contributions to the gamma radiation dose.

2.14 Conversion Factors Applied

Concentration of Sample

The concentration of sample are required to determine the activity Gamma ray sample. This is deduced by the relation

Sample Concentration = $\frac{cps\ of\ sample}{CF}$ (Bq/Kg)

Where,

Cps = Counts per second

CF = Calibration Factor

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials and Software.

(a)Hand-held Radiation Detectors

(i)Rados (ii)FH40F2

(b)Analytical systems

(i)Gamma ray Spectrometry system

(ii)X-ray Fluorescence Spectrometry system

(c)Sampling Materials

30cm soil auger

Polythene bags for gangue/overburden, milled and Tailing samples

Topographical map of the study area

Gas mask

Masking Tape

3.2 Field Measurements (Radiation Readings)

The field measurements of terrestrial gamma radiation were based on the assumption that there exists lateral uniform distribution of natural radionuclides in the environment and that the vertical contribution is limited to the horizon (Ibeanu, 1999).Measurements were taken under three broad categories; the mining sites, the milling sites and the sedimentation/panning sites.

Two types of detectors, RADOS and FH40F2, were used to take radiation readings at workers' position in each of the selected mines.. Radiation readings at the entrances of each cave and at some distances into these caves were taken. The two

types of portable survey meters used were constantly reset to give zero reading after each measurement as been taken and recorded to avoid erroneous outputs. For each position, a series of three readings were taken with allowance of about 20 second's time frame interval between each reading for normalization of instrument.

3.3.1 Soil Samplings

(i)Mining Zone

Soil sampling procedure involves the use of an auger. The instrument was used in each of the cases to burrow to a depth of about 20-30cm of chiseled rock materials. Each soil sample collected was emptied into a black polyethylene-sampling bag, tied and labeled. The bags were double-bagged to reduce chances of cross-contamination of samples.

Plate 3.1 *An entrance to one of the young mining caves. This cave is one of which radiation readings and soil samples were taken.*



(ii)*The milling zone*

The dimensions of the sheds on average were about 3m by 3m. Most of this space is swallowed by the milling machine and its accessories, the sacs of crushed rocks for milling as well as sacs of milled materials. Added notable features associated with the sheds are lack of strong partitioning of one shed from the other, and the reduction in visibility due to generated dust from the pulverized radioactive rocks in milling processes.

(iii)Sedimentation/panning Zone

The procedure at the sedimentation zone were similar to the previous cases, from each of the sedimentation units investigated, two samples each, of Tailings were collected from a number of the pile-up bags of Tailings. The consciousness of knowledge of effect of leaching was a guiding factor in the sampling procedure.

3.3.2 Sample preparations

For the two sites, a total number of 57 samples were collected. Each of the soil/tailing samples were crushed to fine powder with the use of a pulverizer. The process was followed by packaging into plastic containers selected based on the space allocation of the detector vessel. A 3-stage sealing system was made for each of the packaging to prevent radon -222 escapes; smearing of the inner rims of each container lid with Vaseline wax, filling the lid assembly gap with candle wax to block the gaps between lid and container, and finally the lid-container was tightly sealed with a masking adhesive tape. The so prepared samples were then stored for a period of about 35 days for attainment of secular equilibrium.

3.4 (a) System Calibration

The calibration of the MCA is important for the generation of platform for finding an expression that relates particle energy to the channel number (particle-energy storage).For this work, the MCA housing a MAESTRO (a version of software analyzer)card was used. The process applied in calibrating the NaI(Tl) detector involved the setting of amplification system steadily and gradually to 900V along with the routine procedure of initializing readings. The calibrating standard sources selected for use were placed inside the detector, one after the other, and counted for a period of 100 seconds. The resulting gamma spectrum of each standard source output were obtained, the centroid of the peak of each energy was determined and their associated uncertainties. These were saved and served as the calibrated benchmark for the measurement.

3.4.(b) Analysis

The standard sources were removed from the detector and replaced in their housing. Samples to be analyzed were then placed, in turn, in the detector. With the use of the calibrated energy, the new centroid energies of required energy peak were determined after a count that lasted for 29000 seconds. The required energy peaks of interest in this observation where of ^{238}U, ^{232}Th and ^{40}K.

The resulting data from the analysis were converted to conventional units by the use of Calibration factors for determination of their activity concentrations. The characteristic photon energy detected was measured and used to quantify different radionuclides.

3.5 Activity determinations

The soil samples were analysed using a 76 × 76 mm NaI(TI) detector crystal (Model No. 802 series, Canberra Inc.) enclosed in a graded 10 cm-thick Canberra lead shield. The detector was coupled to a Canberra Series 10 plus Multichannel Analyser (MCA) (Model No. 1104) through a preamplifier using 5 m connection co-axial cables.

The detector has a resolution (FWHM) of about 8% at energy of 0.662 MeV (137Cs), which is considered adequate to distinguish the gamma ray energies of interest in the present study. The choice of radionuclides to be detected was predicated on the fact that the NaI(Tl) detector used in this study had a modest energy resolution; hence, the photons emitted by them would only be sufficiently discriminated if their emission probability and energy were high enough and the surrounding background continuum was low enough. Therefore, the activity concentration of 214Bi (determined from its 1.760 MeV γ-ray peak) was chosen to provide an estimate of 226Ra (238U) in the samples, while that of the daughter radionuclide 208Tl (determined from its 2.615 MeV γ-ray peak) was chosen as an indicator of 232Th. Potassium-40 was determined by measuring the 1.460 MeV γ-rays emitted during its decay.

With reference to Ibeanu (1999), there are two reknowned ways of achieving spectra analysis for the energy discrimination needed for the qualitative and quantitative analysis of the radionuclides; the integral and the differential spectrometry. The *integral spectrometry* approach involves the recording of the whole spectrum from a predetermined low position that covers the energy peak of

interest. The *differential spectrometry* involves acquisition of information on the energy peaks with an energy window set at about the peak.

In this particular work, differential spectrometry is employed in three channels. The ^{40}k channel which is determined from the 1460keV energy peak, the ^{238}U channel of 1764keV energy peak and the ^{232}Th channel having energy peak of 2614keV.

Table 3.1 Spectral Energy windows used in analysis using NaI (Tl) gamma spectroscopy system

Element analyzed	Isotope Used	-Ray Energy(keV)	Energy windows(keV)
Th	Tl	2614.5	2460-2820
U	Bi	1764.0	1620-1820
K	K	1460.0	1380-1550

3.6 Calibration Factors (CF)

Determination of calibration factors for each of the standard radionuclide implored for the analysis was done by application of the following relations.

$$\text{CF } ^{40}\text{K} = \frac{cps(40_K)}{ppm(40_K)} \text{ or } \frac{cps(40_K)}{Bq((40_K)/Kg}$$

$$\text{CF } ^{226}\text{Ra} = \frac{cps(226_{Ra})}{ppm(226_{Ra})} \text{ or } \frac{cps(226_{Ra})}{Bq((226_{Ra})/Kg} \quad \text{..... Eq. 3.2}$$

$$\text{CF } ^{232}\text{Th} = \frac{cps(232_{Th})}{ppm(232_{Th})} \text{ or } \frac{cps(232_{Th})}{Bq((232_{Th})/Kg}$$

Source;Ibeanu ,1999.

Based on the above, the obtained calibration factors for this work were entered into table 3.1 and subsequently the activities at calibration were used to arrive at current activities of the radioisotopes. For the estimation of concentration of these nuclides in the samples, they were counted and net count per second (cps) obtained with the

same region of interest as set in standards. Then the evaluations of activity concentrations are made thus;

$$^{40}\text{K sample} = \frac{cps(40K)sample}{CF_K} \quad \text{(Bq/Kg)}$$

$$^{226}\text{Ra Sample} = \frac{cps(^{226}Ra)sample}{CF_{Ra}} \quad \text{(Bq/Kg)}$$

$$^{232}\text{Th Sample} = \frac{cps(^{232}Th)sample}{CF_{Th}} \quad \text{(Bq/Kg)}$$

..... Eq. 3.3

The calibration factors (CF), were obtained from the experimental works of Ibeanu (1999) on the same instrument and same set of radionuclides. The resulting table from the stated work on the calibration factor is shown in Table 3.1;

Table 3.2 Energy calibration for Quantitative spectra analysis

Isotope	Calibration Factor		Conversion Factor ($BqKg^{-1}$/ppm)	Detection Limit	
	$X10^{-3}$ cps/ppm	$X\ 10^{-4}$ cps/Bqkg^{-1}		Ppm	Bq/kg
^{40}k	0.026	6.431	0.032	454.54	14.54
^{226}Ra	10.500	8.632	12.200	0.32	3.84
^{232}Th	3.612	8.768	4.120	2.27	9.08

Source: Ibeanu 1999,

CHAPTER FOUR

4.0 Results and Discussion

Introduction

Assessment of radionuclides in soils and rocks in many parts of the world has been on the increase in the past two decades because of their hazard on the health of the populace (Belivermis *et al*., 2009). While the above is the case, the research into natural radionuclide in the soils and rocks of North-western Nigeria is grossly at the lowest ebb. To open focus on this area, a number of radiological indices were measured based on samples from the two mining fields of Awwal and Bagega, the mean values of In-situ readings were obtained and the necessary comparison were made. The result will form baseline data for these regions under investigation and may resonantly open up the un-observed health risks that lurk behind the exercises.

As a measure to ensure that hazard assessments covers an acceptable range, elemental assessment was carried out on the samples collected to identify chemical properties of the elements involved with a view of predicting possible hazards from poisoning/contamination. As a means of giving direction to this work, the results are organized into phases at the end of which comparison were made.

Phase 1: Radiological Assessments

4.1.1 Zone A: AWWAL MINING EXERCISES

4.1.1(a)Radioactivity concentration levels

Radionuclide concentration for the collected surface soil samples indicates the

nature of geological formation for the area studied. Table 4.1 summarizes the specific activity of ^{226}Ra, ^{232} Th, and ^{40} K in the soils in Bq kg.

Table 4.1 SPECIFIC ACTIVITY OF AWWALRADIONUCLIDES

SAMPLE CODE	SAMPLE NUMBER	K - 40(Bq/kg)	Ra - 226(Bq/kg)	Th-232(Bq/kg	TOTAL
C-1, S-1	1	994.70 ± 4.34	43.39 ± 2.71	74.52 ± 0.91	1112.61 ± 7.96
C-1, S-2	2	792.92 ± 1.92	13.54 ± 0.72	15.84 ± 1.54	822.30 ± 4.18
C-2, S-1	3	680.66 ± 11.32	41.77 ± 2.73	18.09 ±1.22	740.52 ± 15.27
C-2, S-2	4	516.90 ±3.83	20.06 ± 0.05	15.99 ± 0.81	552.95 ± 4.69
C-3, S-1	5	1176.96 ±10.08	6.07 ± 0.24	N.D	1183.03 ± 10.32
C-3, S-2	6	768.00 ±0.47	21.78 ± 0.75	16.12 ± 1.06	805.90 ± 2.28
C-4, S-1	7	537.86 ± 4.34	21.90 ± 2.71	7.82 ± 0.68	567.58 ± 7.73
M-1, S-1	8	191.21 ± 2.72	27.41 ± 4.16	9.75 ±1.73	228.37 ± 8.61
M-1,S-2	9	260.86 ± 5.19	44.15 ± 0.12	N.D	305.01 ± 5.31
M-2, S-1	10	154.04 ± 3.79	42.86 ± 12.40	N.D	196.90 ± 16.19
M-2,S-2	11	111.99 ± 3.31	31.28 ± 1.29	3.47 ± 1.57	146.74 ± 6.17
M-3, S-1	12	114.32 ± 21.68	16.54± 2.07	11.09 ± 2.60	141.95 ± 26.35
M-3,S-2	13	255.82 ± 6.42	13.59 ± 0.44	17.77 ± 0.16	287.18 ± 7.02
T-1, S-1	14	322.16±5.08	3.79±2.32	N.D	325.95 ± 7.40
T-1,S-2	15	137.05±2.67	15.78±2.35	N.D	152.83 ± 5.02
T-2, S -1	16	298.8 ± 5.43	19.57±0.21	16.39±1.05	334.76 ± 6.69
T-2, S-2	17	350.12 ± 5.10	18.96±0.74	N.D	369.08 ± 5.84
T-3, S-1	18	N.D	19.25±2.15	N.D	19.25 ± 2.15
T-3, S-2	19	2.89 ± 2.35	31.44±0.03	N.D	34.33 ± 2.38
Mean	-	425.96 ± 5.56	23.85 ± 2.01	18.80 ± 1.21	468.61 ± 8.87
Range	-	2.89 - 1176.96	3.79 - 44.15	3.47 - 74.52	34.33 – 1183.03

KEY

C= MINING CAFÉ,
S= SAMPLE,
M= MILL
T= TAILINGS
N.D=NOT DETECTED

The ^{40}K activity is distinctly higher than the ^{232} Th and it ranges between 2.89 and 1176.96 Bq kg $^{-1}$ with a mean activity of 425.96 ± 5.56 Bq kg $^{-1}$. The ^{232} Th concentration ranges from 3.47 to 74.52 Bq kg $^{-1}$ with a mean activity of 18.80 ± 1.21 Bq kg $^{-1}$. The ^{226}Ra concentration ranges from 3.79 to 44.15 Bq kg $^{-1}$ with a mean activity of 23.85 ± 2.01 Bq kg $^{-1}$.

