ENSIGN COLLEGE OF PUBLIC HEALTH, KPONG, EASTERN REGION

INDOOR RADON LEVELS AT KPONG IN THE EASTERN REGION OF GHANA

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A thesis report submitted to the faculty of Public health in partial fulfilment of the requirements for the master of public health degree

April, 2017

DECLARATION

I hereby certify that except for reference to other people work, which I have duly cited, this Project submitted to the Department of Community Health, Ensign College of Public Health, Kpong is the result of my own investigation, and has not been presented for any other degree elsewhere.

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DEDICATION

I dedicate this work to the Kitson-Mills Family; my husband Larry Reginald Nii Lantey Kitson-Mills and my daughter Darilyn Call Naa Korshie Kitson-Mills.

ACKNOWLEDGEMENT

To God Almighty thou had been my pillar of strength since I was born. I show gratitude and honour for thou blessings and favours especially during times of difficulties.

When it comes to motivation and ensuring the up-grade of women, no one comes to mind than my husband Larry Kitson–Mills. ‘Laro’ as I affectionately call you I appreciate your continuous encouragement and the motivation you give me to rise through life as a woman. I will not forget your support and patients to ‘mother’ our home while I was away every weekend to pursue this Master’s Program.

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DEFINATION OF TERMS

Reference level

In existing controllable exposure situations, this represents the level of dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimization of protection should be implemented. .

Detector

A device or instrument designed to measure whether radioactive material is present. This can be followed up by using a properly calibrated instrument to estimate how much radioactive material is present.

Background radiation

Background radiation includes radiation from cosmic sources, naturally occurring radioactive materials (including radon), and global fallout (from the testing of nuclear explosive devices).

Effective dose

Radiation exposures to the human body, whether from external or internal sources, can involve all or a portion of the body.

Exposure

Exposure is commonly used to refer to being around a radiation source. By definition, exposure is a measure of the amount of ionizations produced in air by photon radiation

ABSTRACT

Radiation and radioactive isotopes form part of our natural environment. Elevated levels of these radioactive isotopes in the environment can pose a threat to our health. Although it cannot be detected by human senses, radon and its progenies are a public health concern because they can cause lung cancer when inhaled over a period of time. This thesis seeks to provide the life time risk of lung cancer due to inhalation of the measured concentrations and the interpretation of any possible correlations that may exist between the concentration, housing characteristics and altitude

Solid State Nuclear Track Detector (SSNTD, LR-115 type II) was deployed in 82 homes at Kpong for a period of three months (October-December 2016), the detectors were etched in 2.5 M sodium hydroxide (NaOH) solution at (60±1) ºC, for 90 minutes, digitally scanned and counted at the Nuclear Track Detection Laboratory of the National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC).

Indoor radon concentration (IRC) for the town was found to range from 4.05-176.27 (Bqm^{-3}) with mean 57.19±38.9 (Bqm^{-3}). The values 0.12±0.08 ($WLMy^{-1}$), 0.71±0.48 ($mSvy^{-1}$), 0.39±0.26 (%) were the mean; radon exposure, effective dose to the lung and the excess lifetime cancer risk respectively. Generally there was weak correlation between indoor concentration and the selected housing characteristics but not significant (Prob>F=0.20).

The mean IRC at Kpong have been found to be below the recommended limit (100Bqm^{-3}) set by WHO with very low estimated lifetime lung cancer risk hence dwellers are safe as far as risk attributable to radon exposure is concerned.

ABBREVIATIONS/ACRONYMS

ACS	American Cancer Society
ATSDR	Agency for Toxic Substances and Disease Registry
BEIR	Biological Effects of Ionizing Radiation
DT	Absorbed Dose
ELCR	Excess Lifetime Cancer Risk
EPA	Environmental Protection Agency
GAEC	Ghana Atomic Energy Commission
GPS	Global Positioning System
GSS	Ghana Statistical Service
HT	Equivalent Dose
IARC	International Agency for Research on Cancer
ICRC	International Commission of Research on Cancer
ICRP	International Commission on Radiological Protection
IRC	Indoor radon concentration
KOH	Potassium Hydroxide

NaOH	Sodium Hydroxide
NAS	National Academy of Science
NNRI	National Nuclear Research Institute
NRC	National Research Council
NTP	National Toxicology Program
S/E	South Eastern
SSNTD	Solid State Nuclear Track Detector
Sv	Sievert
UNSCEAR	United Nations Scientific Committee on the Effect of Atomic Radiation
WHO	World Health Organisation
WLM	Working Level in Mines
WR	Radiation Weighting Factor
WT	Tissue Weighting Factor

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CHAPTER ONE

INTRODUCTION

1.1 Background Information

Radon is a radioactive gas formed naturally from the continuous breakdown of Uranium. Uranium is found in diverse quantities in soil and rocks worldwide (International Commission on Radiological Protection (ICRP), 1993). According to the ICRP (1993), radon gas is colorless, odorless and tasteless. It is chemically noble but overly dissolvable in polar solvents and water, with a half-life of 3.84 days. Radon produces progenies which get attached to aerosols. These aerosols when inhaled emit alpha particles which damage the basal cells of the lung tissue (American Cancer Society (ACS), 2016).

Radon has been classified as a known human carcinogen according to the International Commission of Research on Cancer. It was originally listed in the Seventh Annual Report on Carcinogens in 1994 (National Toxicology Program (NTP), 2014). Epidemiological studies confirm that radon in homes increases the risk of lung cancer in the general population (Lubin *et al*., 2004; Krewski *et al*., 2006; Darby *et al*., 2006). Other health effects of radon have not consistently been demonstrated but currently it is the second leading cause of lung cancer, next to cigarettes smoking (Environmental Protection Agency (EPA), 2016).

As a gaseous substance, radon easily mobilizes throughout the geosphere, atmosphere, and biosphere (International Agency for Research on Cancer (IARC), 2013). It can be found at higher levels in the air in houses and other buildings (ACS, 2016). Most of the radon exposure to the population occurs indoors where most of our time is spent (Risica, 1998; Hamori *et al*., 2004).

The soil, building materials (sand, rocks, cement, etc.,), tap water, natural energy sources used for cooking such as (gas, coal, etc.,), the topography of the area, house construction type, ventilation rate, atmospheric pressure are the main natural sources of indoor radon. Similarly different housing characteristics such as building type, foundation type, housing type, and construction year have been found to be predictors of indoor radon. The underling bedrock on which a house is built can be a huge predictor of high Indoor Radon Concentrations (IRC) (Demoury *et al*., 2013).

The level of health risk associated with radon is related to the concentration of radon and the time an individual is exposed. According to United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2008), the annual average individual effective dose contributed by radon is 1.15mSv. Meanwhile a study conducted at Dome (Accra) showed a mean annual effective dose with a Radon concentration of (14.13±0.22) mSv and (466.9±1.2)Bq/m^3 respectively (Nsiah-Akoto *et al*., 2011). This is very high and individuals exposed to this dose are at high risk of lung cancer. The American EPA suggests that, the only way to know one's level of radon exposure is to test for it specifically within the home (EPA, 2016).

The first indoor radon tests were conducted between the years of 1975 and 1978 by the US Department of Energy (George, 2015). Since then, worldwide measurements of radon activities in the indoor air of dwellings are continuously presented. In Morocco, a study conducted by Choukri and Hakam (2015) identified radon concentration to vary in houses, between 31 and 136Bq/m^3. Similarly in India, Singh and Kumar (2002) findings were below the recommended indoor radon average of 100Bq/m^3 but the values were in general higher in winter than in summer. Meanwhile in Kassena-Nankana Area of the Upper East Region of Ghana the IRC ranged from 35.28-244.22Bq/m^3 (Quashie, 2009). Comparably the range was higher at Dome (Accra) from 278.09-740.12Bq/m^3 (Nsiah-Akoto *et al*., 2011).

Many countries have defined an Action Level of radon concentration to guide their program to control domestic exposure to radon (table 1) (World Health Organization (WHO, 2004). The Action Level is not a boundary between safe and unsafe, but rather a level at which action on remediation will usually be justified.

Table 1.1: Domestic radon concentrations and Action Levels in some selected countries

Country	Average radon concentration in homes (Bq/m^3)	Action Level (Bq/m^3)
United Kingdom	20	200
USA	46	150
Germany	50	250
Ireland	60	200
Lithuania	37	100

Source: (WHO, 2004)

Currently Ghana lacks a national average on radon concentration in homes. This is due to the fact that studies conducted are not enough to estimate a national average hence the need for more indoor radon studies. Though some attempts have been made to study radon exposure in households, unfortunately these studies have not caught the attention of the ordinary Ghanaian and relevant authorities the way it was expected. For that matter awareness of radon in the country is low. This is the situation in most African countries (Afolabi *et al*., 2015).

Unlike Ghana, the United States of America use different approaches such as webinars, public fora, and social media outlets to raise awareness at a national level (Cheng, 2016). The Agency for Toxic Substances and Disease Registry (ATSDR) has partnered with many different states to raise awareness nationally through the education system (Foster, *et al.*, 2015). These are done in attempt to increase household radon measurements.

The main measurement requirements for large radon surveys depend on the following: (i) sampling periods of 3 to 12 months, (ii) low cost, and (iii) low impact, i.e. small size of the measuring device. Passive measuring device such as the Solid State Nuclear Track Detector (SSNTD) fulfill these requirements (IAEA, 2013). In this work, the technique of SSNTD (LL II5, Type II) was utilized in assessing the indoor radon levels at kpong in the Lower Manya Krobo Municipality. From literature, most of the indoor radon tests deployed the use of SSNTDs. Such studies include ((Nsiah-Akoto *et al*., 2011, Singh and Kumar, 2012, Choukri and Hakam, 2015, Nita et al 2013… etc).

1.2 Problem statement

Globally, indoor radon exposure is estimated to cause 22,000 deaths annually (WHO, 2015). The USA-EPA quantifies the extent of death caused by radon per year to be more than that caused by drank driving, falls in the home, drowning, or home fires (EPA, 2012).

Considering the public health implication of radon exposure, the WHO released a comprehensive global initiative on radon that recommended a reference level of $100Bq/m^3$ and should not exceed $300Bq/m^3$ for indoor radon. This is because, according to ICRP, $300Bq/m^3$ of radon produces an effective dose of about 10 mSv per year, which is the maximum annual effective dose the public is supposed to receive. The WHO has therefore urged all member states to strengthen indoor radon measurement and also establish a national reference level (WHO, 2009).

Regions such as Western, Central, Greater Accra and Ashanti have experienced some research work (Badoe *et al,* 2012). However, the work done was not enough to arrive at a national average and also to zone potential hazard areas. Again regions such as Eastern, Volta and the Northern parts of Ghana have no or very few study done. It could be identified that the IRC levels in some of the areas of the country were high, above WHO reference level of 100Bqm^{-3} (Table 1.2). These high measurements according to those studies were probably due to the building characteristics, altitude, and lifestyle of the dwellers…etc.

Kpong is a town surrounded by range of mountains constituting rocks such as quartzite, shale and sandstone (Amponsah, 2002). Buildings are at varying elevations, comprising of both old and modern houses (GSS, 2010). These characteristics are a good source of high IRC hence this work seeks to identify if Kpong has IRC that can have effects on the health of inhabitants in order to provide the necessary remediation method.