Fig.4.1 Activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th

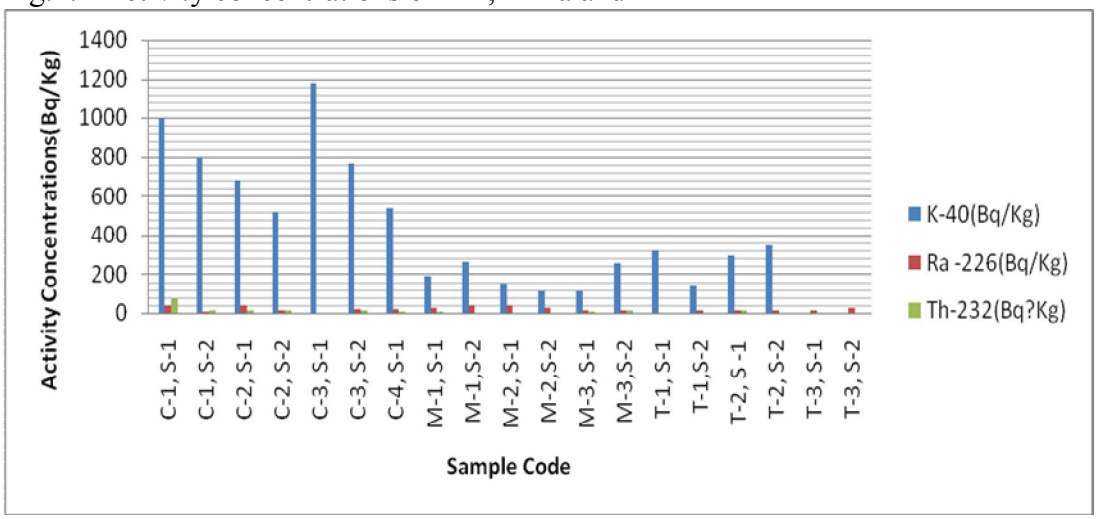


Fig. 4.1 above reveals activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th. It can be observed that activity concentrations of the radionuclide declines with processing stages with thorium suffering the worst of depletion as shown in sample number 5,9,10,14,15,17,18and 19. A particular situation of portions 14 to 19 should be noted to belong to sedimentation zones (T1 to T3). In line with the chemical nature of the radionuclide- thorium; thorium is essentially not soluble in normal surface waters and so its transport is within particulate matter(dust) rather than by solution. With reference to the study site in question, the heavy dust and windy atmosphere at the period of study could have explained thorium transportation. Thorium is usually more abundant in the suspended load than in the bottom sediments (Abbady,2005) resulting in its near absolute zero detection in the product of the sedimentation zone.

4.1.1(b)Air-absorbed dose rate

The absorbed dose rates (*D*) due to gamma radiations in air at 1m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) were calculated based on guidelines provided by UNSCEAR 2000.

Table 4.2 AIR ABSORBED DOSE RATES(AWWAL)

SAMPLE CODE	K-40	Ra-226 (nGy/hr)	Th-232 (nGy/hr)	TOTAL (nGy/hr)
C-1, S-1	41.48 ± 0.18	20.05 ± 1.25	46.28 ± 0.57	107.81 ± 2.00
C-1,S-2	33.06 ± 0.08	6.26 ± 0.33	9.84 ± 0.96	49.16 ± 1.37
C-2, S-1	28.38 ±0.47	19.30 ± 1.26	11.23 ± 0.76	58.91 ± 2.49
C-2,S-2	21.55 ± 0.16	9.27 ± 0.02	9.93 ± 0.50	40.75 ± 0.68
C-3, S-1	49.08 ± 0.42	2.80 ± 0.11	N.D	51.88 ± 0.53
C-3,S-2	32.93 ± 0.20	10.06 ± 0.35	10.01 ± 0.66	52.10 ± 1.21
C-4, S-1	22.43 ± 0.18	10.12± 1.25	4.86 ± 0.42	37.41 ± 1.85
M-1, S-1	7.97 ± 0.11	12.66 ± 1.92	6.05 ± 1.07	26.68 ± 3.10
M-1,S-2	10.88 ± 0.22	20.40 ± 0.05	N.D	31.28 ± 0.27
M-2, S-1	6.42 ± 0.16	19.80 ± 5.73	N.D	26.22 ± 5.89
M-2,S-2	4.67 ± 0.14	14.45 ± 0.60	2.15 ± 0.97	21.27 ± 1.71
M-3, S-1	4.77 ± 0.90	7.64 ± 0.98	6.89 ± 1.61	19.30 ± 3.49
M-3,S-2	10.67 ± 0.27	6.28 ± 0.20	11.04 ± 0.10	27.99 ± 0.57
T-1, S-1	13.43 ± 1.75	1.75 ± 1.07	N.D	15.18 ± 1.28
T-1,S-2	5.71 ± 0.11	7.29 ± 1.09	N.D	13.00 ± 1.20
T-2, S -1	12.46 ± 0.23	2.51 ± 0.10	10.18 ± 0.65	25.15 ± 0.98
T-2,S-2	14.60 ± 0.21	8.76 ± 0.34	N.D	23.36 ± 0.55
T-3, S-1	N.D	8.89 ± 0.99	N.D	8.89 ± 0.99
T-3,S-2	0.12 ± 0.10	14.53 ± 0.01	N.D	14.65 ± 0.11
Mean value	17.81	10.67	11.68	34.26 ±1.59
Range	0.12 - 49.08	1.75- 20.40	2.15 – 46.28	8.89 – 107.81

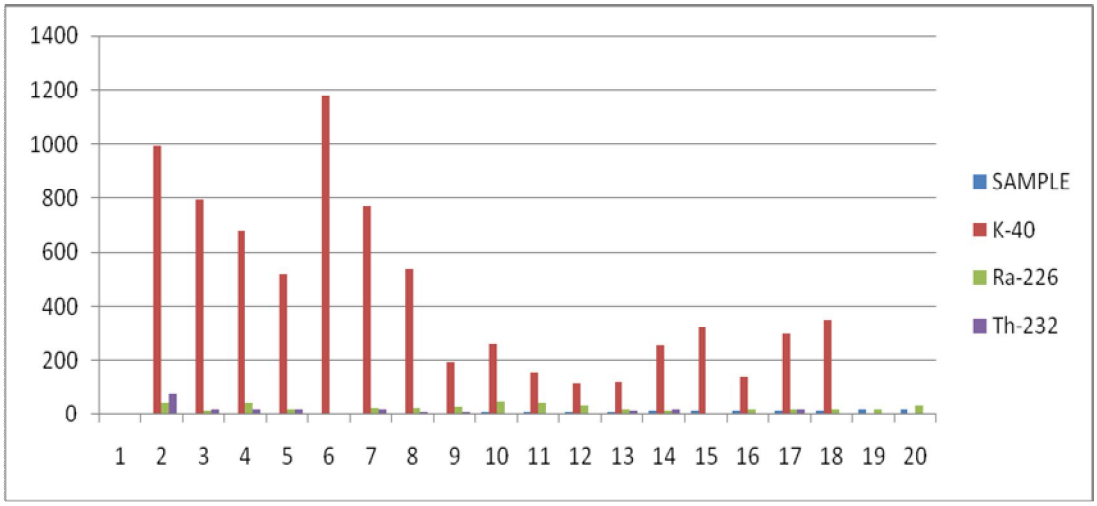
Using these guidelines, it is assumed that the contributions from other naturally occurring radionuclides were insignificant. Therefore, *D* can be calculated according to UNSCEAR 2000, using,

$$D(nGy.h^{-1}) = 0.462\ A_{Ra} + 0.621\ A_{Th} + 0.0417\ A_K \quad \text{..... Eq. 4.1}$$

This zone under study has distinctively a relatively higher concentration of potassium, less thorium and Radium. A rough ratio of their relationship is 21:1:1, which reflects in the soil low radioactivity concentration. Table 4.1 showed a

graphic domination of potassium over the remaining two radionuclides of interest. The low level of radium content do not signify an absolute risk-free from radiation hazard from this radionuclide. The powdered dust, which is very noticeable at the site as seen in the milling, possibly containing radium and likely other related elements, is the most dangerous decay product of uranium due to the gaseous nature of its daughter; radon, whose half-life is 3.8 days. Inhalation of the dust leads to passage of alpha particles emanating from radon into the lungs. The alpha particles induce radiation damage to the lungs.

Fig. 4.2 Absorbed Dose rate in air of ^{40}K, ^{226}Ra and ^{232}Th



Thorium present similar behavioral characteristics to radium by feature of the mining method. Thorium is usually more abundant in the suspended load than in the bottom sediments (Abbady, 2005). A chemical property of Thorium related to its solubility plays important role in the mobility of the radionuclide; thorium is essentially not soluble in normal surface waters and so its transport is within particulate matter rather than by solution. The above observation shows strongly that in this site 1 of the study area, Radium and Thorium go together.

Soils are considered as the weathered products of rock types and the distribution of radioactive elements is immensely affected by processes like weathering and erosion (Mandakini, 2010). The obtained maximum value of concentration of potassium is from one of the slightly deeper mines in comparison to the others. The results obtained from the present study were compared to the world as well as Nigerian average values shown in Table 4 .3.

Table 4.3 Comparison of mean radionuclide concentration in soils of the studied areas with south-western Nigeria and world values

Regions	^{40}K(Bq/kg)	^{226}Ra(Bq/kg)	^{232}Th(Bq/kg)	References
Amman,Jordan	501	56.4	28.8	Ahamad *et. al.*(1997)
Agaba-Amunan, Highway,jordan	208	44.4	36.3	Al-Jundi *et.al.* (2003)
Taiwan	794	54	32.4	Wang *et.al.*(1997)
Rajasthan,India	50.0 - 137.0	30.0 - 78.0	43.0 - 105.0	Nageswara-Rao et.al.(1996)
Istanbul,Turkey	342	210	37	Karahan and Balyukan(2000)
Abeokuta,Nigeria	51.81 - 82.80	4 - 11.5	7.62 - 22.8	Gbadebo(2011)
Awwal, kebbi,Nigeria	425.96	23.85	18.80	The present study
Bagega,Zamfara, Nigeria	370.79	18.32	16.86	The present study
World Average	140.0 - 850.0	17.0 - 60.0	11.0 - 64.0	UNSCEAR 2000, USNRC, Washington(2007)

Comparison of the mean radionuclide concentration levels at the different stages of mining processes shows that the concentration level drops steadily with different stages of the processing in the order of Mine>Mill> sedimentation units. This is represented by the bar chart in fig. 4.1, the mean value of potassium concentration obtained in this experiment is raised generally above the other regions to which it is compared with; however, it is within the world's acceptable limit as given by UNSCEAR(UNSCEAR,2000). Furthermore, the abundance of Potassium can be explained by the fact that potassium is usually the most abundant element in the soil

(Okeyode and Oluseye, 2010). Being a major element in rock-forming minerals, it occurs mainly in alumino silicates such as feldspar and micas. For this particular zone, the very high level of potassium is in line with the very high percentage of silica level in the elemental assessment that accompanies this work (Table 4.12).

4.1.1(c) Mean Effective Dose Rates

To estimate the mean effective dose rates which is sometimes referred to as Outdoor annual effective dose equivalent, the conversion coefficient from absorbed dose in air to effective dose ($0.7 Sv.Gy^{-1}$) and outdoor occupancy factor (0.2) proposed by UNSCEAR 2000 were used. This calculation takes into account that the people spend 20% of their time outdoors. Therefore, the mean effective dose rate ($mSv.yr^{-1}$) was calculated by the following formula:

Mean Effective dose rate ($\mu Sv.y^{-1}$) = Dose rate ($nGy.h^{-1}$) X 24 hours X 365.25 days X 0.2 (occupancy factor) X 0.7 $Sv.Gy^{-1}$ (conversion coefficient) X 10^{-3}

The above gives,

D eff. ($\mu Sv.y^{-1}$) =Dose rate ($nGy.h^{-1}$) X 24h X 365.25 X 0.2 X 0.7 $Sv.Gy^{-1}$ X 10^{-3}

Hence, D eff = Dose rate ($nGy.h^{-1}$) X 1.23h.($Sv.Gy^{-1}$) ……Eq.4.2

According to UNSCEAR (2000) report, the dose rate in air outdoors from terrestrial gamma-rays in normal circumstances is about $60nGyh^{-1}$ while the world-wide average effective dose is approximately 70 μSv**.**

The absorbed dose rate, a relevant quantity when considering radiation risk to humans, at a height of 1 m above the ground surface due to the concentrations of ^{226}Ra, ^{232} Th, and ^{40} K in the soil is estimated using Eq. (4.2) for all the sampling locations and

presented in Table 4.2. The absorbed dose rate estimated from soil for Ilorin, a middle belt region of Nigeria, is 134 nSv/h (Nwakwo and Akoshile, 2005b) and the world average is 56 nSv/h. Site 1(Awwal) of the present survey yielded the average outdoor gamma dose for soil ranged from 8.89 to17.81 nGy h^{-1} with a mean value of 34.26 nGy h^{-1} which agrees well with the global average values. The effective dose in the environment to the population was estimated using Eq. (4.2). The conversion coefficient of 0.7 Sv Gy^{-1} and an occupancy factor of 0.2 are provided according to UNSCEAR reports. The conversion coefficient gives the equivalent human dose in (Sv y^{-1}) from the absorbed dose rate in air (nGy h^{-1}), while the occupancy factor gives the function of the time an individual is exposed to outdoor radiation. In the present study, the effective dose rate ranged between 10.93 and 132.61μSv y^{-1} with a mean value of 42.15 μSv y^{-1} (= 0.042 $mSvy^{-1}$), which is just less than 0.07 mSv y^{-1} given in UNSCEAR 1993 as the worldwide representative value.

Table 4.4 Dose rates and hazard indicies(Awwal)

SAMPLE CODE	AIR ABSORBED DOSE RATES (nGy/hr)	EFFECT.DOSE (μSv.y-1)	Ra_{eq} ($Bq.kg^{-1}$)	H_{ex} (Bq kg–1)	H_{in} (Bq kg–1)
C-1, S-1	107.81 ± 2.00	132.61 ± 2.46	226.62 ± 4.34	0.61	0.73
C-1, S-2	49.16 ± 1.37	60.47 ± 1.69	97.24 ± 3.07	0.26	0.29
C-2, S-1	58.91 ± 2.49	72.46 ± 3.06	120.05 ± 5.34	0.32	0.44
C-2,S-2	40.75 ± 0.68	50.12 ± 0.84	82.73 ± 1.50	0.61	0.28
C-3, S-1	51.88 ± 0.53	63.81 ± 0.65	96.72 ± 1.02	0.31	0.27
C-3, S-2	52.10 ± 1.21	64.08 ± 1.49	103.97 ± 2.31	0.25	0.34
C-4, S-1	37.41 ± 1.85	46.01 ± 2.28	74.5 ± 4.08	0.25	0.26
M-1, S-1	26.68 ± 3.10	32.82 ± 3.81	56.07 ± 6.84	0.15	0.23
M-1, S-2	31.28 ± 0.27	38.47 ± 0.33	64.24 ± 0.52	0.17	0.29
M-2, S-1	26.22 ± 5.89	32.25 ± 7.24	54.72 ± 12.69	0.15	0.26
M-2, S-2	21.27 ± 1.71	26.16 ± 2.10	44.86 ± 3.79	0.11	0.2
M-3, S-1	19.30 ± 3.49	23.74 ± 4.29	41.20 ± 7.46	0.1	0.15
M-3,S-2	27.99 ± 0.57	34.43 ± 0.70	58.70 ± 1.16	0.16	0.19
T-1, S-1	15.18 ± 1.28	18.67 ± 1.57	28.6 ± 2.71	0.08	0.09
T-1,S-2	13.00 ± 1.20	15.99 ± 1.48	26.33 ± 2.76	0.07	0.12
T-2,S -1	25.15 ± 0.98	30.93 ± 1.21	66.11 ± 2.13	0.17	0.23
T-2,S-2	23.36 ± 0.55	28.73 ± 0.68	45.92 ± 1.03	0.12	0.17
T-3, S-1	8.89 ± 0.99	10.93 ± 1.22	19.25 ± 2.15	0.05	0.1
T-3,S-2	14.65 ± 0.11	18.02 ± 0.14	31.66 ± 0.21	0.08	0.17
Mean	34.26± 1.59	42.15± 1.96	70.50±3.42	0.21	0.25
Range	8.89 – 107.81	10.93 – 132.61	19.25 – 226.62	0.05 – 0.61	0.09 – 0.73

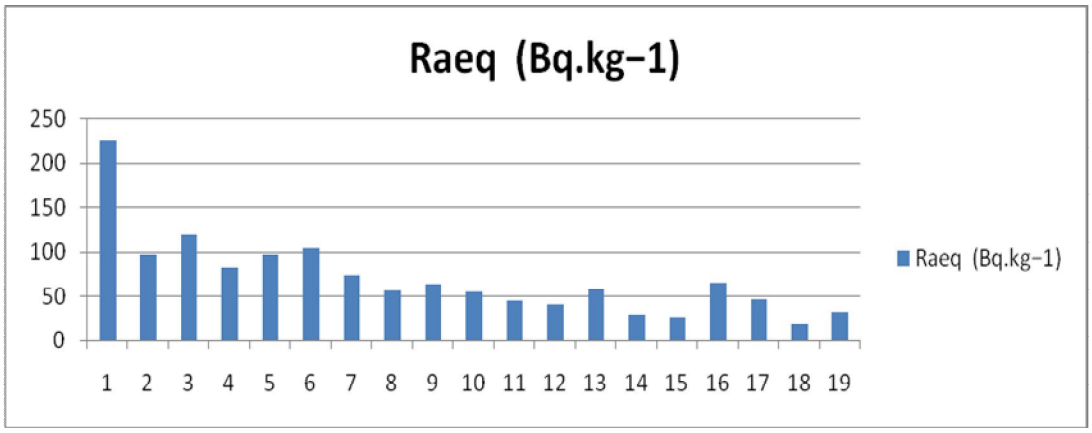
4.1.1(d) Radium equivalent (Ra_{eq}) activity

To compare the specific activities of the samples, the radium equivalent activity (Ra_{eq}) can be used as a common index. The radium equivalent activity takes into account the radiation hazards associated with ^{226}Ra, ^{232}Th and ^{40}K and thus provides a useful guideline in regulating the safety standards on radiation protection for the general public. It is the sum of the weighted activities of ^{226}Ra, ^{232}Th and ^{40}K based on the estimation that 10 Bq kg^{-1} of ^{226}Ra, 7 Bq kg^{-1} of ^{232}Th and 130 Bq kg^{-1} of ^{40}K will deliver an equal or the same gamma dose rate (Tufail *et al.*, 2007; Ademola, 2008a–b; Shiva, *et al.*, 2008). According to Diab (2008), this index is mathematically defined by UNSCEAR, 2000 as:

$$Ra_{eq}\ (Bq.kg^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077\ A_K \quad \text{……...…Eq. 4.3}$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. . The recommended maximum value of radium equivalent is 370 Bq/kg as expressed by Bertka and Mathew (1995). Figure 4.3 below shows the radium equivalent activity in $Bqkg^{-1}$ for various sections in the study area. The mining cafes area shows enrichment of activity, this must have been due to partly enclosed nature of the café resulting in restricted ventilation. Therefore, the radionuclides tend to accumulate in the partly enclosed café and milling sheds resulting in progressive fall depending on the nature of work environment, up till the sedimentation section with the lowest radium equivalent values.

Fig. 4.3 Radium equivalent activity as a function of sample number/location



The result of the radium equivalent as seen is well below 250Bq/Kg; far from the maximum limit of 370Bq/kg set for radiation hazard. The radium equivalent of 370 $Bqkg^{-1}$ corresponds to the dose limit of 1 mSv for the general population. (Jibiril *et.al.*2009)

4.1.1(e) Estimation of radiation hazard indices

The decay of naturally occurring radionuclides (^{226} Ra, ^{232}Th, and ^{40}K) in soil produces a radiation field that transcend the soil-air interface to produce significant

human exposure. External hazard index is a relation that quantifies the exposure factor. According to UNSCEAR, 2000 it is defined as follows:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} = \leq 1$$

According to Jibiril *et.al.(2009)*, the external hazard index is obtained from the expression for the radium equivalent through the supposition that its maximum allowed value corresponds to the upper limit of Ra_{eq} (370 Bq kg^{-1}). The calculated H_{ex} value for the soil/rock samples studied for Awwal site ranged between 0.05 and 0.61 with an average value of 0.21 (Table 4.4). These values are less than unity which is the benchmark for radiation safety against air absorbed doses (UNSCEAR, 2000).

4.1.1(f)Internal hazard index (Hin)

The hazardous effect of radon and its short-lived products to the respiratory organs need be taken into consideration. The internal exposure to radon and its daughter products is quantified by the internal hazard index H_{in}, which is given by the equation

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} = \leq 1$$

The values of the indices (H_{ex}, H_{in}) as stated by UNSCEAR 2000, must each be less than unity for the radiation hazard to be negligible. The resulting calculated H_{in} value for the soil/rock samples studied for the same site ranged between 0.09 and 0.73 with an average value of 0.25 (Table 4.4). Comparing the mean H_{in} value to the mean H_{ex} value it can be inferred that the workers in the enclosures such as the in-cave and the milling shed that lacks good ventilation are potentially at risk. This observation, however do not give the sedimentation zone workers clean bill because other

cumulating risk has been shown by the result of the elemental analysis based on the form and the raised level of crystalline silica identified.

The results obtained from the present work provide a baseline data on the radioactivity levels in the surface soil from the Awwal mining environment. The measured activity concentrations of radionuclides and gamma dose rates are compared with the global and Nigerian average values. Gamma spectrometric analysis of the soil/rock samples indicates that the major activities are due to potassium with thorium and radium contributing insignificant values to it. The high value of potassium is largely due to its being the major constituent of the rock forming minerals as well as due to the high proportion of silica content in the soil of the environment as contained in the elemental analysis that follows. There is a good correlation between thorium and radium in the site, both being at very low proportions.

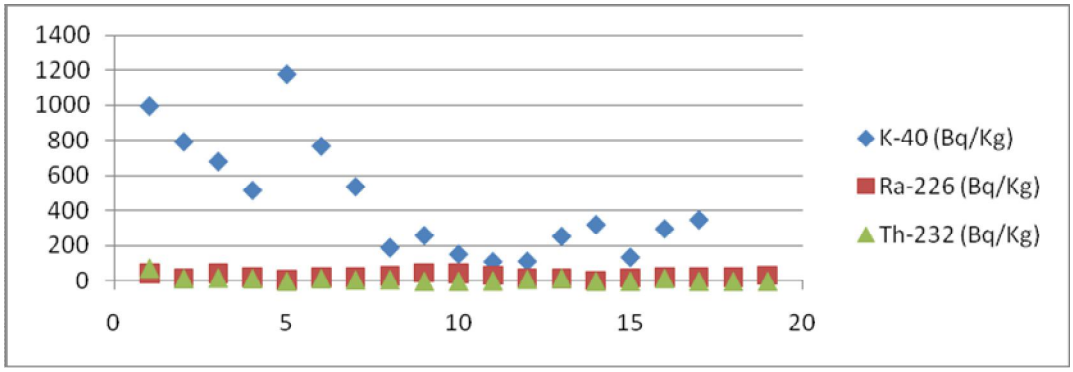
The resulting work also revealed the level of reliability of the hand-held survey meters and the necessity for approaches that will lead to better sense of judgments in their uses in In-situ measurements so as to be able delineate the root cause of degree of errors noted in these works by their usage. The value of the external hazard index determined in the soil is within the recommended levels.

4.1.1(g) Correlation studies

Performance of correlation studies is an important tool for determining the existence of these radionuclides together at a particular location. A very poor correlation is observed between Thorium and Potassium as well as between Radium and Potassium. However a very good correlation exists between radium and

thorium (Fig.4.4). Thus, there exists correlation between thorium and radium but not with potassium in this site.

Fig. 4.4 Scatter plot showing relationship between the radionuclides being studied



An attempt was made to delineate the contribution of individual handheld survey meters (Rados and FH40F2) used in the In-situ dose rate measurements. Table 4.6 shows mean values of In-situ dose rate readings and corresponding calculated effective values.