Table 1.2: Indoor Radon Levels in some studied areas in Ghana

Area (year)	Number of Houses	Average Concentration (Bq/m^3)	Range (Bq/m^3)
Dome (1989)	26	91.8	5.2 - 336.4
Kwabenya	20	9.4	5.0 -34
Biakpa	14	80.4	31 – 194
South Eastern(S/E) part of Ghana	20	518.7	169.3 - 2047.7
Prestea	39	118.9	0.4 -909.1
Kassenna- Nakana	45	132.7	35.3 -244.2
Aburi (2014)	30	49.78	19.07 -124.36

Source: (Yeboah, 2014)

1.3 Significance of study

The knowledge obtained from this study will contribute to our understanding on Radon levels in Kpong Township. Using the available testing data along with feedback from surveys of residents, it may be possible to appropriately focus future educational campaigns in areas that can make the most impact.

In addition this research will provide essential radiological information and baseline value of indoor radon in the area to contribute to the national radon level database. This can be useful for relevant authorities (policy makers, regulatory bodies and construction firms) in the development and implementation of radiation protection guidelines and standards for the populace in the country. This study will also engender interest for further research into radon in other homes or areas (work place, schools, restaurants etc.) in all the regions of the country.

1.4 Hypothesis

There is relationship between indoor radon concentration and housing characteristics at Kpong.

H_o: There is no relationship between indoor radon concentration and housing characteristics at Kpong.

$H_{A:}$ There is a relationship between indoor radon concentration and housing characteristics at Kpong.

1.5 Research questions

- What is the level of indoor radon concentration at Kpong?
- How much of this radioactive gas are the inhabitants exposed to?
- Of these exposures, what are the percentages of lung cancer risk to the inhabitants?
- And are there any patterns in the radon distribution levels in the community?

1.6 Goal

The goal of this study is to increase global database of residential radon exposure at the national level in line with the World Health Organization International Radon Project towards reducing the risk of lung cancer attributable to radon exposure.

1.7 General Objective

The study aims to measure indoor radon concentrations levels at Kpong in the Eastern Region of Ghana to assess the lung cancer risk attributable to radon exposure and determine radon concentration patterns to help provide the necessary remediation strategies.

1.8 Specific objectives

- To measure indoor radon concentration levels.
- To determine radon exposure and consequent lifetime lung cancer risk.
- To identify if there is correlation between radon levels and housing characteristics.
- To create spatial radon concentration distribution map for the study area.

1.9 Profile of study area

Kpong is one of the towns situated in the Lower Manya Krobo Municipality. The Municipality is strategically located at the eastern corner of the Eastern Region of Ghana which lies between latitude 6.05N and longitude 0.20W with an altitude of 457.5m above sea level (Ghana Statistical Service (GSS), 2010).

With a household population of 87,649 the Lower Manya Krobo Municipality has an average household size of four persons per households. The main construction material for outer walls of dwelling units in the Municipality is cement blocks/concrete accounting for 69.7% with mud bricks/earth constituting 25.9% of outer walls of dwelling units. Cement (86.8%) and mud/earth

(10.1%) are the two main materials used in the construction of floors of dwelling units in the district (GSS, 2010).

Lower Manya Krobo Municipality lies within the semi-equatorial climate belt with a mean annual rainfall ranging between 900mm to 11,500 mm. Relative humidity is high during the wet season and low in the dry season. The Municipality experiences two major seasons; wet (from April to October) and dry (from November to March) seasons. Temperatures are generally high, ranging between 26^{o}C and 35^{o}C (GSS, 2010).

The main bedrock is the Togo Formations (schists, quartzite and phyllites, unaltered shale and sandstone) forming the Akwapim range of hills trending northeast from the coast West of Accra through Kpong, Aburi, Anum into the Republic of Togo (Amponsah, 2002).

The Municipality falls under the influence of two wind systems: the southwest monsoon winds which blow from the Atlantic Ocean between March and July and the northeast trade winds (harmattan) from the Sahara Desert between November and early March (GSS, 2010).

Map 1.1: Kpong and its environs

Source: (GSS, 2010)

1.10 Scope of Study

The work is intended to cover measurement of only indoor radon levels in selected households in Kpong Township using SSNTD for a period of three months.

To enhance comparisons and contrast, households were sampled from different communities.

1.11 Organization of Report

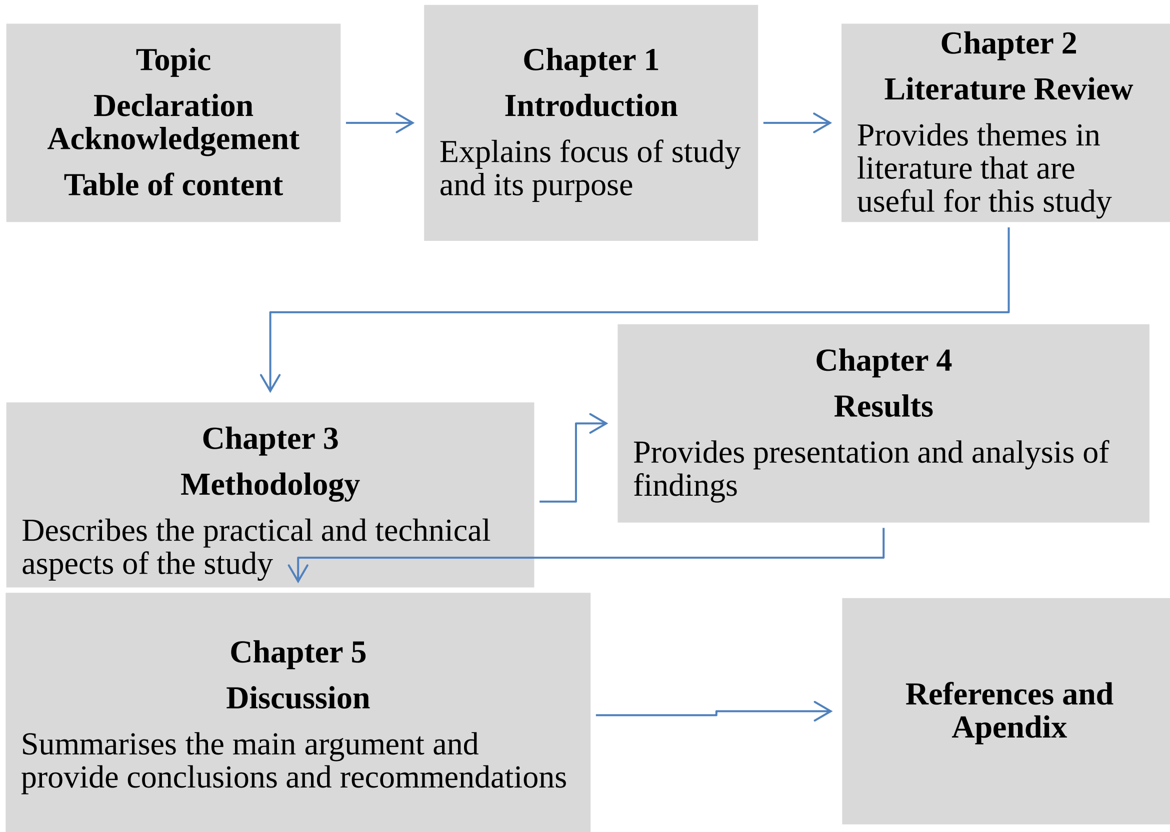


Fig. 1.1 Chart-flow of structure of the thesis report

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This section provides a review on works done by other professional researchers on indoor radon and other media. Some important facts about indoor radon, contribution of Radon (Ra^{222}) to health as well as assessment of health risk have been presented. Methods and tools for the measurement of radon concentration and remediation strategies have also been addressed.

2.1.1 Methodology on literature search

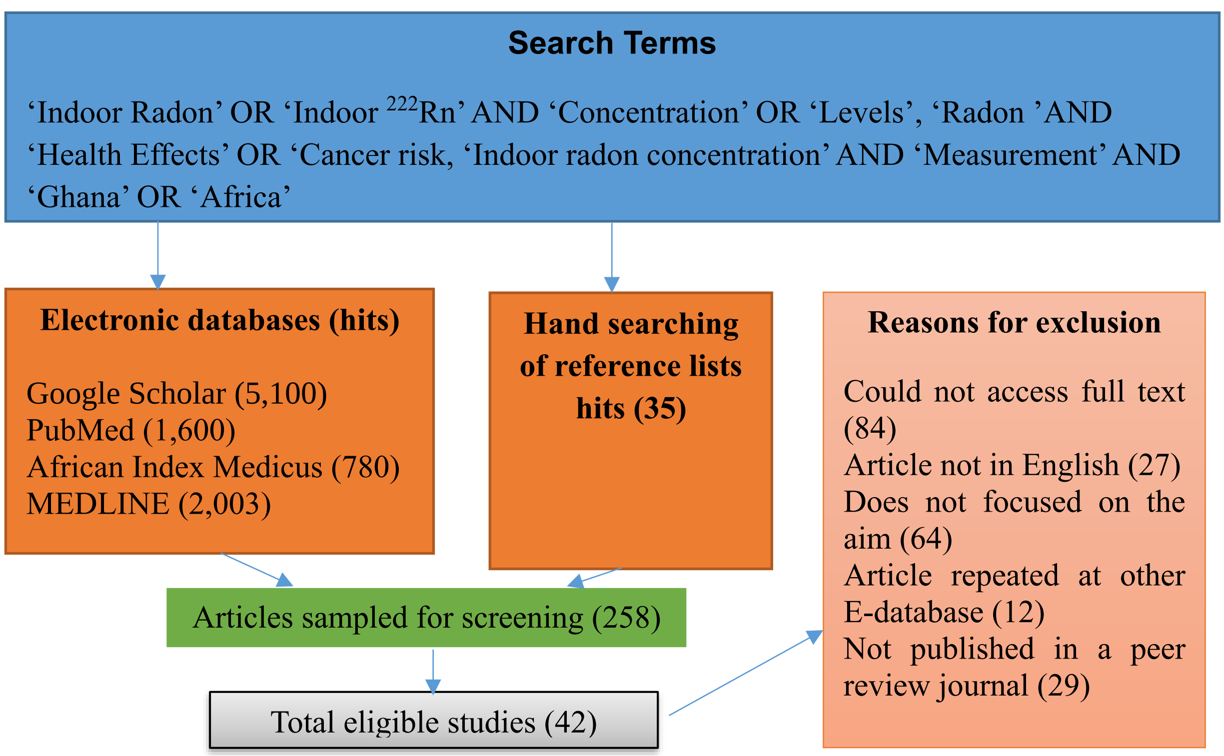


Fig. 2.1 Literature Search Flow Chart

2.1.2 Mapping of the literature

The mapping of literature summarizes the themes and provides the focus of the literature review.

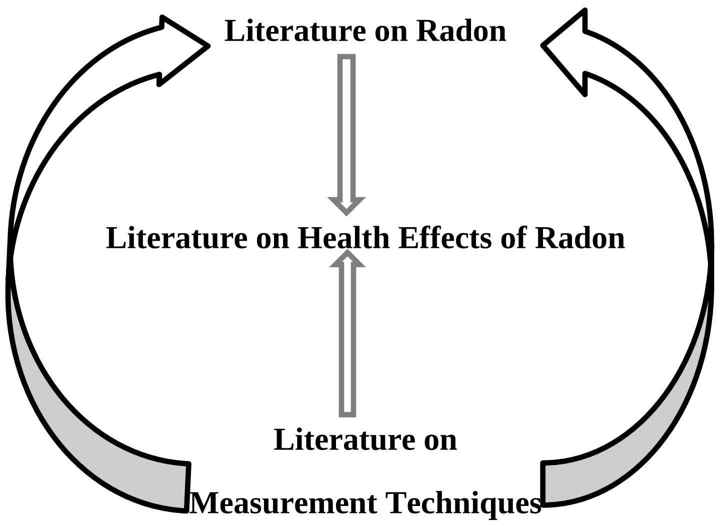


Fig. 2.2 Mapping of the Literature

2.2 Radon: Characteristics, Sources, Indoor Concentrations and their Variations

2.2.1 Physical characteristics of radon

Radon was first acknowledged in 1900 by Friedrich Ernst Dorn (IAEA, 2013). United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) defines radon as a naturally occurring radioactive gas which is colorless, odorless, tasteless, and imperceptible to senses and chemically inert, produced continuously from the natural decay of Uranium and Thorium (UNSCEAR, 2000). Uranium is an element found in diverse quantities in soil and rocks worldwide (ICRP, 1993).