The effective values of dose rate were obtained from;

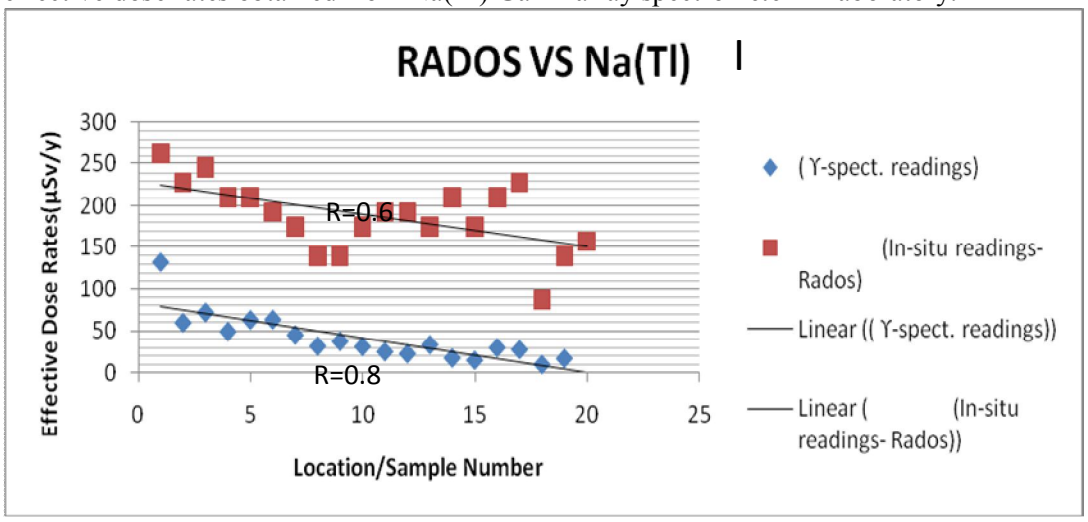
Effective dose rate ($\mu Sv.y^{-1}$) = Dose rate ($\mu Sv/h$) x 24h x 365.25 x 0.2

Table 4.6 Awwal In-situ Dose rates

	DETECTOR 1;RADOS		DETECTOR 2; FH40F2	
Location Code	Averaged Dose rates (µSv/h)	Mean annual Dose rates (µSv/y)	Averaged dose rates (µSv/h)	Mean annual Dose rates (µSv/y)
C1	0.15	262.98	0.25	438.3
C2	0.13	227.92	0.19	333.11
C3	0.14	245.45	0.25	438.3
C4	0.12	210.38	0.17	298.04
E1	0.12	210.38	0.18	315.58
E2	0.11	192.85	0.14	245.45
E3	0.1	175.32	0.15	262.98
E4	0.08	140.26	0.11	192.85
M1	0.08	140.26	0.16	280.51
M2	0.1	175.32	0.14	245.45
M3	0.11	192.85	0.16	280.51
MC1	0.11	192.85	0.17	298.04
MC2	0.1	175.32	0.16	280.51
MC3	0.12	210.38	0.12	298.04
S1	0.1	175.32	0.16	280.51
S2	0.12	210.38	0.14	245.45
S3	0.13	227.92	0.12	210.38
T1	0.05	87.66	0.13	227.92
T2	0.08	140.26	0.12	210.38
T3	0.09	157.79	0.1	175.32
Mean	**0.10**	**180.58**	**0.16**	**277.88**
Range	**0.05 – 0.15**	**87.66 – 262.98**	**0.10 – 0.25**	**175.32 – 438.3**

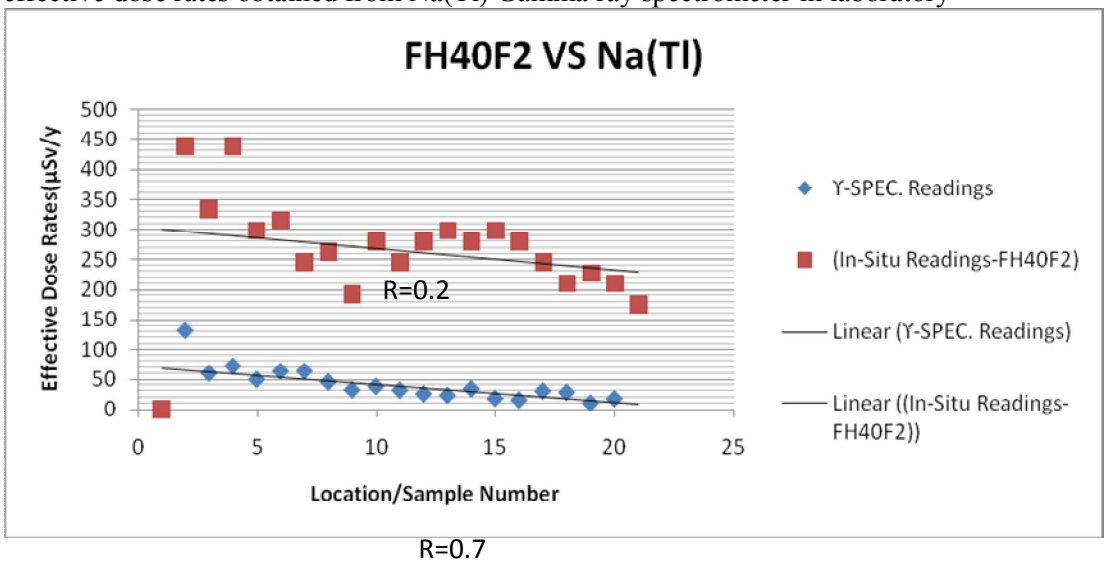
Correlation studies were performed between the In-situ dose rates obtained by the two hand-held survey meters (RADOS and FH40F2) and dose rates reading obtained by gamma spectrometer. The output of RADOS in the In-situ dose rate measurement follow same trend as the sodium Iodide detector set up used to determine the gamma ray emission in the laboratory.

Fig.4.7 Comparisons of effective In-situ dose rates obtained by RADOS to analytical effective dose rates obtained from Na(Tl) Gamma ray spectrometer in laboratory.



There is a good agreement between the two detecting systems, however differences in regression values; the correlation result of NaI(Tl) is R=0.8 implying strong and positive correlation coefficient. The RADOS reading that gives regression value of R= 0.6 implies a weak but positive correlation.

Fig.4.8 Comparison of effective In-situ dose rates obtained by FH40F2 to analytical effective dose rates obtained from Na(Tl) Gamma ray spectrometer in laboratory



R=0.7

The resulting correlation output of the second survey meter is shown in Fig.4.8. It can be seen readily that just as the earlier case, a good trend of similar gradient is observed showing that the gamma ray emission in both cases elicits negative slope indicating that the emission reduces steadily from mining >milling>sedimentation. The weak coefficient can be explained on the bases of possibilities of error in judgments during In-situ readings coupled with the capacity of energy resolution of the detecting material and volume. However, a rather very poor correlation coefficient is obtained from the detector FH40F2. The regression, R= 0.2 indicates that result grossly tend towards *no correlation*. Since the laboratory result and the result of the first detector (RADOS) reveals similar trend but with better correlation in close agreement with each other, it can safely be inferred that either the counting system of FH40F2 has been judged erroneously or the resolution of the detector is poor for low dose rates. The overall output of the two detectors has strongly agreed with the NaI (Tl) output.

4.2.2 Zone B: BAGEGA/SUNKE MINING EXERCISES

4.2.2. (i) Radioactivity concentration levels

Table 4.7 summarizes the specific activity of ^{226}Ra , ^{232} Th, and ^{40} K in the soils in Bq kg. Again, the ^{40}K activity is outstandingly higher than the ^{232} Th with ranges from 94.17 to 775.56 Bq kg $^{-1}$ with a mean activity of 370.79±7.98 Bq kg $^{-1}$. The ^{232} Th concentration ranges from 10.01 to 18.99 Bq kg $^{-1}$ with a mean activity of 16.86 ± 0.94 Bq kg $^{-1}$. The ^{226}Ra concentration ranges from 0.76 to 47.06Bq kg $^{-1}$ with a mean activity of 18.3 ± 1.77 Bq kg $^{-1}$. The study area comes under the brittle fault zone which cuts hornfels that occurs between a granodiorite batholit and

politic metasedimentary rocks of the schist belt.The schist belt is well noted for high concentration of silica that predominantly favours high values of potassium.

Table 4.7 Activity concentrations of Bagega radionuclides

Sample Code	^{40}K(Bq/kg)	^{226}Ra(Bq/kg)	^{232}Th(Bq/kg)	TOTAL
C1S1	518.82±3.06	43.92±0.57	N.D	562.74±3.63
C1S2	94.17±4.99	N.D	N.D	94.17±4.99
C1S3	229.06±4.48	18.27±0.08	N.D	237.33±4.58
C2S1	580.47±6.66	0.76±2.76	N.D	581.23±9.42
C2S2	541.22±4.40	N.D	N.D	541.22±4.40
C3S1	182.32±2.91	29.44±0.44	N.D	211.76±3.35
C3S2	390.67±24.29	25.93±1.09	10.01±1.64	426.61±27.02
C3S2	206.84±4.90	20.64±0.00	N.D	227.48±4.90
C4S1	641.04±7.03	15.58±2.04	N.D	656.62±9.07
C4S2	262.21±3.28	20.46±0.83	N.D	282.67±4.11
C5S1	307.68±57.38	22.49±1.40	N.D	330.17±58.78
C5S2	775.56±8.43	N.D	N.D	775.56±8.49
C5S3	352.98±9.50	17.09±0.96	18.99±0.24	389.06±10.07
C5S1	118.18±3.42	16.33±3.01	N.D	134.51±6.43
C5S2	690.50±7.96	9.77±1.10	N.D	700.27±9.06
E1S1	202.25±5.04	10.46±0.47	N.D	212.71±5.51
E1S2	453.52±3.11	N.D	N.D	453.52±3.11
E2S2	480.07±7.84	18.70±0.00	N.D	498.77±7.84
E3S1	456.26±6.33	17.70±2.04	N.D	473.96±8.37
E3S2	193.75±4.68	27.37±1.01	N.D	221.12±5.69
E4S1	503.17±7.03	17.49±12.62	21.75±1.65	542.41±21.3
E4S2	386.67±5.63	17.70±2.04	N.D	404.37±7.67
E5S1	503.50±7.95	13.10±0.24	N.D	516.6±8.19
E5S2	406.24±3.98	1.16±0.80	16.70±0.24	424.1±5.02
M1S1	178.31±5.21	3.59±0.28	N.D	181.9±5.49
M1S2	314.17±9.87	21.49±0.03	N.D	335.66±9.95
M1S3	910.48±7.09	N.D	N.D	910.48±7.09
M1S4	151.92±6.19	13.83±1.75	N.D	165.75±7.94
M2S1	112.28±7.67	47.06±3.56	N.D	159.34±11.23
M2S3	862.84±6.98	16.14±0.28	N.D	878.98±7.26
MS1	439.37±4.14	15.89±1.12	N.D	455.26±5.26
MS2	656.54±6.87	16.74±0.47	N.D	673.28±7.34
TS1S1	197.12±6.44	26.68±1.96	N.D	223.8±8.4
TS1S3	197.01±5.54	15.58±0.52	N.D	212.58±6.06
TS2S1	171.48±7.66	12.72±0.52	N.D	184.2±8.18
TS2S3	118.18±3.42	16.33±3.01	N.D	134.51±6.43
TS3S1	141.28±13.40	19.27±1.03	N.D	160.55±14.43
TS4S2	161.72±7.84	22.47±3.20	N.D	184.19±11.04
Mean	**370.79±7.98**	**18.33±1.77**	**16.86±0.94**	**394.16**
Range	**94.17- 775.56**	**0.76 – 47.06**	**10.01 – 18.99**	**134.51-910.48**

The radionuclide concentration assessed followed a slightly regular and similar pattern between the mining and milling zones, however the sedimentation zone, which is the site where tailings are located, showed a rather much lower concentration (Fig. 4.9). It can be inferred that the rainfall unset and the geological factor may have influenced the observed fairly regular scenario at the three mining stages of the zone (Bagega).

Fig. 4.9 and 4.10 presents the bar chart outlooks of the specific activities and Dose rates of area under study. It can be seen that an overall dose rates delivered separately by radium and thorium, are far greater than that delivered by potassium in spite of the high activity concentration of the latter. The results obtained from the present study were compared to the world average values shown in Table 4.3.