The main isotopes of radon are ^{222}Rn (known as radon, which belongs to the radioactive decay series starting with ^{238}U and ending with stable ^{206}Pb). Two other isotopes ^{220}Rn (known as thoron, belongs to the radioactive decay series starting from ^{232}Th and ending with stable ^{208}Pb) and ^{219}Rn (known as actinon, belongs to the radioactive decay series starting from ^{235}U and ending with stable ^{207}Pb) (IAEA, 2013). Fig. 2.3 shows the series of ^{238}U and ^{232}Th. Radon is the only gaseous element of these radioactive decay series. The indoor concentration of radon, due to its half-life is quite longer than that of the other two isotopes (3.8 days, compared with 55.8s and 3.96s for thoron and actinon, respectively) (IAEA, 2013). This makes IRC worth studying.

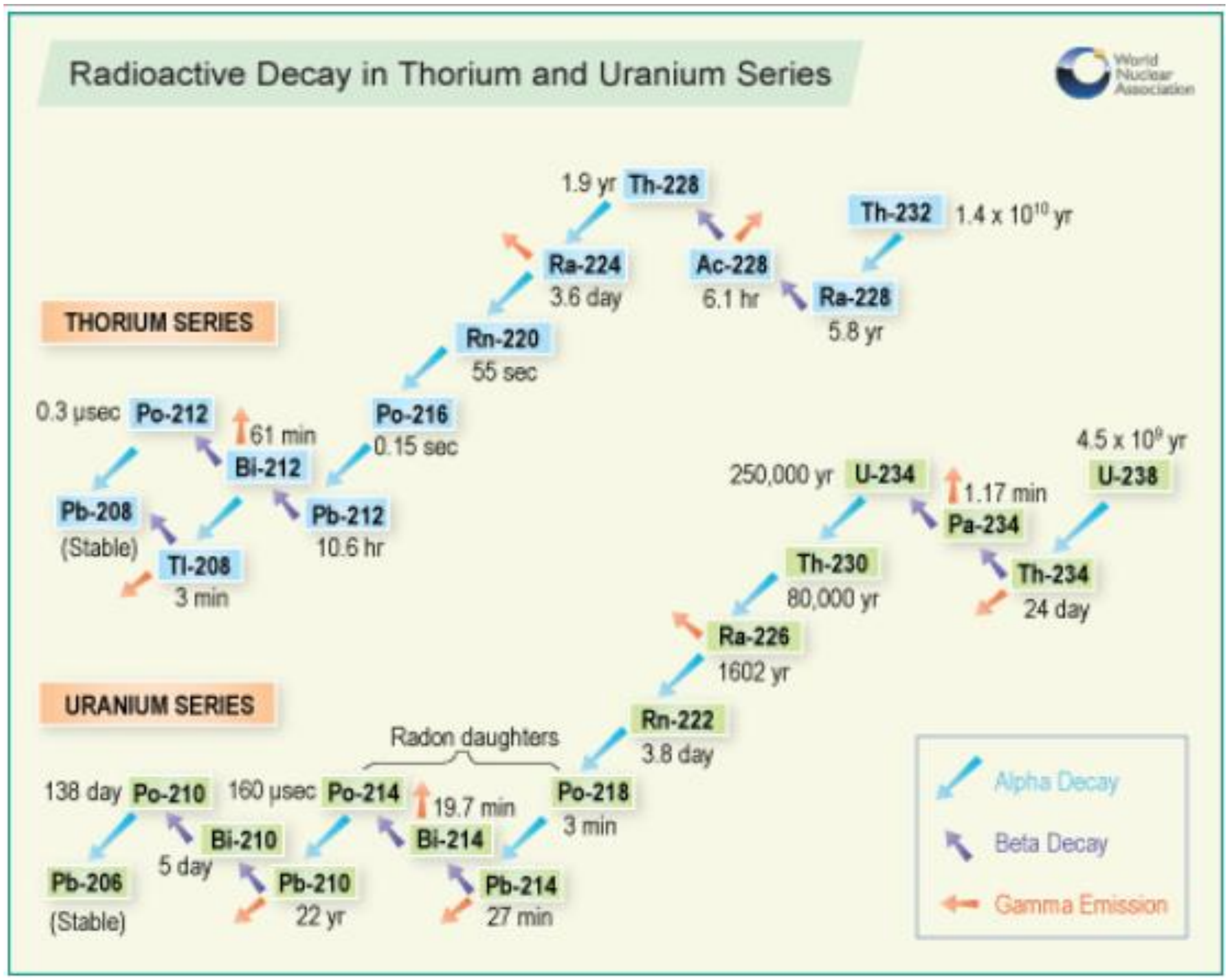


Fig. 2.3 Radioactive Decay in the Thorium (Th) and Uranium (U) series

Source: (www.world nuclear association.com)

2.2.2 Sources of radon

In any planetary material, radon and its decay products are present wherever radium and thorium exist. Thus the human environment is one in which ionizing radiations are present at all time and at all places (WHO, 2009). The understanding of radon sources and its transport mechanisms has evolved over several decades. In the 1950s, high concentrations of radon were observed in domestic and drinking water from drilled wells and the concern about radon in water focused on health effects from ingesting the water. Later, it was determined that the primary health risk of radon in water was from the inhalation of radon released indoors. By the mid-1970s, emanation of radon from building materials was identified to be a problem in some areas due to the use of alum shale with pronounced levels of radium. About a decade on, houses were identified where the indoor radon concentrations were not associated with well water transport or emanation from building materials but soil gas infiltration became recognized as the most important source of indoor radon (WHO, 2009).

2.2.2.1 Soil

Uranium; the parent element of Radon is an element found mainly in soil and rocks. Soil is the main source of radon for those who live close to the ground, e.g. in detached houses or on the ground floor of apartment's buildings without cellars (ICRP, 1993). According to UNSCEAR, (1993) radium; the immediate parent of radon has concentration in soil usually in the range 10 Bq/kg to 50 Bq/kg, but it can reach values of hundreds Bq/kg, with an estimated average of 40 Bq/kg. The mechanism of radon from the soil is predominantly one of pressure-driven flow which is dependent on the air pressure difference between soil air and indoor air, the tightness of the surfaces in contact with the soil on the site, and the radon exhalation rate. Where there are no airtight layer between the basement and the ground, radon is drawn in from the ground indoors (Nielson et al., 1997).

2.2.2.2 Building materials

Over the years there had been a lot of debate in the scientific world in considering building material a main source of indoor radon. In the 70s they were considered the principal source of indoor radon (UNSCEAR, 1988). Again Nero (1988 and 1989) confirms that the main source of indoor radon is its immediate parent ^{226}Ra in the ground of the site and in the building materials. Meanwhile UNSCEAR (2006) considers building materials as minor contributors of high indoor radon but their contributions can be relatively more important in case of low indoor radon levels. However, since the 1980s, some building materials have been recognized as possible sources of high radon concentrations, such as building materials containing by-product gypsum (UNSCEAR, 2006) concrete containing alum shale (Swedjemark, 1988), and bricks made with soil and rocks with high levels of natural radioactivity as volcanic tuffs and pozzolana (Sciocchetti et al., 1983) . For example, in a study by Choukri et al. (2015) radon concentration was found to be 47 Bq/m3 in a house in stones and 31 Bq/m3 in other construction not in stones. IRC is therefore related to variables which can change among neighborhood houses and on the time scale of hours (Groves-Kirkby et al., 2006; Miles, 2001). Meanwhile EPA (2003) concludes that the greatest risk of radon exposure is from tight, insufficiently ventilated buildings and buildings that have leaks that let in soil air from the ground into the basement and upper dwelling rooms.

2.2.2.3 Year of construction, Building type and Foundation type

The year of construction of a building is associated with several other variables like building materials and the method of construction. These variables have been shown to have a significant influence on indoor radon concentration as reported in several studies (Cucoş Dinu et al., 2012; Hauri et al., 2012; Kropat et al., 2014).

Building types such as apartment, detached houses, farm, school etc. have been found to have significantly different IRC mean values (Kropat et al., 2014). According to a study conducted by Kropat et al, (2015) in 240,000 IRC measurements carried out in about 150,000 houses with the use of Kernel predictive model found that different building characteristics resulted in different IRC maps. Maps corresponding to detached houses with concrete foundations indicated systematically smaller concentrations than maps corresponding to farms with earth foundation. It is very well known that the type of foundation has an influence on IRC within a building, that concrete foundation, earth foundations, and foundations that were concreted after construction show significantly different results (Jelle, 2012; Mäkeläinen et al., 2001; Kropat et al., 2014).

2.2.2.4 Altitude

According to earlier observations, altitude is related to indoor radon concentration. This can be explained by the fact that geology depends on altitude. For example igneous rocks like granites (considered to be a good deposit of radium) have a higher abundance at higher altitude than at lower altitudes (Kropat et al., 2014). Once radon reaches a height of one meter approximately above the soil surface, its dispersion is predominately determined by atmospheric stability. Temperature inversions in the early morning act to produce a stable atmosphere which keeps radon in the soil or near the ground or water surface. Generally, radon levels in air decreases exponentially with altitude since solar radiation breaks up inversion leading to upward dispersion of radon which reverses with radiant cooling in the afternoon (WHO, 2009).

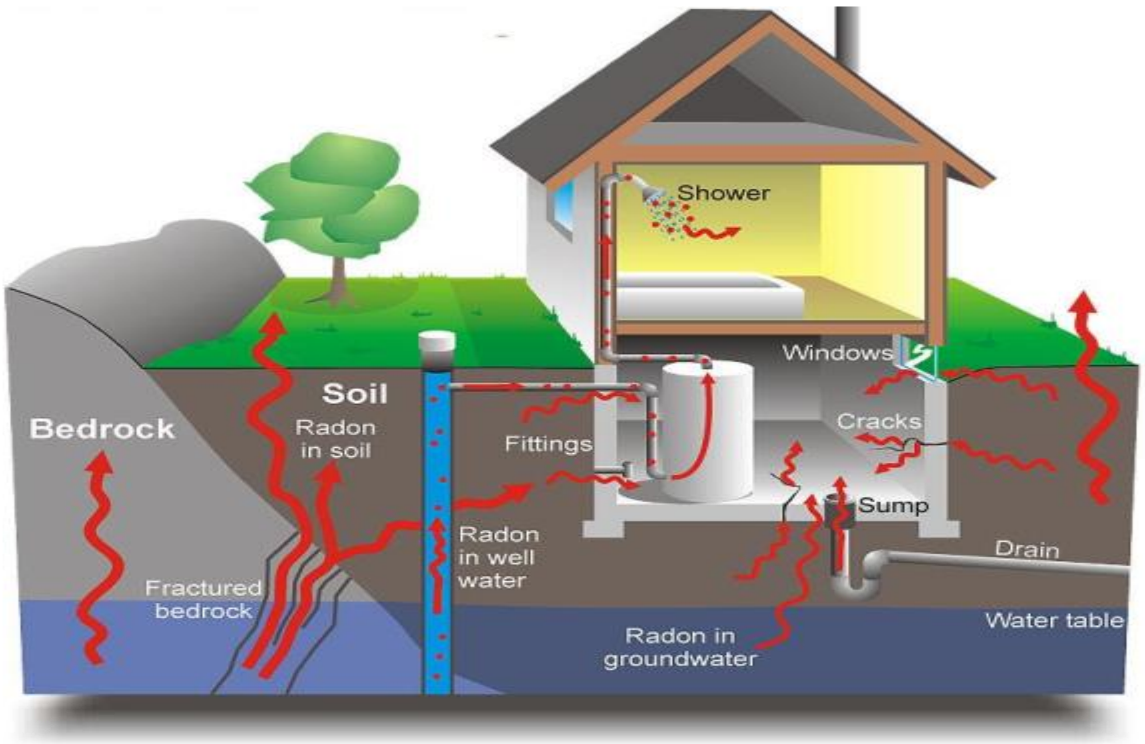


Figure 2.4: Major Radon source and Entry Routes (WHO, 2009)

2.3 Health Effects of Radon

Natural radiation is harmless to humans in ambient environment but contributes significant quantities of radiation towards the total radiation exposure that humans receive. Radon can pose a threat to public health when it accumulates in poorly ventilated homes as well as workplaces since it contributes more than 60% of the natural radiation and accounts for more than half of the total average annual exposure to radiation, about 2 of 3.6 mSv/yr. Radon progenies actually cause the cell damage, these progenies get attached to aerosols, and when inhaled emit alpha particles which damages the basal cells of tissues specifically lung tissue (ACS, 2016).

Exposure of cells and tissues to ionizing radiations can result in both short and long term health effects. At high doses (above a threshold) acute damage to organs and tissues mainly arise as a result of loss of function involving cell killing and extreme cases can cause death of the exposed individual. This type of damage is the deterministic effect now termed "tissue reactions" by the ICRP (2005). At lower doses and low dose rates these tissue reactions are usually not seen, but damage to the genetic material may occur that can result in an increase in the risk of cancer many years later or may cause hereditary disease in future generations. Such damage continues to be termed stochastic as the probability of the effect not its severity (ICRP, 2005).

Generally the detrimental health effects that can result from exposure to radiation include: Carcinogenesis, Mutagenesis, Teratogenesis and Acute toxicity. Radon has been classified as a known human carcinogen according to the ICRP (2005). Epidemiological studies confirm that radon in homes increases the risk of lung cancer in the general population (Lubin et al. 2004, Krewski et al., 2006; Darby et al., 2005, 2006). Other health effects of radon have not consistently been demonstrated but currently it is the second leading cause of lung cancer, next to cigarettes smoking (EPA, 2016). The National Research Council (NRC) (1999), in its report (BEIR VI) on the Health Effects of Exposure to Radon estimated that about 14% of the 164,000 lung cancer deaths in the United States each year were attributable to exposure to radon correlating to approximately 15,000 to 22,000 lung cancer deaths each year in the most recent National Academy of Science (NAS) report on radon. Henshaw et al., (1996) recently suggested that elevated levels of indoor radon exposure may be implicated in the occurrence of other cancers such as childhood leukemia.

According to NCRP Report (1988), several national and international organizations have developed inhalation risk models based on epidemiological and radiobiological data for radon. Risk projections have been made using three of these models. The BEIR IV (NRC, 1988) suggest that the average lifetime risk from inhalation exposure to radon daughters is likely to be of the order of less than 100 cases per million Working Level in Mines (WLM) to perhaps 500 cases per million WLM, with the lower value being applicable to females and non-smoking males and the higher values being applicable to a mixed population of females and smoking and non-smoking males. Comparatively, few epidemiological studies have investigated the exposure to natural background radon levels, and those that are available show no significant increase in lung cancer death rate from inhalation exposure to normally occurring levels of radon and radon progeny (Létourneau et al., 1994).

2.3.1 Risk Assessment

Risk assessment has been defined by the NRC as the characterization of the potential adverse health effects of human exposures to environmental hazard (NRC, 1983). Assessments of radiological hazards and all other types of hazard require some or all of the following components:

1. Exposure or dose assessment, which is the determination of the extent to which human will be exposed to the hazard.

2. Dose-response assessment, in which the relation between the magnitude of the dose and probability that the health effect will occur is determined.

3. Hazard identification which is investigated to determine whether a particular hazard has a corresponding health effect

4. Risk characteristics, which describe the magnitude and nature including uncertainties surrounding that risk (NRC, 1983). It is the risk characterization that integrates the results of the previous three components into risk model that includes one or more quantities estimates.

2.4 Measurement techniques: Dosimetry and indoor radon measurement requirement

This section gives a summary on the specific methods used in indoor radon concentration measurement and the estimation of the various dose measurements as a result of radon exposure

2.4.1 Dosimetry

The specific dose measurements of radon exposure to the body are described in this section.

2.4.1.1 Absorbed Dose

All dose quantities are based on the fundamental definition of absorbed dose in a point as the statistical average of the energy absorbed per unit mass at a point (Mattson & Soderbeg, 2013). Absorbed dose is derived from the mean value of the stochastic quantity of energy imparted and therefore does not reflect the random fluctuations of the interaction events in tissue (ICRP, 2005). The unit of absorbed dose is the gray (Gy), and 1 Gy is equal to 1 J/kg. To illustrate the specific nature of energy absorption when it relates to ionizing radiation, it may be of interest to know that energy absorption of 280 J in a 70 kg person (which is equivalent to the energy in a sip of hot coffee or tea) gives a mean whole-body absorbed dose of 4 Gy (which is a lethal absorbed dose from ionizing radiation) (Mattson & Soderbeg, 2013). The annual absorbed dose or exposure to indoor radon is thus measured as: $D_T = C_{Rn} \times D \times H \times F \times T$

Where: C_{Rn}= measured radon concentration (in Bq/m^3), D = Dose conversion factor (9×10^{-6} mSv/hr per Bq/m^3; UNSCEAR, 2000), H = Indoor occupancy factor (Nsiah-Akoto, 2011),

F = Indoor radon equilibrium factor (0.4; UNSCEAR, 2000) and T = Hours in a year (24 hrs×365 days=8760 hrs/yr)

2.4.1.2 Equivalent dose

The concept of equivalent dose applies only to radiation exposures received by human beings. The SI unit of measure is the Sievert (Sv). Equivalent dose is defined mathematically as:

$H = D.Q$

where D is the absorbed dose and Q is the quality factor at that point thus taking into account the fact that different particle types have biological effects that are enhanced, per given absorbed dose. The factor Q is dependent on both particle type and energy, and for any radiation field, its value is an average of the overall components (Mattson & Soderbeg, 2013).

The ICRP (1991) has recognized that absorbed dose is insufficient, on its own, for assessing harm caused by radiation exposure. In order to establish a correlation between dose quantities applied in radiological protection and the effects, two types of weighting factors have been introduced, a radiation weighting factor (WR) and a tissue weighting factor(WT). WR has been defined as a factor by which the mean absorbed dose in any tissue or organ is multiplied to account for the detriment caused by different radiations relative to photon radiation. WT accounts for the different radio-sensitivities of the various organs and tissues in the human body with respect to radiation detriment from stochastic effects. The weighting factors are intended to take account empirically of many types of radiation and of stochastic effects in different organs and tissues of the body (ICRP, 1991). ICRP thus uses (WR) to connect absorbed dose (D_T) to the protection quantity dose equivalent (HT). The dose equivalent in tissues or organs is defined mathematically as: $HT=\sum WR .D_T$

2.4.1.3 Effective Dose

International Commission on Radiological Protection (ICRP) defines effective dose as the product of the equivalent dose (HT) and the WT for that tissue. Thus, Effective dose (E) is given as: $E=\sum WT \sum WR.\ D_T$ or $E= \sum WT.\ HT$ Effective dose is not based on data from any one individual person and does not provide an individual-specific dose but rather that for a reference person under a given exposure situation. It is however a practical value for comparing the relative doses related to stochastic effects from different diagnostic examinations, provided that the representative patients or patient populations for which the effective doses are derived are similar with regard to age and gender.

2.4.1.4 Excess Lifetime Cancer Risk (ELCR)

There are different models used to estimate the lung cancer risk. These include the model in the BEIR III report. The BEIR III report [NRC, 1980] gives an elaborate age dependent risk factors of 10×10^{-6} per WLMy for ages 35-45, 20×10^{-6}WLM.y for ages 45-65, and 50×10^{-6} per WLM.y for ages above 65 and latency period of 10 years. The EPA recommends 4pCi/L (148Bq/L) as the action level for a lifetime exposure to indoor radon. Depending on whether a person is a smoker, non-smoker or former-smoker the EPA estimates that the risk of developing lung cancer is 1 to 5 percent. The NRC estimates the risk as 0.8% to 1.4%. The overall risk of radon exposure is related not only to its average level in the home, but also to the occupants and their lifestyles (USEPA, 1984). Factors that influence the risk of lung cancer from radon exposure are as follows: age, duration of exposure, gender, physical condition, geographic location, other carcinogenic exposure, cigarette smoking, time since initiation of exposure and genetic tendency either to resist or be affected by internal radiation exposure. The risk of lung cancer associated with a lifetime inhalation of airborne radon at a concentration of 1 Bq/m^3 was estimated on the basis of studies of underground miners. The values were based on risk projections from three follow-up studies: NIH (1994), BEIR IV (NRC, 1988); BEIR VI (NRC, 1998). Data from 4 to 11 cohorts of underground miners in seven countries were obtained from the three reports and developed risk projections of 1.0×10^{-4}, 1.2×10^{-4}, 1.3×10^{-4} per unit concentration in air (1.0 Bq/m^3), respectively. As the number of radiation particles increase in the body, there is an increase in the chance of getting cancer and the risk to people is proportional to the length of exposure and the radon concentration in air. The excess lifetime risk is estimated as follows:

$ELCR = E_R \times T \times F_R$ (EPA, 2003)

Where E_R= radon daughter exposure in WLM per year, T= average lifetime expectancy, F_R= Risk coefficient for exposure to ^{222}Rn gas in equilibrium with its progeny ($5x10^{-4}$ per WLM) (ICRP, 2005)

2.4.2 Indoor radon measurement requirement

Testing of radon in homes takes about some few days to months and this depends on the kind of test being used. Short-term testing (active) and long term testing (passive) are the two main ways to test for radon in homes. The active test is the quickest way and takes about two to 90 days, depending on the type of device used. Charcoal canister, electrets ion chamber, charcoal liquid scintillation, Alpha track detectors and continuous monitors are some of the detectors used for short-term indoor radon testing (IAEA, 2013). According to USEPA (1992) and IAEA (2013), the results of short-term measurements cannot be used to accurately estimate the long-term average value.

The passive test remains in homes for more than 90 days. These measurements give the best estimates of the average value. In particular one-year is the most appropriate, except in cases in which the dwelling is not lived in for a while. Some of the detectors that are used for long term-testing are electrets ion chamber and Alpha track detectors (ATD) (IAEA 2013).

A radon concentration measurement technique is needed with the following main requirements: (i) sampling periods of 3 to 12 months, (ii) low cost, and (iii) low impact (small size of the measuring device). Passive measuring devices based on *ATD* deployed in this study fulfil all the above requirements, and therefore are reviewed in this section. ATDs are also called SSNTD. The possible use of these detectors for radon monitoring was first suggested by Fleischer et al

(1975). The lower limit of detection for this technique for a 3-month exposure is 5–10 Bq/m^3, depending on the size of the scanned detector area (IAEA, 2013).