Fig.4.9 Bar chart of specific activities of the samples

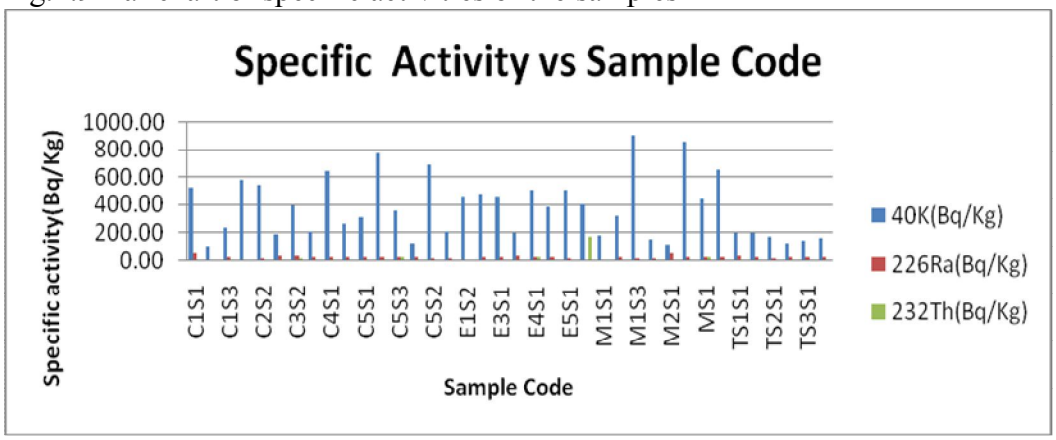


Fig.4.10 Dose rates of ^{40}K, ^{226}Ra and ^{232}Th from Bagega field

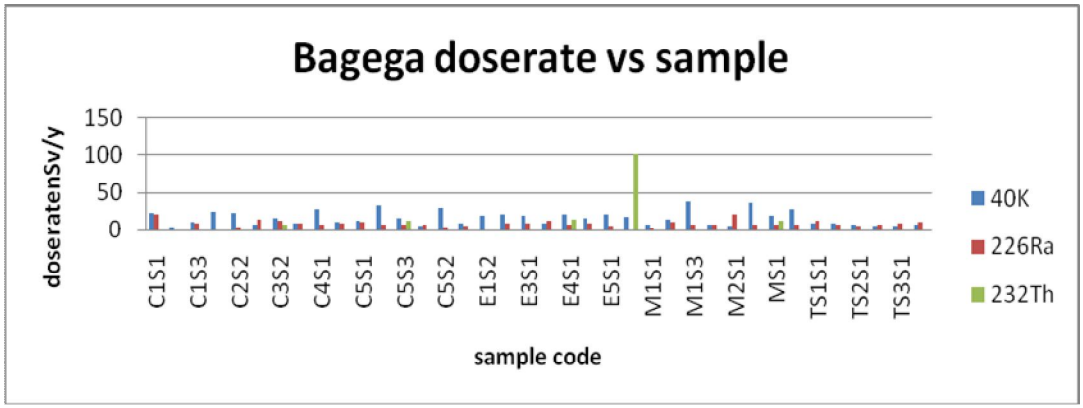


Table 4.8 Bagega Air absorbed Dose rates

Sample Code	BAGEGA DOSERATES(Bq/Kg) ^{40}K	^{238}Ra	^{232}Th	TOTAL
C1S1	21.63±0.13	20.29±0.26	N.D	41.92±0.39
C1S2	3.93±0.21	N.D	N.D	3.93±0.21
C1S3	9.55±0.19	8.44±0.04	N.D	17.99±0.23
C2S1	24.21±0.28	0.35±1.27	N.D	24.56±1.55
C2S2	22.57±0.18	N.D	N.D	26.87±0.18
C3S1	7.60±0.12	13.60±0.20	N.D	21.20±0.32
C3S2	16.29±10.40	11.98±0.50	6.21±1.02	34.48±11.92
C3S2	8.63±0.20	N.D	N.D	18.16±0.20
C4S1	26.73±0.29	7.20±0.94	N.D	33.92±1.23
C4S2	10.93±0.14	9.45±0.39	N.D	20.39±0.53
C5S1	12.83±2.39	10.39±0.65	N.D	23.22±3.04
C5S2	32.34±0.35	N.D	N.D	40.13±0.35
C5S3	14.72±0.40	7.89±0.44	11.79±0.15	34.41±0.99
C5S1	4.93±0.14	7.55±1.39	N.D	12.47±1.53
C5S2	28.79±0.33	4.51±0.51	N.D	33.31±0.84
E1S1	8.43±0.21	4.83±0.22	N.D	13.27±0.43
E1S2	18.91±0.13	N.D	N.D	18.91±0.13
E2S2	20.02±0.33	N.D	N.D	28.66±0.33
E3S1	19.03±0.26	8.18±0.94	N.D	27.20±1.20
E3S2	8.08±0.20	12.65±0.47	N.D	20.73±0.67
E4S1	20.98±0.29	N.D	13.51±1.03	42.57±1.32
E4S2	16.12±0.23	8.18±0.94	N.D	24.30±1.17
E5S1	21.00±0.33	6.05±0.11	N.D	27.05±0.44
E5S2	16.94±-.17	0.54±0.37	102.28±0.15	119.75±0.69
M1S1	7.44±0.22	1.66±0.13	N.D	9.09±0.35
M1S2	13.10±0.41	9.93±0.02	N.D	23.02±0.43
M1S3	37.97±0.30	N.D	N.D	44.67±0.30
M1S4	6.34±0.26	6.39±0.81	N.D	12.73±1.07
M2S1	4.68±0.32	21.74±0.13	N.D	26.42±0.45
M2S3	35.98±0.29	7.46±0.52	N.D	43.43±0.81
MS1	18.32±-.17	7.34±0.22	N.D	38.16±0.39
MS2	27.38±0.29	7.73±0.90	N.D	35.11±1.19
TS1S1	8.22±0.27	12.33±0.24	N.D	20.55±0.51
TS1S3	8.22±0.23	7.20±0.24	N.D	15.41±0.47
TS2S1	7.15±0.32	5.88±1.39	N.D	13.03±1.71
TS2S3	4.93±0.14	7.55±0.48	N.D	12.47±0.62
TS3S1	5.89±0.56	8.90±0.48	N.D	14.79±1.04
TS4S2	6.74±0.33	10.38±1.48	N.D	17.13±1.81
MEAN	**15.46**	**8.38**	**24.38**	**27.25**
Range	**3.93-37.97**	**0.35-21.74**	**6.21-102.28**	

Table 4.9 Bagega Dose rates and Hazard

Sample Code	Doserates(nGy/h)	Effect. Doserates(nSv/y)	Raeq(Bq/kg)	Hex	Hin.
C1S1	41.92±0.39	51.45	158.83	0.43	0.54
C1S2	3.93±0.21	4.82	18.07	0.05	0.06
C1S3	17.99±0.23	22.08	67.84	0.18	0.23
C2S1	24.56±1.55	30.14	112.41	0.30	0.37
C2S2	26.87±0.18	32.97	115.69	0.31	0.39
C3S1	21.20±0.32	26.02	74.72	0.20	0.26
C3S2	34.48±11.92	42.32	127.84	0.35	0.44
C3S2	18.16±0.20	22.29	67.55	0.18	0.23
C4S1	33.92±1.23	41.64	144.03	0.39	0.48
C4S2	20.39±0.53	25.02	77.93	0.21	0.27
C5S1	23.22±3.04	28.50	89.39	0.24	0.30
C5S2	40.13±0.35	49.25	170.27	0.46	0.57
C5S3	34.41±0.99	42.22	124.75	0.34	0.43
C5S1	12.47±1.53	15.31	44.72	0.12	0.15
C5S2	33.31±0.84	40.87	145.68	0.39	0.48
E1S1	13.27±0.43	16.28	52.93	0.14	0.18
E1S2	18.91±0.13	23.21	87.02	0.24	0.28
E2S2	28.66±0.33	35.17	117.36	0.32	0.39
E3S1	27.20±1.20	33.39	111.44	0.30	0.37
E3S2	20.73±0.67	25.44	74.13	0.20	0.26
E4S1	42.57±1.32	52.24	159.04	0.43	0.54
E4S2	24.30±1.17	29.82	98.09	0.26	0.33
E5S1	27.05±0.44	33.20	114.30	0.31	0.38
E5S2	119.75±0.69	146.97	362.57	0.98	1.30
M1S1	9.09±0.35	11.16	39.06	0.11	0.13
M1S2	23.02±0.43	28.26	89.28	0.24	0.30
M1S3	44.67±0.30	54.82	193.17	0.52	0.64
M1S4	12.73±1.07	15.62	47.83	0.13	0.16
M2S1	26.42±0.45	32.43	85.06	0.23	0.30
M2S3	43.43±0.81	53.31	187.34	0.51	0.62
MS1	38.16±0.39	46.83	140.18	0.38	0.48
MS2	35.11±1.19	43.09	148.57	0.40	0.50
TS1S1	20.55±0.51	25.22	73.84	0.20	0.25
TS1S3	15.41±0.47	18.92	58.83	0.16	0.20
TS2S1	13.03±1.71	15.99	50.08	0.14	0.17
TS2S3	12.47±0.62	15.31	44.72	0.12	0.15
TS3S1	14.79±1.04	18.15	53.11	0.14	0.18
TS4S2	17.13±1.81	21.02	61.37	0.17	0.21
Mean	**27.25**	**33.44**	**104.97**	**0.28**	**0.36**
Range.	**3.93-119.75**	**4.82-146.97**	**18.07-362.57**	**0.05-0.98**	**0.06-1.30**

The absorbed dose rate (D, nGy h^{-1}) at a height of 1 m above the ground surface due to the concentrations of ^{226}Ra, ^{232} Th, and ^{40} K in the soil is estimated using Eq. (4.1) for all the sampling locations and presented in Table 4.7. In the present survey the average outdoor gamma dose for soil ranged from 3.93 to119.75 nGy h^{-1} with a mean value of 27.25 nGy h^{-1} which is well below the global average values.

The effective dose in the environment to the population was estimated using Eq. (4.2). The effective dose rates were calculated (Table 4.9), the effective dose rate ranged between 4.82 and 146.97μSv y^{-1} with a mean value of 33.44 μSv y^{-1} (=0.03mSvy^{-1}), which is much less than 0.07 mSv y^{-1} given in UNSCEAR as the worldwide representative value. From a radiological point of view, these values are low and do not imply any significant concerns on the health effects on the local population outdoors, as the values are generally not significantly higher than the world average dose equivalents to individuals from soil (0.30 mSv y^{-1}) (Ademola, 2008).

4.2.2.(ii) Correlation studies

A very poor correlation is observed between individual activity concentrations of ^{226}Ra and ^{40}K as well as between ^{232}Th and ^{40}K.However a good relation is registered between ^{226}Ra and ^{232}Th; both yielding very low specific activities (Fig.4.11

Fig.4.11 Scatter plots of Specific activities of ^{40}K,^{226}Ra and ^{232} Th obtained for Bagega exercises

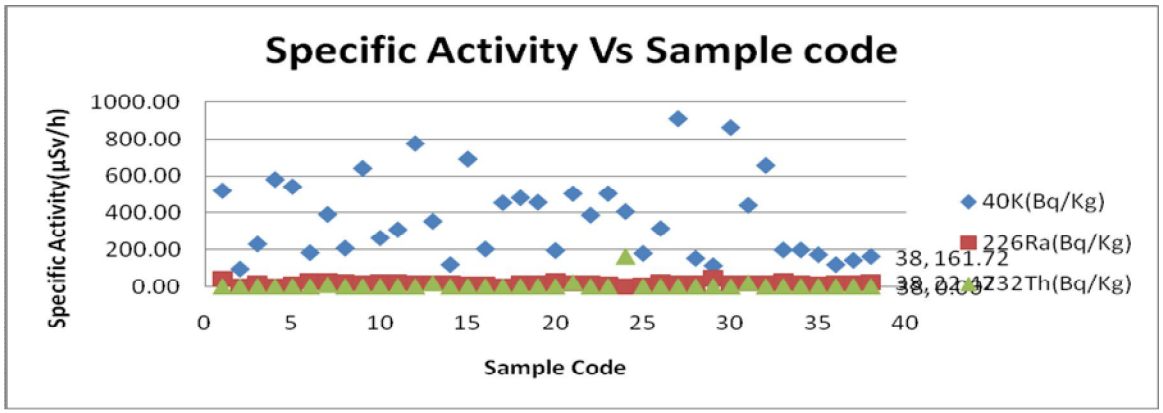


Fig.4.12 Scatter plots of Dose rates of examined radionuclides for Bagega site

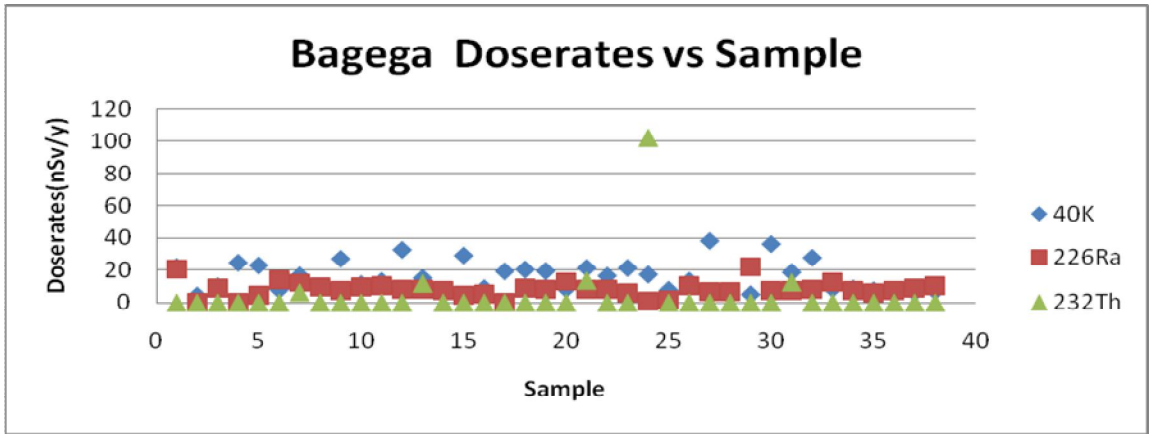


Fig.4.12 reveals that the high activity of potassium seen in Fig.4.11 does not directly translate to corresponding degree of dose rates delivered by potassium is seen to be very low and close to thorium and radium values, however, the generally low values obtained in the regions are comparable to those reported (Jibiril, *et.al*,, 2008) for Lagos city which has similar sedimentary formation as the southeastern and northwestern regions.

These variations and similarities are in agreement with previous studies that terrestrial radioactivity to large extent depends on the local geology and other related factors in the environment (Wollenberg and Smith, 1990).

4.3 Phase 2: Elemental Assessments

Introduction

Mining, not only of heavy metals but also of coal and other minerals, is a major route of exposure of toxic metals. To achieve the objective of this phase; that is determination of level of soil pollution by heavy metals generated by the mining processes in the two sites under study, X-ray fluorescence analysis was carried out on another number of the same set of samples in phase1 and results are entered and discussed as follows.

In making the presentation, the total number of elements analyzed were 31, however, most of these elements occur in the sample at much less than 1% composition. Hence, these elements with this percentage concentration are judged to be at too low level for analytical discussion. The remaining elements that now exist above this value are hereby presented. Special cases of Cu, As and Cd were entered into the tables even though they occur at below the benchmark of 1% composition that has been set in most of the analyzed samples. This is done to show-case their evident absence against the backdrop of their usual outstanding presence in many cases of soil analysis from mining.

4.3.1 Zone A: AWWAL MINING EXERCISES (KEBBI STATE)

From the 31 elements analysed (Ca, K, Fe, Si, S, Al, P, Ti, V, Cr, Mn, Cu, Zn, Rb, Mo, Rh, Ba, Re, O, Pb, W ,Sb, Cl, Zr, As, Ag, Cd, Te, Au, Ta, Ir), only 10 of them were able to meet the minimum 1% composition level (Al, Si, K, Ti, Fe, Cu, Rb, Rh, Pb, As). The most abundant in the mining zone was Si with an average concentration of 24.32 ppm. The highest values of Si occur with sample labeled

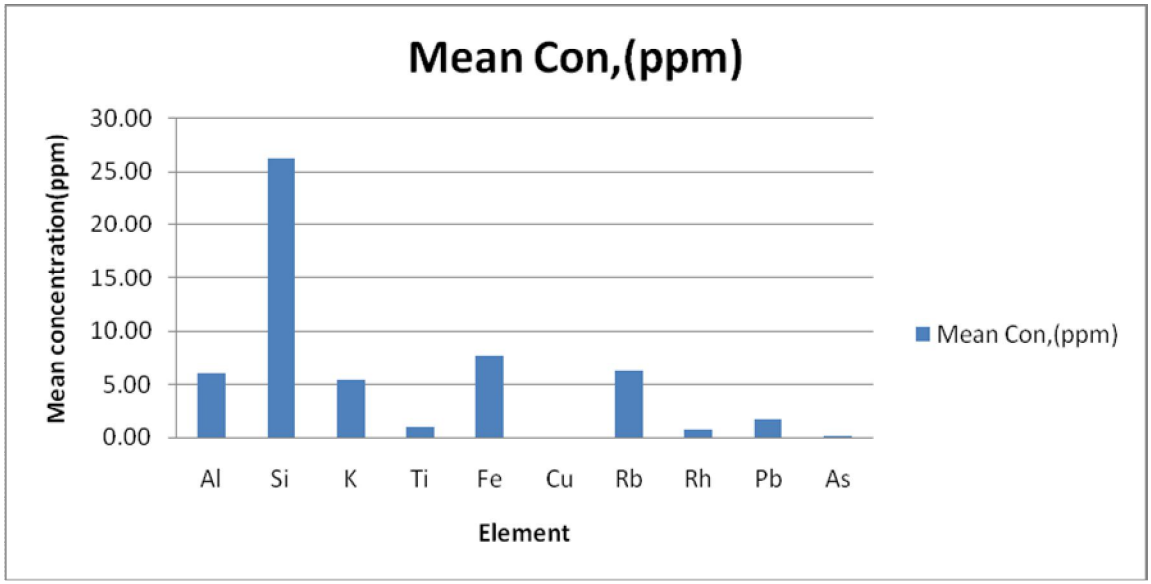
C2S1. This was expected since the schist belt which favours gold mining is predominantly made of crystalline silica that host the overburden.(Fig,4.10).

Table 4.10 Elemental concentration values from Awwal Mine

	AWWAL:KEBBI STATE									
UNIT 1: MINING CAFÉ SAMPLES										
SAMPLE CODE/ELEMENT CONCENTRATION x10^4 ppm)										
ELEMENT	C1S1	C1S2	C2S1	C2S2	C3S1	C3S2	C4S1	**Mean**	**Max.**	**Range**
Al	7.04	6.51	4.39	6.24	6.56	6.30	5.13	**6.02**	**7.04**	**4.39 - 7.04**
Si	17.71	32.14	32.29	27.61	18.96	25.78	29.75	**26.32**	**32.29**	**17.71 - 32.29**
K	7.20	5.10	3.31	4.65	8.55	6.56	2.84	**5.46**	**8.55**	**2.84 - 8.55**
Ti	1.70	0.36	0.53	0.69	1.95	0.93	0.63	**0.97**	**1.95**	**0.53 - 1.95**
Fe	14.65	0.06	6.11	4.33	11.40	5.77	12.25	**7.80**	**14.65**	**0.06 - 14.65**
Cu	0.07	0.03	0.10	0.04	0.06	0.07	0.07	**0.06**	**0.10**	**0.03 - 0.10**
Rb	10.97	N.D	N.D	11.88	11.88	9.14	N.D	**6.27**	**11.88**	**6.27 - 11.88**
Rh	0.71	0.32	0.81	0.38	0.78	1.14	0.97	**0.73**	**1.14**	**0.32 - 1,14**
Pb	2.13	1.11	1.58	1.67	2.13	1.58	2.04	**1.75**	**2.13**	**1.11 - 2.13**
As	0.17	0.07	0.37	0.23	0.21	0.13	0.15	**0.19**	**0.37**	**0.07 - 0.37**

All other elements in this section of mining occur at rather low concentrations compared to silica.

Figure 4.13 Bar chart of elemental concentration in Awwal mine samples

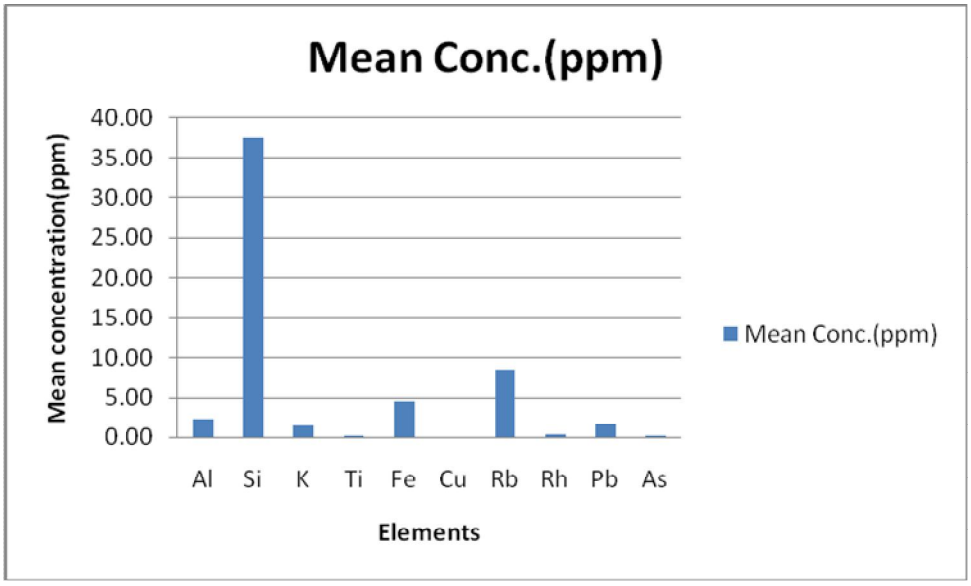


Samples from the milling zone of Awwal presents more aggressive presence of silica with a mean concentration of 37.58mg/kg.

Table 4.11 Elemental concentrations of soil sample from Awwal milling shed

UNIT 2: MILLING SHED SAMPLE									
SAMPLE CODE/ CONCENTRATION x10^4(ppm)									
ELEMENTS	M1S1	M1S2	M2S1	M2S2	M3S1	M3S2	Mean	Max.	Range
Al	2.8	2.8	2.49	2.38	1.32	2.59	2.40	2.8	1.32 - 2.8
Si	39.19	39.28	37.79	35.64	34.38	39.19	37.58	39.28	34.38 - 39.28
K	1.83	1.68	1.49	1.48	0.97	1.47	1.49	1.83	0.97 - 1.83
Ti	0.17	0.17	0.14	0.17	0.2	0.15	0.17	0.2	0.14 - 0.2
Fe	2.77	2.79	5.23	8.21	4.91	3.53	4.57	8.21	2.77 - 8.21
Cu	0.09	0.08	0.09	0.1	0.11	0.04	0.09	0.11	0.04 - 0.11
Rb	N.D	N.D	N.D	N.D	8.59	N.D	8.59	8.59	0 - 8.59
Rh	0.43	0.35	0.32	0.53	0.77	0.28	0.45	0.77	0.28 - 0.77
Pb	0.19	1.86	2.5	2.98	2.5	0.19	1.70	2.98	0.19 - 2.98
As	0.37	0.3	0.36	0.55	0.23	0.07	0.31	0.55	0.07 - 0.55

Figure 4.14 Graphic representation of elemental concentration of samples from the Awwal mills



The maximum value of silica in this zone is 39.28 mg/kg with a resulting range of 34.28 - 39.28mg/kg. The dominance of silica in the two zones so discussed has evidently dwarfed the chances of toxicologically notable considerations of other elements registered for the zone.

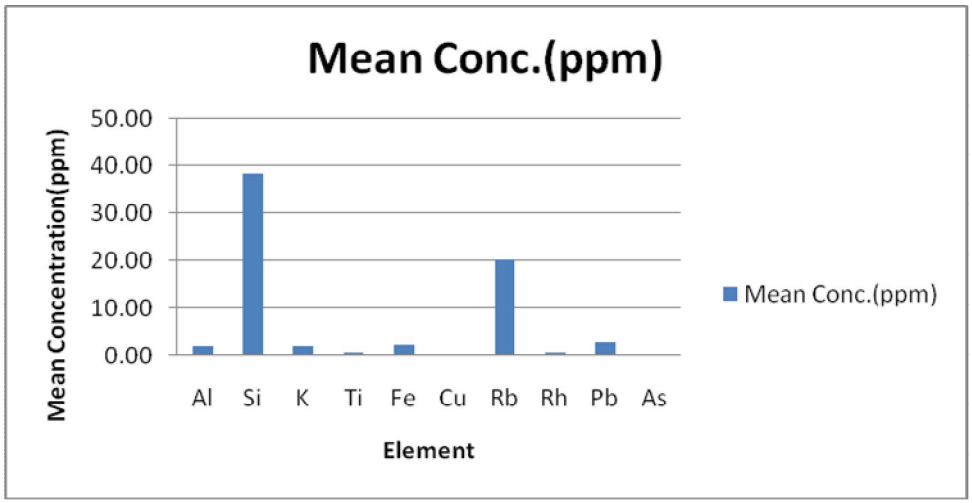
Table 4.12Elemental concentrations of Awwal sedimentation zone samples

	UNIT3: SEDIMENTATION ZONE SAMPLES								
	SAMPLE CODE / CONCENTRATION x10⁴(ppm)								
ELEMENT	T1S1	T1S2	T2S1	T2S2	T3S1	T3S2	**Mean**	**Max.**	**Range**
Al	1.18	1.80	2.38	2.54	2.85	0.53	**1.88**	**2.85**	**0.53 - 2.85**
Si	41.43	42.04	40.12	38.86	40.68	27.28	**38.40**	**42.04**	**27.28 - 42.04**
K	2.16	1.04	2.39	3.34	1.29	N.D	**2.04**	**3.34**	**1.04 - 3.34**
Ti	0.08	0.27	0.50	2.88	0.12	0.09	**0.66**	**2.88**	**0.08 - 2.88**
Fe	1.25	1.61	2.65	2.61	1.90	2.65	**2.11**	**2.65**	**1.25 - 2.65**
Cu	0.05	0.02	0.03	0.06	0.03	0.08	**0.05**	**0.08**	**0.02 - 0.08**
Rb	N.D	N.D	N.D	N.D	N.D	20.11	**20.11**	**20.11**	**0 - 20.11**
Rh	0.97	0.41	0.48	0.81	N.D	0.66	**0.67**	**0.97**	**0.41 - 0.97**
Pb	N.D	0.58	N.D	N.D	1.02	2.69	**2.86**	**2.86**	**1.02 - 2.86**
As	N.D	N.D	N.D	N.D	0.02	0.16	**0.09**	**0.16**	**0.02 - 0.16**

The recurring high concentration of silica recorded in the first two stages of the

Awwal mine so discussed continued in the sedimentation stage with more vigor. A mean value of close-to-all-time-high concentration of 38.40mg/kg was recorded with a maximum value of 42.04 obtained at sample T1S2. All other elements present are in very insignificant level toxicologically, except Rubidium which occur at a concentration of 20.11 mg/kg mean value

Figure 4.15 Chart showing Mean concentration of elements in sediment sample of Awwal site



4.3.2 Preliminary conclusion

The dominant elements in the Awwal mineral composition are Si,Fe, Ru and to some extent Pb. All the elements stated, except Rb, are known to be directly or indirectly connected to radiological problems leading to cancer development in an individual that is exposed. The silica properties are due to be discussed to buttress this observation. On the contrary, Cu, As and Hg that have been well known radiological issues in mining record zero events in this site, even Lead records very little significant presence in the site so discussed.

4.3.3 Zone B: BAGEGA/ SUNKE MINING EXERCISES (ZAMFARA STATE)

The Bagega/sunke mining samples exhibits more competitive concentration among the elements analyzed. Table 4.13 revealed that four elements showed significant concentration right from the first stage of the mining processes: Si, Fe, Rb and Pb.