2.4.2.1 Solid State Nuclear Track Detector (SSNTD)

The SSNTD is a solid material (basically dielectric organic or inorganic materials e.g. plastics, glass and mica) with thickness ranging from about 0.1 to 1mm. The main materials used for SSNTD are the three following polymeric plastics: poly-allyl-diglycol-carbonate (PADC) (generally known by its commercial name *CR-39*), cellulose nitrate (CN) film (commercial names *LR 115* and *CN 8* and polycarbonate (PC) (commercial names *Makrofol* and *Lexan*). The passage of an alpha particle through an SSNTD produces a narrow primary damage trail or latent track along the length of its path in the material (typically 20 to 70 µm). The diameter of latent tracks is in the order of tens of nm, whereas the diameter of etched tracks can reach some µm thus being visible under an optical microscope (IAEA, 2013).

2.4.2.2 Track etching and counting methods.

After exposure, latent tracks in the detectors can be made visible by a chemical etching with aqueous alkaline solutions of potassium hydroxide (KOH) or sodium hydroxide (NaOH), thus obtaining enlarged pits that can be easily counted. The main etching parameters are temperature, etchant concentration and etching time. Stirring can also affect etching results. Tracks in CN detectors are usually etched with a 10% NaOH solution (2.5 N) at about 60ºC for 90 to 110 (or a few more) minutes. For PADC detectors, 25% NaOH solutions (6.25 N) are generally used with different combinations of temperature and etching times (Tommasino, 1997).

Depending on the type of detector, track density can be measured with different approach. Tracks in CN detectors can be viewed with an optical microscope and are manually or automatically counted, or (in the ‘strippable’ version, the 100-µm thick polyester support of which can be removed after etching) they can be counted with a non-optical system, such as a spark-counter (Tommasino, 1997). This technique is quite simple, although a significantly non-linear response occurs at high track due to the size of the typical evaporated aluminum area, which is quite larger than the track areas. Tracks in PADC detectors can be counted by automatic systems based on an optical microscope or on a scanner acquiring images of detector surface and a computer program analyzing such images to identify and count tracks (IAEA, 2013).

2.5 Radon mitigation and Remedial methods

Preventing radon entry is often the best strategy since it has a high probability of success, even in locations with very high radon levels. Regardless of the strategy considered, any mitigation plan must take into account a number of considerations. In addition to preventing the entry of radon, the mitigation system should be unobtrusive, quiet, and capable of indicating system failure. It should be economical and easy to maintain and operate. Mitigation systems also must be a permanent part of the building rather than portable or window-mounted devices that can be removed when the building is sold. Typical mitigation methods are: depressurization (process in which soil gas drawn indoors are regulated by altering low air pressure in a house and the higher air pressure in the soil). Sub slab installations as well as sealing cracks and other openings in floors and walls are very effective (USEPA, 1992).

In buildings, where indoor-radon activities have been identified to exceed the action level, it is prudent to implement remedial measures. The most obvious remedy is to increase the ventilation in the building and prevent the entry of radon into the building. The mitigation technique that should be adopted is dependent on, for example, (i) whether the building is a new or old (ii) the building construction details, (iii) the requirement of magnitude of reduction in IRC, (iv) the associated costs (Nsiah-Akoto, 2013). Techniques that reduce radon after entry are most appropriate for buildings with relatively low radon levels, where radon entry cannot be prevented, or in which increased ventilation could provide valuable benefits in addition to radon reduction (USEPA, 1992).

CHAPTER THREE

METHODOLOGY

3.1 Research Methods and Design

Exposure assessment of inhabitants of Kpong Township to radon gas was conducted. Quantitative method was used for the study where indoor radon concentration was measured and analysed statistically. Probability sampling was used to obtain participants.

3.2 Data Collection Tools and Techniques

Radon Kit Preparation

- Cellulose Nitrate LR 115 type II SSNTD
- Cardboard
- Paper glue
- Scissors
- Ruler
- Pencil

Etchant preparation and track counting

- Sodium Hydroxide (NaOH) pellets
- Electronic balance
- Beaker
- 1 Liter Volumetric flask
- Glass rod
- Distilled water
- Malleable Thread
- Scanner and Digital Counter (Epson Perfection V600)

Geo-referencing and Survey Questionnaire

- Handheld Global Positioning System(GPS)
- Lenovo Laptop
- Note books
- Pens

3.2.1 Survey questionnaire and Geo referencing technique

Once a homeowner agreed to participate in the study, a survey questionnaire was administered. The questionnaire was designed with Epi Info version 7.2 and the responds captured electronically as well as hand recorded. The following information were reported or observed about the housing characteristics: age of house, foundation type, building type….etc. The socio-demographic characteristics of occupants were assessed. In addition, the respondents were asked to answer questions about the following: presence of smoking and any prior knowledge of radon**.** Basic information such as start and end date, house numbers and contact numbers were taken. The geographical reference of each house (that agreed to participate) was taken using GPS.

3.2.2 Indoor radon kit placement

The kits were prepared from SSNTD cut into rectangles of size (2cm x 3cm) and placed in specially made cardboard envelopes. The detectors were fixed on the walls (Fig,3.1) of the bedroom and or halls of households at a height 1.65m from the floor level. Two third of the detector was exposed to the emergent radon in the room. The unexposed part measured the background radon disintegration. The detectors were placed for a period of 102 days.

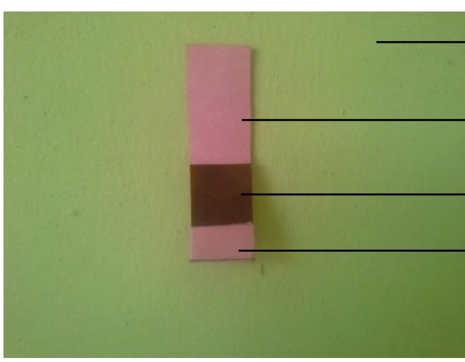


Fig. 3.1 A picture showing how the detector was deployed in the rooms

3.2.3 Etchant preparation and track counting

After the 3 months' exposure, the detectors were collected and subjected to chemical etching in a 2.5 M NaOH solution. The solution was prepared from 100grams of NaOH pellets dissolved in about 100cm^3 of distilled water and topped up to 1 litre. The detectors were etched for a period of 1hr 30min in a constant temperature (60±1) ºC.). Then washed and dried. For image processing and track counting, a commercial scanner (Epson Perfection V600) and ImageJ (Image Processing and Analysis in Java), a free digital image-processing software was used. These procedures were performed at the Nuclear Track Detection Laboratory of the National Nuclear Research Institute (NNRI), Ghana Atomic Energy Commission (GAEC).

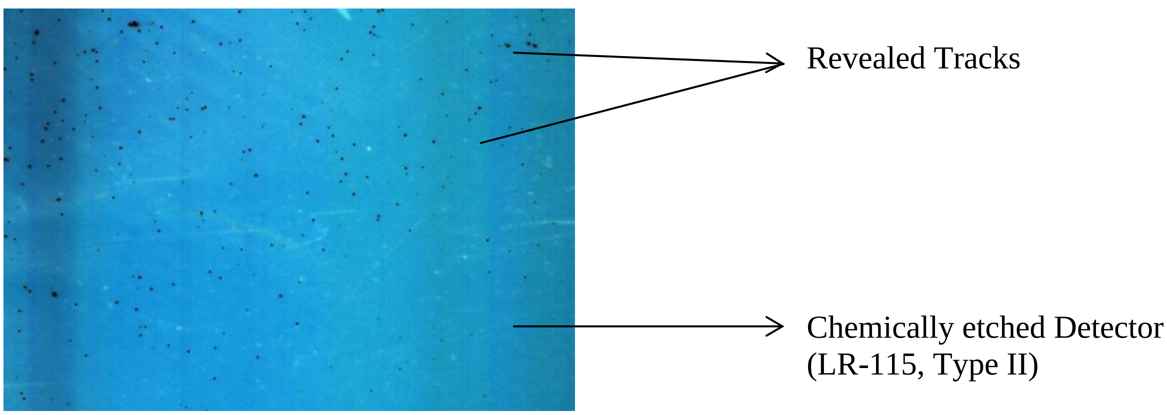


Fig. 3.2 A picture of a scanned detector showing radon tracks

3.3 Study Population

The study population comprised of all dwellings in the Kpong Township. Dwelling characteristics rather than householders' ones have effects on radon concentration in a dwelling and it can reasonably be assumed that all the householders are exposed to the same radon concentration. Therefore it is equivalent to consider the housing units or the householders as the target population of the survey. The choice depends on the availability of complete lists from which the sample units could be randomly selected (IAEA, 2013). In this study it was easier to have a complete list of dwellings rather than inhabitants.

3.4 Study Variables

The various variables of this study include:

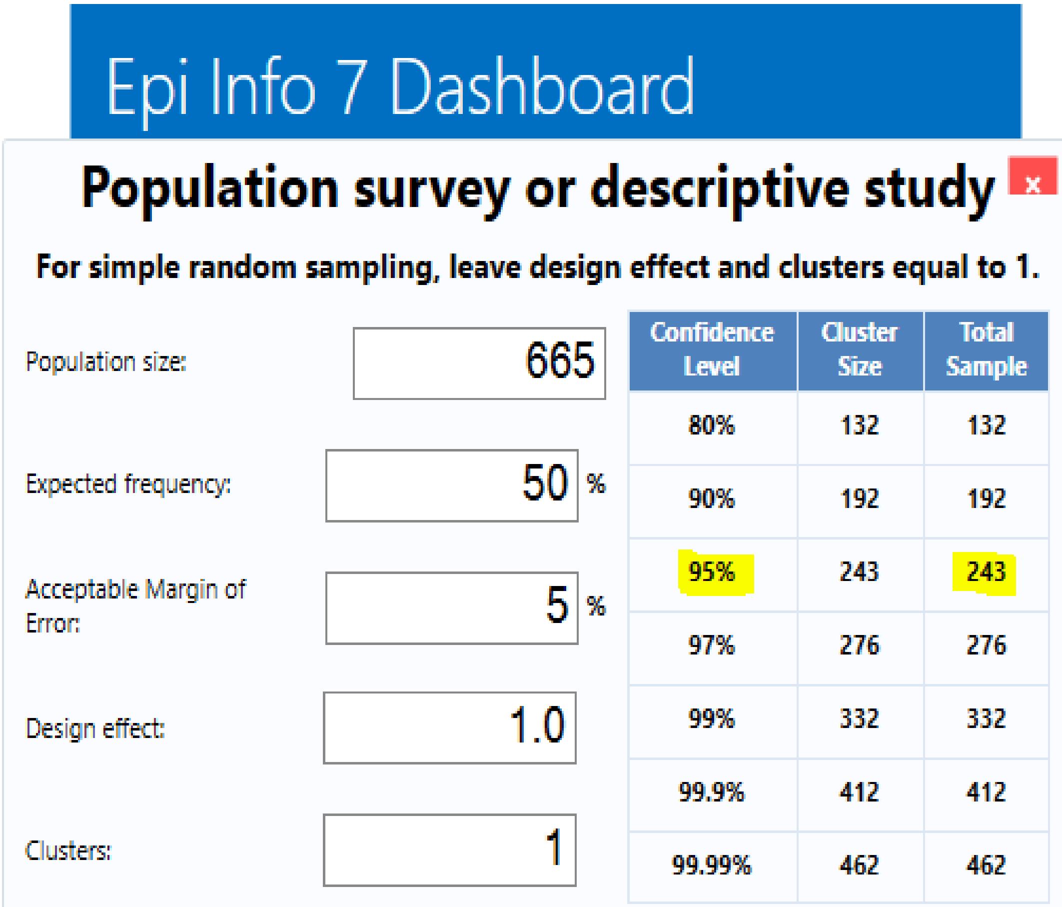
- Radon Concentration
- Housing Characteristics (Age of house, type of building, number of windows, forms of ventilation, Floor type, altitude...)
- Annual absorbed dose, effective dose to the lung and the effective life time cancer risk

3.5 Sampling

A multi stage sampling method was used for the study. The township was divided into geographical units following the administrative boundaries of the communities. This sampling method was chosen due to recommendation by IAEA (2013) on indoor radon local survey since it gives a representative of the indoor readings of the area.