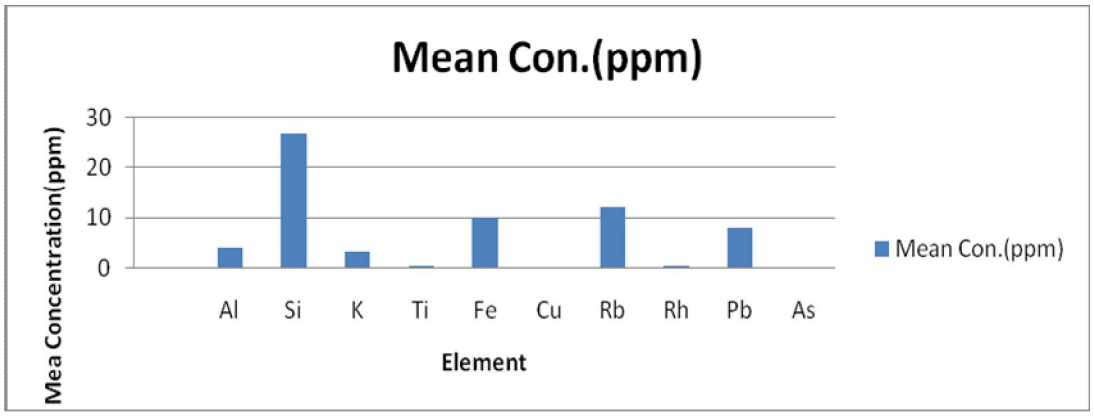
Table 4.13 Elemental concentration obtainable from Bagega mine trench zone

BAGEGA/SUNKE :ZAMFARA STATE													
		UNIT 1:MINING ZONE SAMPLES											
	SAMPLE CODE/ELEMENT CONCENTRATION x10⁴(ppm)												
ELEMENTS	C_2S_2	C_2S_3	C_1S_1G	C_1S_1	C_1S_2	C_3S_1	C_3S_2	C_3S_3	C_3S_4G	C_4S_3	Mean	Max.	Range
Al	5.24	7.41	0.37	5.29	4.13	3.33	2.33	5.82	1.32	6.35	4.16	7.41	0.37 - 7.41
Si	14.95	27.84	33.16	33.68	29.61	33.07	17.28	26.48	23.82	28.82	26.87	33.68	14.95 - 33.68
K	5.54	5.58	N.D	4.21	2.08	1.42	2.49	3.35	0.75	3.69	3.23	5.58	1.42 -5.58
Ti	0.66	0.78	N.D	0.33	0.17	0.32	0.6	0.78	0.05	0.45	0.46	0.78	0.05 - 0.78
Fe	15.58	8.25	7.9	6.3	8.25	5.53	17.47	11.81	8.11	12.79	10.20	17.47	6.3 - 17.47
Cu	0.45	0.27	0.53	0.2	0.83	0.2	0.47	0.34	0.37	0.13	0.38	0.83	0.2 - 0.83
Rb	8.14	N.D	11.88	N.D	N.D	N.D	16.45	N.D	N.D	N.D	12.16	16.45	8.14 - 11.88
Rh	0.16	0.16	0.41	N.D	N.D	N.D	1.78	0.07	N.D	N.D	0.52	1.78	0.16 - 1.78
Pb	11.13	3.52	1.3	1.39	9.93	9.27	4.27	7.61	30.24	1.86	8.05	30.24	1.3 - 30.24
As	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	0.00	0	0

Si exhibits the traditional all-time-high noted for the geological zone with a mean concentration of 26.87 mg/kg .Its maximum value of 33.68 mg/kg was obtained from sample C1S1., while the range of concentration for silica at this zone is between 14.97 and 33.68. Silica has shown repetitively high concentration as seen by the graphic representation on the bar chart in Figure 4.15 Notable at the two mine sites are volumes of dust which ranged in concentration from the mine to the processing units. Due to the lack of respiratory protective devices, the levels of dust should represent the actual personal exposures of these workers. Many factors

probably contribute to the heavy dust exposures, such as drilling and blasting without any water for dust suppression, insufficient ventilation systems and blasting when the miners were evacuated to a relatively short distance away. Thus, the concentration of post-explosion dust was presumably still very high when the miners re-entered the blasting site. International Labor Organization (ILO, 1999), warns that the working conditions in mines by artisanal miners in African countries is likely to place a high prevalence of silicosis in these regions and called for further surveys. The presence of silicosis is reported to increase the risk of developing pulmonary tuberculosis, which is associated with the HIV epidemic in Africa (Cowie, 1994).

Figure 4.16 elemental concentration recorded in mining sample of Bagega mine.



The result of the studies in the area under consideration strongly negates Rollinson assertions that Uranium (consequently radium) and thorium generally increases with silicon during differentiation, fractionalization and partial melting in final stages of magmatic procedures (Rollinson,1993),because strangely enough radium (uranium) and thorium has consistently exhibited very low–near-zero concentration from all measurements in the two fields under study.

Table 4.14 Elemental concentration of samples from Bagega milling zone

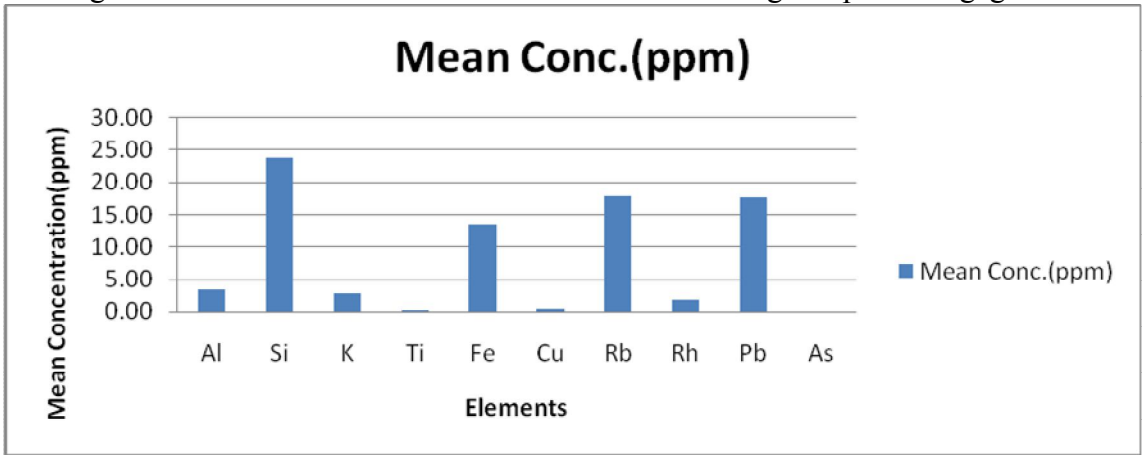
		UNIT 2: THE MILLING SHED SAMPLES									
		CODE/ ELEMENT CONCENTRATION x10⁴(ppm)									
ELEMENTS	M_1S_2	M_1S_3	M_2S_1	M_2S_2	M_2S_3	M_3S_1	M_3S_2	M_3S_3	Mean	Max.	Range
Al	1.32	0.53	0.74	N.D	7.41	6.35	0.95	6.88	3.45	7.41	0.53 - 7.41
Si	25.6	12.61	21.16	26.17	24.76	27.33	23.64	29.33	23.83	29.33	12.61 - 29.33
K	0.73	N.D	N.D	N.D	5.82	3.67	0.2	3.57	2.80	5.82	0.20 - 5.82
Ti	0.1	0.06	0.02	N.D	0.75	0.53	0.04	0.28	0.22	0.75	0.02 - 0.75
Fe	7.54	6.95	5.25	3.78	7.13	14.04	52.17	11.53	13.55	52.17	3.78 - 52.17
Cu	0.49	0.46	0.32	0.81	0.14	0.16	0.53	0.13	0.38	0.81	0.13 - 0.81
Rb	N.D	13.71	N.D	23.77	10.97	N.D	N.D	N.D	17.82	23.77	10.97 - 23.77
Rh	N.D	0.97	N.D	2.59	N.D	N.D	N.D	N.D	1.78	2.59	0.97 - 2.59
Pb	25.05	18.55	38.5	7.24	N.D	2.23	31.26	1.67	17.79	38.5	1.67 - 38.50
As	0.05	0.08	N.D	N.D	N.D	N.D	N.D	N.D	0.07	0.08	0.00 - 0.05

The National Institute for Occupational Safety and Health (NIOSH) recommended exposure limit (REL) for respirable crystalline silica is 50 $\mu g/m^3$ as time-weighted average (TWA) for up to 10 hours/day during a 40-hour workweek [NIOSH 1974b]. This REL is intended to prevent silicosis. However, evidence indicates that crystalline silica is a potential occupational carcinogen [NIOSH 1988a; DHHS 1991], and NIOSH is reviewing the data on carcinogenicity.

Caution is needed when the concentrations of Fe is becoming relatively high, because Fe can lead to the release of other elements (Kabata-Pendias & Pendias 1992, Chen *et al*. 2000). The milling zone is seen from the chart to be having an increase in concentration of Fe when compared to the mining zone with a mean concentration value of 13.55 mg/kg with a max concentration of 52.17 mg/kg recorded with sample M3S2. The range of Fe in the sample is between 3.78 and 52.17 mg/kg.

Rb from the chart is on the increase with mining processes when considering its value in the mining zone, this probably can be related to mobility.

Figure 4.16 Elemental concentration recorded in milling sample of Bagega mine



Lead(Pb) at this milling stage is about reaching threshold level set by some of the regulatory bodies. The Pb mean value is 17.79 mg/kg reaching a maximum concentration of 38.50 mg/kg. The value is already at action level in relation to contamination by children. Children are known to have developing systems that is vulnerable to toxic elements even at low concentrations. The rise in concentration of Pb in milling stage shows that it is present well in the mine but its poor mobility (VROM,2000) did not allow its detection at the stage. Thus the mining activity accelerates its emergence. lead (Pb) results, average and discrete, are below both interim action and trigger levels at this stage for adults but definitely is at crisis point for developing systems of the children who are largely exposed by their hand-to- mouth behaviors, their lower body weight and closeness of their breathing zones to the ground, and thus closer to soil contaminants and low-lying layers in the air.

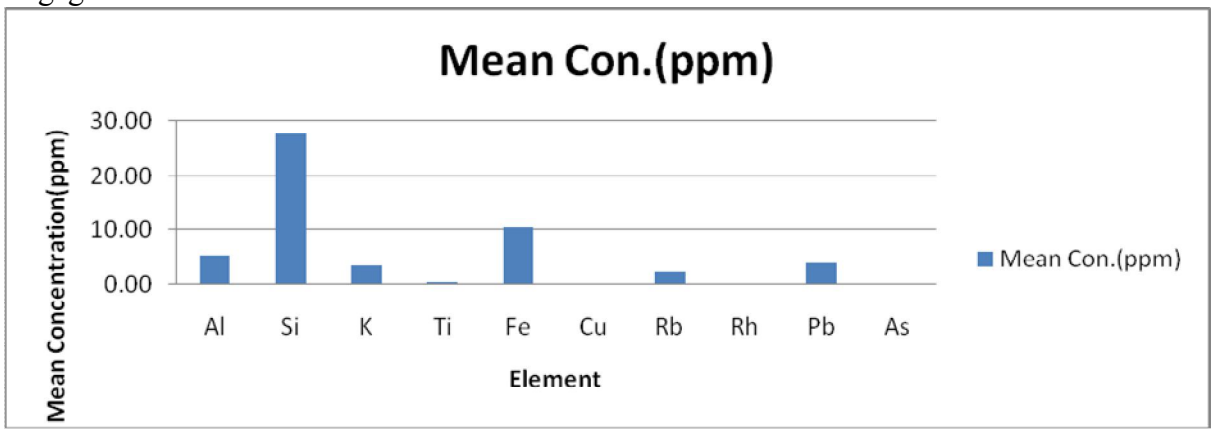
The samples from mine-trench entrances showed high concentration for Si only, the concentrations of the rest of the metals Ti, K, Rh, As, etc., were very low and in some cases below detection limit.

Table 4.15 Elemental concentration of samples from the trench entrance of Bagega mine

BAGEGA/SUNKE UNIT3: ENTRANCE OF MINE- TRENCH SAMPLE											
	SAMPLE CODE/CONCENTRATION x10^4 (ppm)										
ELEMENT	E_1S_1	E_1S_2	E_2S_1	E_2S_2	E_3S_2	E_4S_1	E_4S_2	E_4S_3	**Mean**	**Max.**	**Range**
Al	3.12	7.41	5.82	2.06	1.38	5.82	8.99	8.99	**5.45**	**8.99**	**1.38 - 8.99**
Si	40.59	22.42	23.82	29.43	40.68	18.68	22.33	22.7	**27.58**	**40.68**	**18.64 - 40.68**
K	1.11	5.59	6.67	1.69	0.54	6.51	3.57	3.08	**3.60**	**6.67**	**0.54 - 6.67**
Ti	0,10	1.2	0.37	0.21	0.06	0.51	0.74	0.65	**0.53**	**1.20**	**0.06 - 0.74**
Fe	1.94	14.4	8.53	13.21	4.36	15.79	12.51	12.72	**10.43**	**15.79**	**1.94 - 15.79**
Cu	0.09	0.2	0.22	0.34	0.14	0.18	0.61	0.68	**0.31**	**0.68**	**0.09 - 0.68**
Rb	N.D	N.D	8.6	N.D	N.D	10.97	N.D	N.D	**9.80**	**10.97**	**8.6 - 10.97**
Rh	N.D	2.11	N.D	0.08	0.26	N.D	N.D	N.D	**0.82**	**2.11**	**0.08 - 2.11**
Pb	0.88	N.D	3.99	6.96	1.95	2.6	7.98	8.16	**4.65**	**8.16**	**0.88 - 8.16**
As	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	-	-	-

This could be as a result of leaching of these metals due to the high rainfall of the area and the acidic conditions of the area as result of the high sulphides and pyrites.