3.5.1 Sample size calculation

For an estimated total housing population of 665 within the selected communities, an allowable error of 5%, the total sample size needed for the study was 243 with a 95% confidence level



Epi Info 7 Dashboard

Population survey or descriptive study

For simple random sampling, leave design effect and clusters equal to 1.

Population size: 665

Expected frequency: 50 %

Acceptable Margin of Error: 5 %

Design effect: 1.0

Clusters: 1

Confidence Level	Cluster Size	Total Sample
80%	132	132
90%	192	192
95%	243	243
97%	276	276
99%	332	332
99.9%	412	412
99.99%	462	462

Table 3.1 Total sample size calculation

3.5.2 Sample size calculation per cluster

Simple random sample was used to select the housing units in each community. The total houses with their house numbers were obtained and random numbers were generated to select the required sample from each cluster. Below is the work up of the various sampling units per cluster. Using the formulae: $n_u = (N_u/N) \times n$

Where n_u = sample size of a particular stratum

N = total sample size

N_u = population size of a particular stratum

N = total size of a population

Table 3.2: sample size per community

Name of community	**Number of houses**	**Sample size**
Ahundjo	185	68
Zongo	265	97
Ayikpala	30	11
Batokordgi	45	16
Tandon	25	9
Parkson	65	24
Kortokolie	50	18
Total	**665**	**243**

3.6 Pre-testing

Pretesting of questionnaire was done among 10 dwellings in the Shai Osoudoku District. The actual measurement of indoor radon could not be piloted due to the three month duration detectors have to be placed before results could be obtained. Rather the recommendations, limitations and assumptions of various studies conducted using similar methods were considered.

3.7 Data Handling

Data entered into software were backed up using hard drive, email and drop box. Scanned detectors have been stored in a safe locker box with their appropriate codes. Requirements of the Data Protection Act (1998) have been followed

3.8 Data Analysis

The data were line listed at EPI Info into MS Excel before exporting to R and STATA for analysis. A descriptive analysis, bivariate and multivariate analyses were run on the data set. Regression analysis was used to test for association predictions. All tests were set to an allowable error of 5%.

Mapping of data was performed with R (version 3.2.5). Semivariance, variogram modelling, and ordinary krigging were carried out to produce radon map of the study area. The map was exported to Google map and Geographic Information System (QGIS version 2.10.1) for visualization.

3.9 Formula for test calculations

Track density

Track density (ρ) = $\frac{Mean\ number\ of\ counts}{Area}$ ………………………………………….……Eqn 1

Concentration of indoor radon gas (Bq/m$^{3/}$h)

$$\text{Conc.} = \frac{Track\ density(\rho)}{Caliberation\ Factor(\mathcal{E}) \times Exposure\ Time(T)}$$ ………………….………..…Eqn 2

Radon Conc. (C_{Rn}) = $\frac{Track\ density(\rho) - Background\ track\ density(\rho B)}{Caliberation\ Factor(\mathcal{E}) \times Exposure\ Time(T)}$…...………………Eqn 3

Calibration Factor ($\mathcal{E}$) =3.96($Tracks.m^3 / cm^2 kBq.h$) of the LR-115 (Type II)

Exposure Time = hrs (≥92 days) for indoor passive monitoring

Background track density (ρB) = Average count on unexposed part of the detector

Annual absorbed dose (mSv/yr)

Annual absorbed dose (D_T) =$C_{Rn} \times D \times H \times F \times T$ ……………………………………………Eqn 4

Where: C_{Rn}= measured radon concentration (in Bq/m^3)

D = Dose conversion factor (9×10^{-6} mSv/hr per Bq/m^3; UNSCEAR, 2000)

H = Indoor occupancy factor (0.4; Nsiah-Akoto, 2011)

F = Indoor radon equilibrium factor (0.4; UNSCEAR, 2000)

T = Hours in a year (24 hrs×365 days=8760 hrs/yr)

Annual effective dose to the lung (mSv/yr)

Annual effective dose (E_T) to lung = $D_T.W_R.W_T$ ………………………………………..Eqn 5

Where D_T = Annual absorbed dose

W_R = Radiation weighting factor (20 for alpha particles; ICRP, 1991)

W_T = Tissue Weighting Factor (0.12 for the Lung; ICRP, 1991)

Radon Exposure

$E_R = C_{Rn}$ x H x F (2.7 x10^{-4}) x 8766/170…………………………………………Eqn 6

2.7x10^{-4} is the conversion of radon concentration to working level (WL per Bq/m^3),

8766 are hours in a year (h/y), and 170 are working hours in mine in a month (h/M)

Excess Lifetime Cancer Risk (ELCR)

$ELCR = E_R \times T \times F_R$………………………………………………………...Eqn 7

Where E_R= radon daughter exposure in WLM per year

T= average lifetime expectancy 62.5 for Ghana (WHO, 2017)

F_R= Risk coefficient for exposure to 222Rn gas in equilibrium with its progeny (5×10^{-4} per WLM) (ICRP, 2005)

3.10 Ethical Consideration

The necessary ethical clearance and approval for the study were obtained from the research ethics committee of Ensign College of Public Health. Permission was sought and gained from the Kpong traditional and political leaders. All study participants were given informed consent prior to the commencement of the study and each data collection activity. The consent form introduces the nature and purpose of the study to participants for their confidentiality and anonymity and the fact that the research procedure would not have element that would pose any harm to them. To ensure confidentiality and anonymity, participants were identified with specially created identification blinded to others.

Inconvenience of entering home owner's rooms were addressed by consent and ensuring the presence of room owner as well as a research assistant before a detector was installed.

3.11 Limitations of Study

Due to loss of detectors on site and during chemical etching, the numbers of concentration point for data analysis were lower than the proposed sample size. This can affect the representativeness of the study.

3.12 Assumptions

- That all the householders are exposed to the same radon concentration
- That all householders lived in their houses all year round

CHAPTER FOUR

RESULTS

4.1 Household recruitment survey

Recruitment logs of houses visited were kept to represent houses that 1) were approached and allowed testing 2) were approached but nobody was home or 3) were approached but did not want to participate in the study. Of the 287 recorded visitor logs, the willingness to participate were 109 (37.99%), 157 (54.70%) unanswered, and 48 (16.72%) unwilling to participate. (Note that not all visitor logs were accounted for). After all recruitment was completed, a total of 118 homes participated in the study. Of the 118 tested households, 17 detectors were lost to follow-up and 19 results came back invalid. The following analysis is therefore based on 82 valid tested households.

4.2 Results of indoor radon concentration measurement in sampled households at Kpong

This section gives the general overview of the measured radon results and below is the aerial view of the sampled points or households (Fig 4.1)

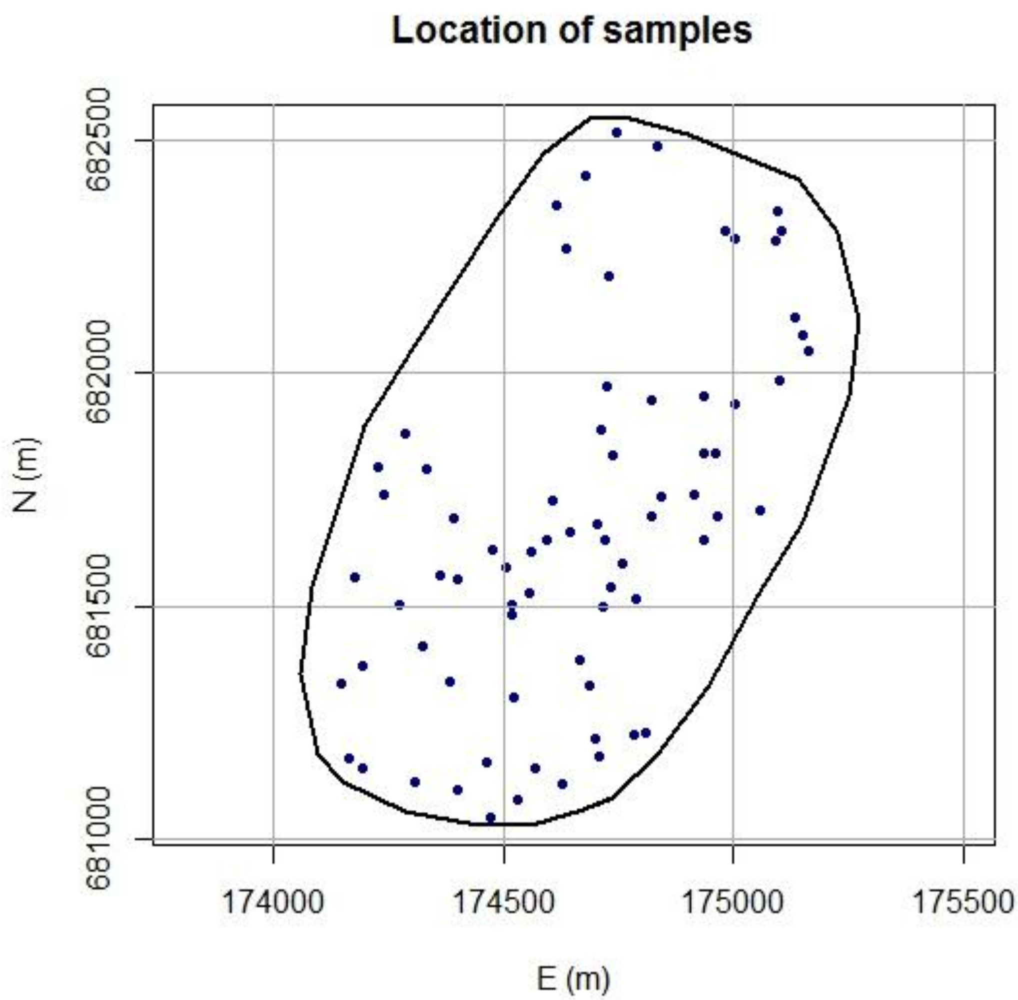


Fig.4.1: Spatial distribution of sampled points (N=82)

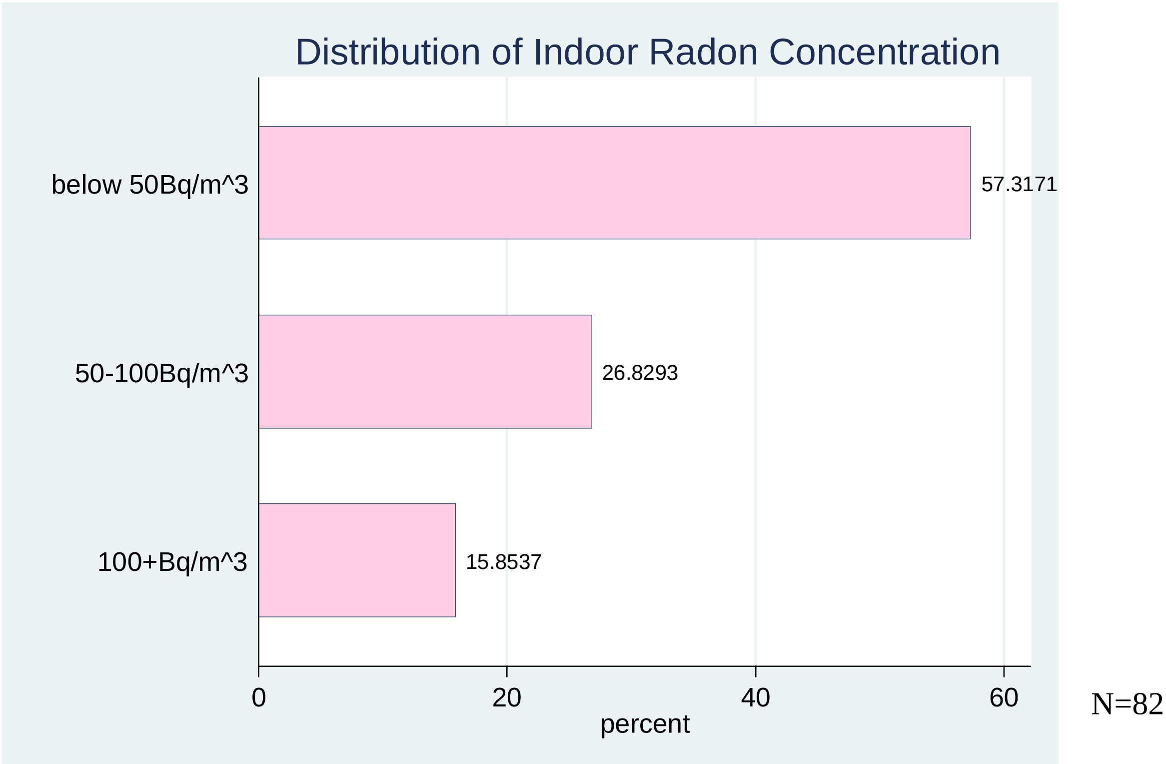


Fig. 4.2: Frequency distribution of indoor radon concentration

Majority (57%) of the measured indoor radon concentrations were below 50Bq/m^3. Meanwhile approximately 16% were above 100Bq/m^3 (WHO recommended reference point), (Fig. 4.2)

Table 4.1: Measured radon concentrations of each household within each sampled community

Parkson	**Conc.(Bq/m^3)**	**Ayikpala**	**Conc.(Bq/m^3)**	**Ahundjo**	**Conc.(Bq/m^3)**
PK1	27.61 ± 5.25	AY2	60.62 ± 7.79	AH1	26.79 ± 5.18
PK2	30.12 ± 5.49	AY3	54.15 ± 7.36	AH2	81.86 ± 9.05
PK3	39.87 ± 6.31	AY4	108.6 ± 10.42	AH3	70.71 ± 8.41
PK4	64.48 ± 8.03	AY5	14.19 ± 3.77	AHN5	68.78 ± 8.29
PK5	43.00 ± 6.56	AY6	25.77 ± 5.06	AHN6	49.71 ± 7.05
PK6	111.59 ± 10.56	AY7	30.99 ± 5.57	AHN7	23.75 ± 4.87
PK7	43.25 ± 6.58	AY8	16.51 ± 4.06	AHN8	35.62 ± 5.97
PK8	31.25 ± 5.59	AY9	39.29 ± 6.07	AHN9	33.40 ± 5.78
PK10	25.77 ± 5.08	AY10	52.80 ± 7.07	AHN10	23.46 ± 4.84
Range	**25.77 - 111.58**		**16.51 - 108.60**	AH12	23.07 ± 4.80
Mean ±Std.	**46.32 ± 27.19**		**44.77 ± 29.14**	AH15	16.79 ± 4.10
				AH16	103.38 ± 10.17
				AH18	92.38 ± 9.61
Tador	**Conc.(Bq/m^3)**	**Kortokoli**	**Conc.(Bq/m^3)**	AH19	106.28 ± 10.31
TN3	47.88 ± 6.92	KT1	170.86 ± 13.07	AH21	100.01 ± 10.00
TN4	40.74 ± 6.38	kT2	96.92 ± 9.84	AH22	93.25 ± 9.66
TN5	39.72 ± 6.30	KT3	102.03 ± 10.10	AH23	81.62 ± 9.03
TN6	31.18 ± 5.58	KT4	88.13 ± 9.39	AH25	19.02 ± 4.36
TN7	32.68 ± 5.72	KT6	176.27 ± 13.28	AH26	46.29 ± 6.80
TN9	36.10 ± 6.01	KT7	104.93 ± 10.24	AH29	53.82 ± 7.34
TN10	43.17 ± 6.57	KT8	37.02 ± 6.08		
TN11	37.74 ± 6.14	KT10	35.62 ± 5.97		
Range	**31.18 - 47.88**		**35.62 - 176.25**		**16.80 - 106.28**
Mean ±Std.	**38.65 ± 5.48**		**101.47 ± 52.25**		**57.50 ± 31.70**
Zongo	**Conc.(Bq/m^3)**			**Batorkodji**	**Conc.(Bq/m^3)**
ZGN1	34.27 ± 5.86	ZG17	69.60 ± 8.34	BT1	40.25 ±6.34
ZGN2	58.40 ± 7.64	ZG18	34.94 ± 5.91	BT2	93.06± 9.65
ZGN3	50.97 ± 7.14	ZG19	34.17 ± 5.85	BT3	60.38±7.77
ZGN4	105.99 ± 10.30	ZG20	7.24 ± 2.69	BT7	50.39±7.10
ZGN5	168.74 ± 12.99	ZG22	30.99 ± 5.57	BT8	70.56±8.40
ZGN7	117.96 ± 10.86	ZG23	4.05 ± 2.01		
ZGN8	108.36 ± 10.41	ZG24	41.44 ±6.44		
ZGN9	7.34 ± 2.71	ZG25	52.37 ± 7.24		
ZGN10	45.08 ± 6.71	ZG27	6.08 ± 2.47		
ZGN14	62.26 ± 7.89	ZG28	20.85 ± 4.57		
ZG15	23.17 ± 4.81	ZG29	45.59 ± 6.75		
ZG16	6.18 ± 2.49				
Range			**4.05 - 168.74**		**40.25 - 93.06**
Mean ±Std.			**49.39 ± 41.69**		**62.93 ± 20.25**

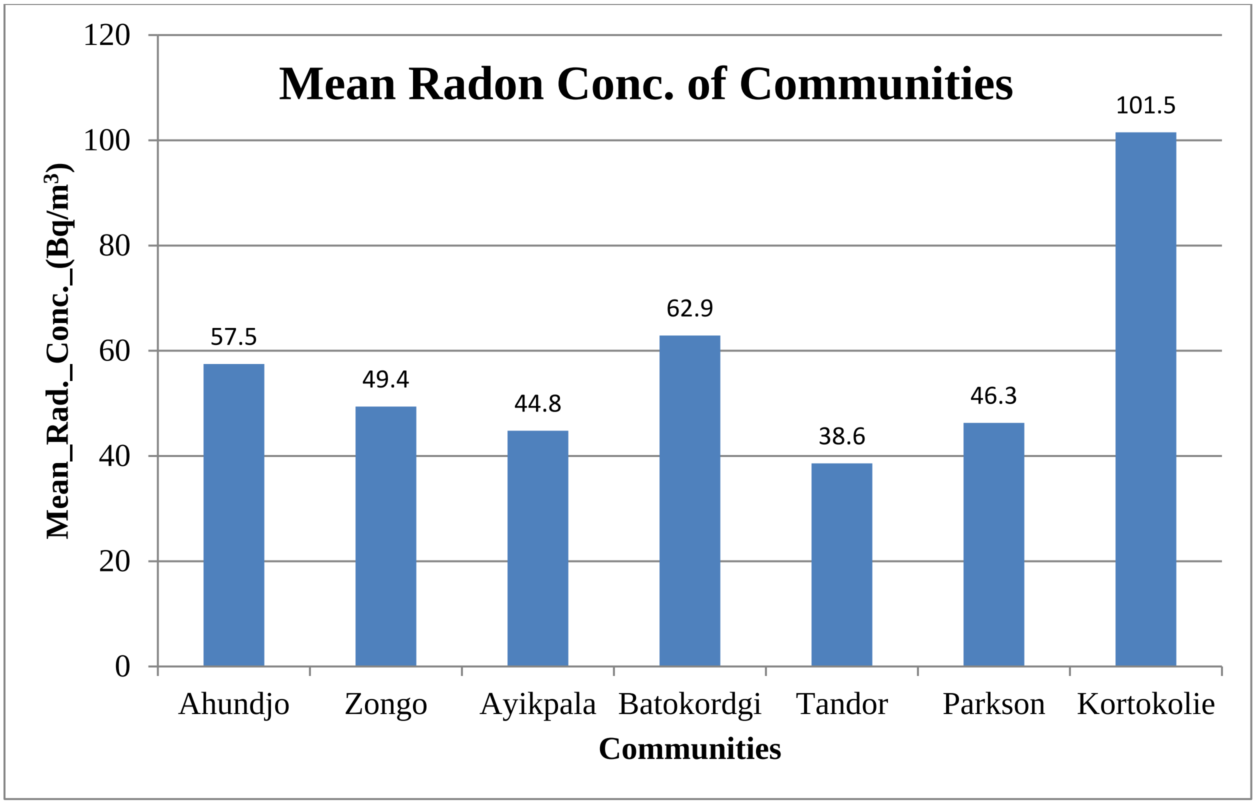


Fig. 4.3: The average indoor radon concentrations of the studied communities

Kortokolie recorded the highest mean indoor radon concentration of 101.5 Bq/m^3 with Tandor (Ensign Area) recording the lowest 38.6 Bq/m^3, (Fig. 4.3)