Figure 4.18 Bar chart of elemental distribution in samples of the trench-entrance of Bagega mines.



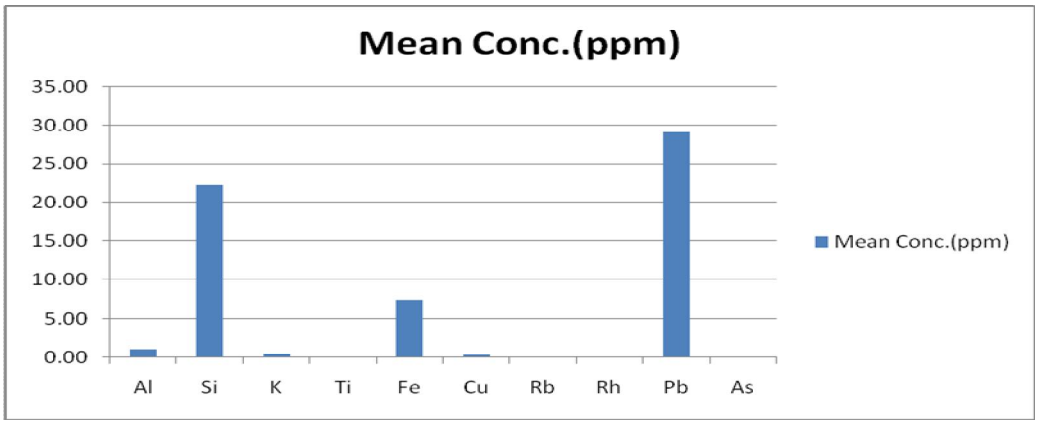
The sedimentation zone strongly reflects the true existence of possible high concentration of Pb in the zone with a sharp rise to a mean value of 29.24 mg/kg with an over-riding effect on Si of mean concentration of 22.26 mg/ kg.

Table 4.16 Elemental distribution from sedimentation zone of Bagega

BAGEGA/SUNKE UNIT4: SEDIMENTATION ZONE											
	SAMPLE CODE/CONCENTRATIONx 10^4(ppm)										
ELEMENT	S_1S_1	S_1S_2	S_1S_3	S_2S_1	S_2S_2	S_2S_3	S_3S_2	S_3S_3	**Mean**	**Max.**	**Range**
Al	0.48	1.59	1.43	1.43	1.01	1.16	1.11	0.95	**1.15**	**1.59**	**0.48 - 1.59**
Si	10.65	31.9	17.38	21.42	15.23	25.27	29.8	26.39	**22.26**	**31.9**	**10.65 - 31.9**
K	N.D	0.56	1.41	0.26	0.56	N.D	0.39	0.58	**0.47**	**1.41**	**0.26 - 1.41**
Ti	0.01	0.12	0.23	0.18	0.13	0.11	0.07	0.05	**0.11**	**0.23**	**0.01 - 0.23**
Fe	5.19	4.97	11.53	8.23	9.78	7.34	6.03	6.42	**7.44**	**11.53**	**4.97 - 11.53**
Cu	0.33	0.25	0.61	0.41	0.58	0.38	0.3	0.42	**0.41**	**0.61**	**0.3 - 0.61**
Rb	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	-	-	.
Rh	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	-	-	-
Pb	57.6	15.77	33.49	24.72	29.69	25.97	19.48	27.18	**29.24**	**57.6**	**19.48 - 57.6**
As	N.D	0.01	N.D	N.D	N.D	0.08	0.06	N.D	**0.05**	**0.08**	**0.01 - 0.08**

The maximum concentrations for these two competing elements were 57.6mg/kg and 31.9 mg/ kg for Pb and Si respectively.

Figure 4.19 Elemental distribution obtainable for sedimentation samples from Bagega mines.



The concentrations of other metals in sedimentation were far lower than for the three ever competing metals: Si, Fe and Pb. The reasons for the low levels of these metals as compared to the major metals could be due to the nature of the soil in the study area as well as heavy rains and low pH values of the area, which could facilitate the leaching of the trace metals. Soils with large surface areas have large adsorption of major cations and on the other hand low adsorption for trace metals such as arsenic and copper. This is because ions have different tendencies to form complexes with different substances. For instance, many cations can form complexes with hydroxyl (OHG) or carboxyl group (COOH) and as a result many metals become easily adsorbed to surfaces of these groups (Asklund and Eldvall, 2005).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Research Summary

5.1.1 Radiological Assessment Summary

Table 5.1 summary of radiological assessments.

S/N	Radiological Indices	Research sites		Benchmarks	References
		Awwal	Bagega		
1	Activity Conc.(Bq/Kg)				
	K-40	425.96	370.79	140.0 - 850.0	UNSCEAR 2000 &USNCR,Washington,2007
	Ra-226	23.85	18.32	17.0 - 60.0	UNSCEAR 2000 &USNCR,Washington,2007
	Th-232	18.8	16.86	11.0 - 64.0	UNSCEAR 2000 &USNCR,Washington,2007
2	Dose Rates(nGy/h)	34.26	27.25	56	UNSCEAR, 1993
3	Effect.Dose Rates(μSv/y)	42.15	33.44	70	UNSCEAR, 1993
4	Ra_{eq}(Bq/Kg)	70.5	104.97	370(Max.)	Bertka and Mathew(1995)
5	H_{ex}(Bq/Kg)	0.21	0.28	<1	UNSCEAR, 2000
6	H_{in}(Bq/Kg)	0.25	0.36	< 1	UNSCEAR 2000

The resulting picture of the radiological events as related to the two mine site are captured in Table 5.1.1 It can be seen at a glance that the specific activities of the radionuclides are all within regulatory benchmarks, Correspondingly dose rates as well as effective dose rates for the two zones studied are all within international benchmarks. Though these values are low, the method of mining , the unprofessional practices and related factors however do make the process to be laden with potential health hazards.

5.2 Elemental Assessment Summary

Table 5.2(a) Percentage composition of mean concentration values of Heavy Metals of interest .

MINING STAGES	PERCENTAGE COMPOSITION OF MEAN VALUES OF HEAVY METALS							
	Pb		Si		Fe		Rb	
	Awwal	Bagega	Awwal	Bagega	Awwal	Bagega	Awwal	Bagega
Mining zone	1.75	8.05	26.32	26.87	7.8	10.2	6.27	12.16
Milling zone	2.98	17.79	39.28	23.83	8.21	13.55	8.59	17.82
Sedimentation zone	2.86	29.24	38.4	22.26	2.11	7.44	20.11	-

Table 5.2(b) Converted values of percentage mean concentration values to parts per million(ppm)

MINING STAGES	PARTS PER MILLION(PPM) COMPOSITION OF MEAN VALUES OF HEAVY METALS CONCENTRATIONS							
	Pb		Si		Fe		Rb	
	Awwal	Bagega	Awwal	Bagega	Awwal	Bagega	Awwal	Bagega
Mining zone	17500	80500	263200	268700	78000	102000	62700	121600
Milling zone	29800	177900	392800	238300	82100	135500	85900	178200
Sedimentation zone	28600	292400	384000	222600	21100	74400	201100	-

Table 5.2 (c) Regulatory limits for comparison to obtained assessed values of Heavy metals in Table 5.2(b)

REGULATORY BODIES	REGULATORY LIMITS						
	Pb		Si	Fe		Rb	
	(mean)	(range)	(mean)	(mean)	(range)	(mean)	(range)
Shacklette & Boerngen(1984)*	19ppm	<10 – 700ppm	-	26000ppm	100 - >100,000ppm	67ppm	<20 – 210ppm
ATSDR Tox. Profiles(2005)*	-	<10 – 30 ug/g soil	-	-	-	-	-
EPA Human Health*	400 ppm	-	-	55,000 ppm	-	N.S.L.	N.S.L.
ACGIH(2004)	-	-	3 µg/m3	-	-	-	-
ISO(1995)	-	-	3 µg/m3	-	-	-	-
NIOSH(1974b)	-	-	5 µg/m3	-	-	-	-
KEY:	N.S.L. = No Screening Level			* = Records updated by March 21, 2008			

There are four competing heavy metals all with concentrations many folds above regulatory limits in the two Gold mine sites under study. Table 5.2(a) shows Percentage composition of mean concentration values of the four competing heavy Metals. The compositions are all shown in parts per million(ppm) in Table 5.2(b) and Table 5.2(c) shows regulatory benchmarks. It can be seen by comparing Tables 5.2(b) and 5.2(c) that almost all the elevated competing metals are in many folds above regulatory benchmarks**.** All, except Rb, have direct contamination/poisoning properties and possible direct or indirect carcinogenic characteristics. Further works need be done to Lead to determine whether it is radioactive type or not to be able to determine the extent of risk that the workers in the mine field of the two sites are

exposed to. Crystalline Silica is indirectly carcinogenic as had been explained earlier with added HIV promoting properties in Africa. Iron may not be directly radioactive or poisonous at ordinary state; however, in its elevated level it essentially stimulates the increase in concentration of other radioactive and toxicologically hazardous element such as arsenic in soil. (Kabata-Pendias & Pendias 1992, Chen *et al*. 2000)..

5.3 Conclusions

Gold mining by the Nigerian History and based on the schist belt in which the majority of Gold vein is found, is considered radiologically safe. This observation is relative to the litho-logical setting of the geological formation. Radiologically, the Awwal values are low and do not imply any significant concerns on the health effects on the local population, it thus form radiological baseline data for Awwal. However, the Bagega measured values are well above the stated world representative values; this implies radiological risks to the exposed population.

The combined two-phase analysis has shown that the geology of a particular location determines the radionuclide concentration and the elemental variations of the location.. Of the four high-concentration-competing metals, two of them present latent and immediate hazards to health; Respiratory crystalline silica (Si), is the major elemental constituent of the ever-well-pronounced mining dusts of the two sites. Its form of occurrence portends irreversible health problem called silicosis and is well linked with cancer forming properties; both of which develops through latency periods. Lead, (Pb), at every concentration portends both immediate and long term hazards with women and children at the greatest risks of exposures.

Consistently high concentrations of respiratory Silica, and up surging Lead in the two sites (especially in Bagega), are dangerous signs of possible risk of exposure to contamination/poisoning by these metals. It can be observed that the artisanal gold mining exercises in the two zones are associated with immediate and long term health risks to the exposed populations. For these sites studied, it is found that in the final analysis, gold mining in the areas are not safe both radiologically and toxicologically going by the artisanal mining method and lack of safety precautions that workers, traders and villagers do exhibit in relation to the exercise.

5.3 Recommendations

In view of the observed events relative to the two zones in terms of variation in behavior of Lead as well as the resultant hazards, further research need be conducted to strongly establish the mobility and solubility strength of the stated element.

Also, since mining has been going on in the zones for years now, the necessity exists for research on Acid mine drainage (AMD) that must have resulted over the length of time and corresponding possible uptake of these metals by crops planted in these areas both during the dry season by irrigation as well as the rainy period, and consequently compare the result to similar output from regions outside the mining zone.

In similar vein, further works need be carried out to study the effects of mining on the wells in neighboring villages to the mining zones.

5.4 Suggestions

Mine workers should be made to take appropriate actions to reduce exposure through the highlighted means stated as follows:

1. **Exposure Monitoring**

   State government or raw materials development units of each state need to ensure that they are up-to-date about mining exercises in their domain so as to move in for proper guidance. This can be done via good linkage and interaction with the mining association of each state. Once this is done, worker exposure surveys should be made by competent industrial hygiene and engineering personnel from ministry of environment or Raw Material research and Development council.. Surveys are necessary to determine the extent of worker exposure and the effectiveness of artisanal working system controls.

2. **Medical Surveillance**

   Preplacement and annual medical examinations should be made available to all workers through efficient link-ups with the workers unions of the artisanal miners. These examinations should include at least:

   a. Comprehensive work and medical histories to evaluate exposure and signs and symptoms of respiratory disease;

b. A 14 x 17 inch posterior-anterior chest radiogram, preferably interpreted using the 1971 ILO U/C classification (1980 ILO classification when available); and

c. Pulmonary function tests including forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV_1), with calculation of the FEV1/FVC ratio.

3. **Work Practices**

Work practices involve both the design of work procedures and the actions of workers. The following work practices are recommended:

a. Work procedures should be developed so they do not produce dust or protected from such dust even if produced;

b. Wear washable or disposable protective clothes at the worksite; shower and change into clean clothes before leaving the worksite to prevent contamination of cars, homes, and other work areas.

c. General housekeeping duties should be intensified so that there is no dust accumulation on surfaces. Such accumulations often contain respirable particles which can become airborne when disturbed. Dustless methods of cleaning such as wetting down should be used. Dry sweeping or blowing with compressed air should be avoided; and

4. **Worker Education**

Worker education is a vital aspect of a good control program. Workers should be informed of the hazardous nature of silica dust and radiation hazards, the results of workplace monitoring and medical tests, and the correct useage and maintenance of respirators.

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