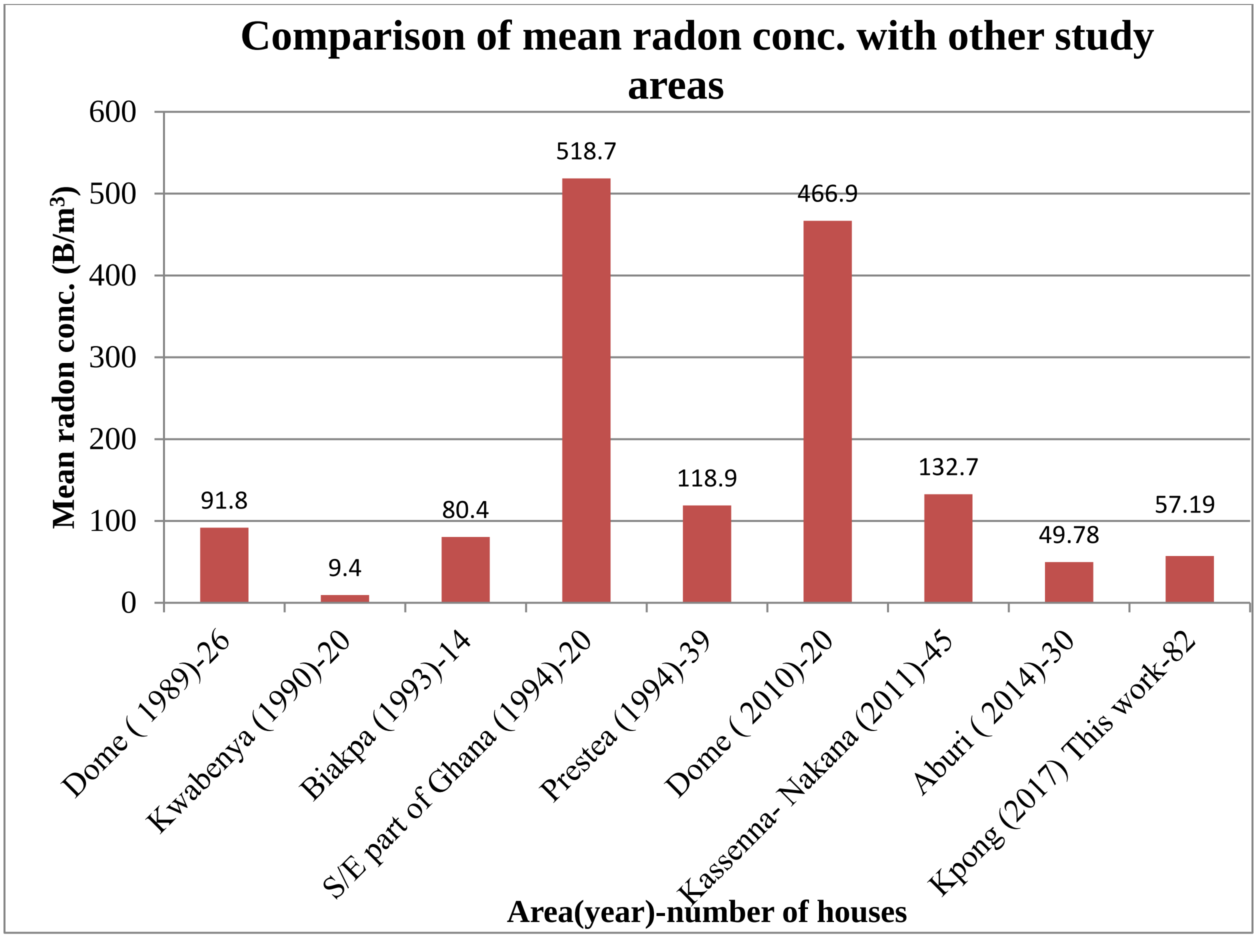
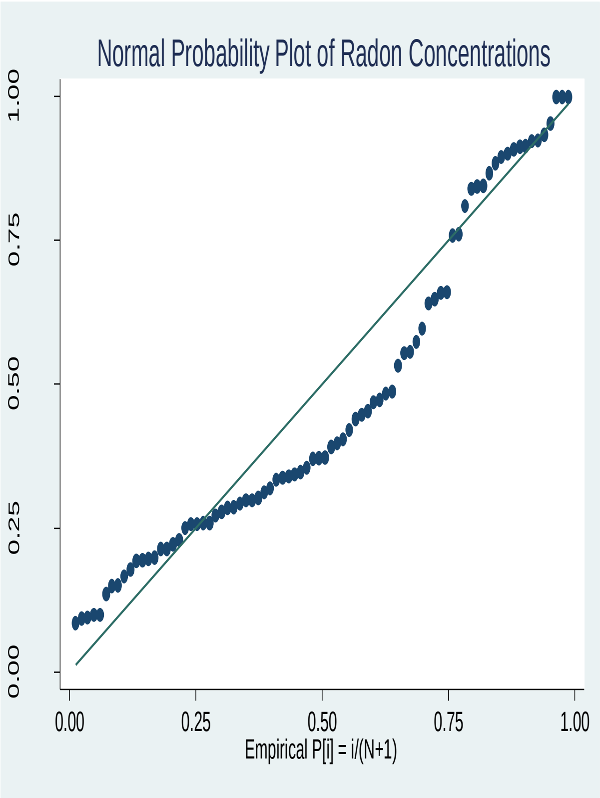


Fig.4.4: Comparison of the average indoor radon concentration in Ghana from previous study areas with this work

Compared to this work, Aburi recorded almost the same average radon concentration (Fig.4.4).



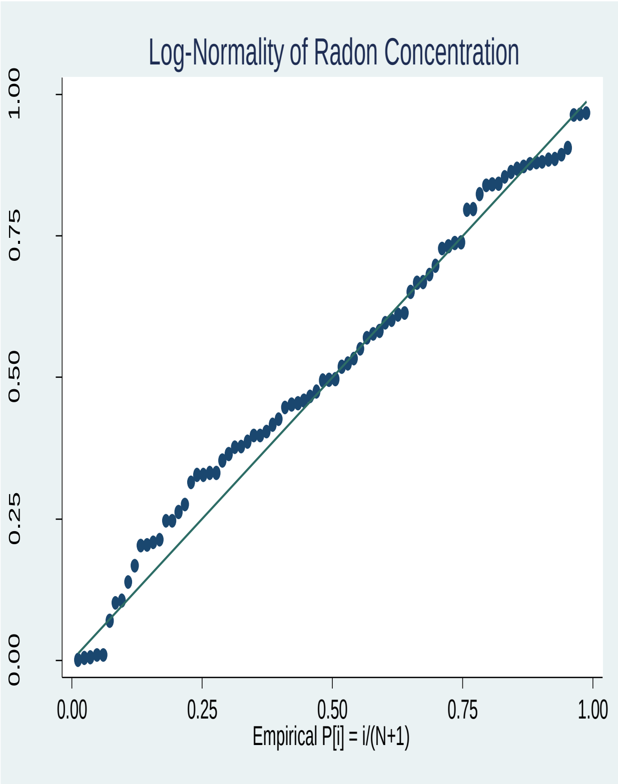


Fig. 4.5: Normality plot of radon concentration: *Left;* actual *Right*; adjusted

A normal probability plot of the logarithm of measured concentrations is done in order to evaluate possible deviations from a pure log-normal distribution. Left: in the observed (uncorrected) distribution, the plotted points deviate wider from the solid line while the corrected distribution (Right) seems closer to the solid line (Fig.4.5).

4.2 Determination of Excess life time lung cancer Risk

Table 4.2: Determination of Radon Exposure, Effective dose to the lung and associated lifetime lung cancer risk

Codes of Homes	Average radon Concentration (Bq/m^3)	Average radon exposure (WLM/y)	Effective dose to the lung (mSv/y)	Excess lifetime cancer risk (%)
PK1	27.61	0.06	0.35	0.19
PK2	30.12	0.07	0.39	0.21
PK3	39.87	0.09	0.51	0.28
PK4	64.48	0.14	0.83	0.45
PK5	43.00	0.10	0.55	0.30
PK6	111.59	0.25	1.43	0.78
PK7	43.25	0.10	0.55	0.30
PK8	31.23	0.07	0.40	0.22
PK10	25.77	0.06	0.33	0.18
ZGN1	34.27	0.08	0.44	0.24
ZGN2	58.40	0.13	0.75	0.41
ZGN3	50.97	0.11	0.65	0.35
ZGN4	105.99	0.24	1.36	0.74
ZGN5	168.74	0.38	2.16	1.17
ZGN7	117.96	0.26	1.51	0.82
ZGN8	108.36	0.24	1.39	0.75
ZGN9	7.34	0.02	0.09	0.05
ZGN10	45.08	0.10	0.58	0.31
ZGN14	62.26	0.14	0.80	0.43
ZG15	23.17	0.05	0.30	0.16
ZG16	6.18	0.01	0.08	0.04
ZG17	69.60	0.16	0.89	0.48
ZG18	34.94	0.08	0.45	0.24
ZG19	34.17	0.08	0.44	0.24
ZG20	7.24	0.02	0.09	0.05
ZG22	30.99	0.07	0.40	0.22
ZG23	4.05	0.01	0.05	0.03
ZG24	41.44	0.09	0.53	0.29
ZG25	52.37	0.12	0.67	0.36
ZG27	6.08	0.01	0.08	0.04
ZG28	20.85	0.05	0.27	0.15

Codes of Homes	Average radon Concentration (Bq/m^3)	Average radon exposure (WLM/y)	Effective dose to the lung (mSv/y)	Excess lifetime cancer risk (%)
ZG29	45.59	0.10	0.58	0.32
BT1	40.25	0.09	0.52	0.28
BT2	93.06	0.21	1.19	0.65
BT3	60.38	0.13	0.77	0.42
BT7	50.39	0.11	0.65	0.35
BT8	70.56	0.16	0.90	0.49
AY2	60.62	0.14	0.78	0.42
AY3	54.15	0.12	0.69	0.38
AY4	108.60	0.24	1.39	0.76
AY5	14.19	0.03	0.18	0.10
AY6	25.77	0.06	0.33	0.18
AY7	30.99	0.07	0.40	0.22
AY8	16.51	0.04	0.21	0.11
AY9	39.29	0.09	0.50	0.27
AY10	52.80	0.12	0.68	0.37
AH1	26.79	0.06	0.34	0.19
AH2	81.86	0.18	1.05	0.57
AH3	70.71	0.16	0.91	0.49
AHN5	68.78	0.15	0.88	0.48
AHN6	49.71	0.11	0.64	0.35
AHN7	23.75	0.05	0.30	0.17
AHN8	35.62	0.08	0.46	0.25
AHN9	33.40	0.07	0.43	0.23
AHN10	23.46	0.05	0.30	0.16
AH12	23.07	0.05	0.30	0.16
AH15	16.80	0.04	0.22	0.12
AH16	103.38	0.23	1.32	0.72
AH18	92.38	0.21	1.18	0.64
AH19	106.28	0.24	1.36	0.74
AH21	100.01	0.22	1.28	0.70
AH22	93.25	0.21	1.19	0.65
AH23	81.62	0.18	1.05	0.57
AH25	19.02	0.04	0.24	0.13
AH26	46.29	0.10	0.59	0.32
AH29	53.82	0.12	0.69	0.37
KT1	170.86	0.38	2.19	1.19
kT2	96.92	0.22	1.24	0.67
KT3	102.03	0.23	1.31	0.71
KT4	88.13	0.20	1.13	0.61

Codes of Homes	Average radon Concentration (Bq/m^3)	Average radon exposure (WLM/y)	Effective dose to the lung (mSv/y)	Excess lifetime cancer risk (%)
KT6	176.27	0.39	2.26	1.23
KT7	104.93	0.23	1.34	0.73
KT8	37.02	0.08	0.47	0.26
KT10	35.62	0.08	0.46	0.25
TN3	47.88	0.11	0.61	0.33
TN4	40.74	0.09	0.52	0.28
TN5	39.72	0.09	0.51	0.28
TN6	31.18	0.07	0.40	0.22
TN7	32.68	0.07	0.42	0.23
TN9	36.10	0.08	0.46	0.25
TN10	43.17	0.10	0.55	0.30
TN11	37.74	0.08	0.48	0.26
Range	**4.05 - 176.27**	**0.01 - 0.39**	**0.05 - 2.26**	**0.03 - 1.23**
Mean ±Std.	**57.19 ± 38.91**	**0.12 ± 0.08**	**0.71 ± 0.48**	**0.39 ± 0.26**

Based on equations 1,3,5,6and 7 it was found that the Mean ±Std. of the radon concentration, radon exposure, effective dose to the lung and the excess lifetime cancer risk were 57.19 ± 38.91(Bq/m^3), 0.12 ± 0.08 (WLM/y), 0.71 ± 0.48 (mSv/y), 0.39 ± 0.26 (%) respectively while the range of values were between 4.05 - 176.27 (Bq/m^3), 0.01 - 0.39 (WLM/y), 0.05 - 2.26(mSv/y) and 0.03 - 1.23 (%) respectively (Table 4.2).

4.3 Spatial Distribution of indoor radon concentration at Kpong

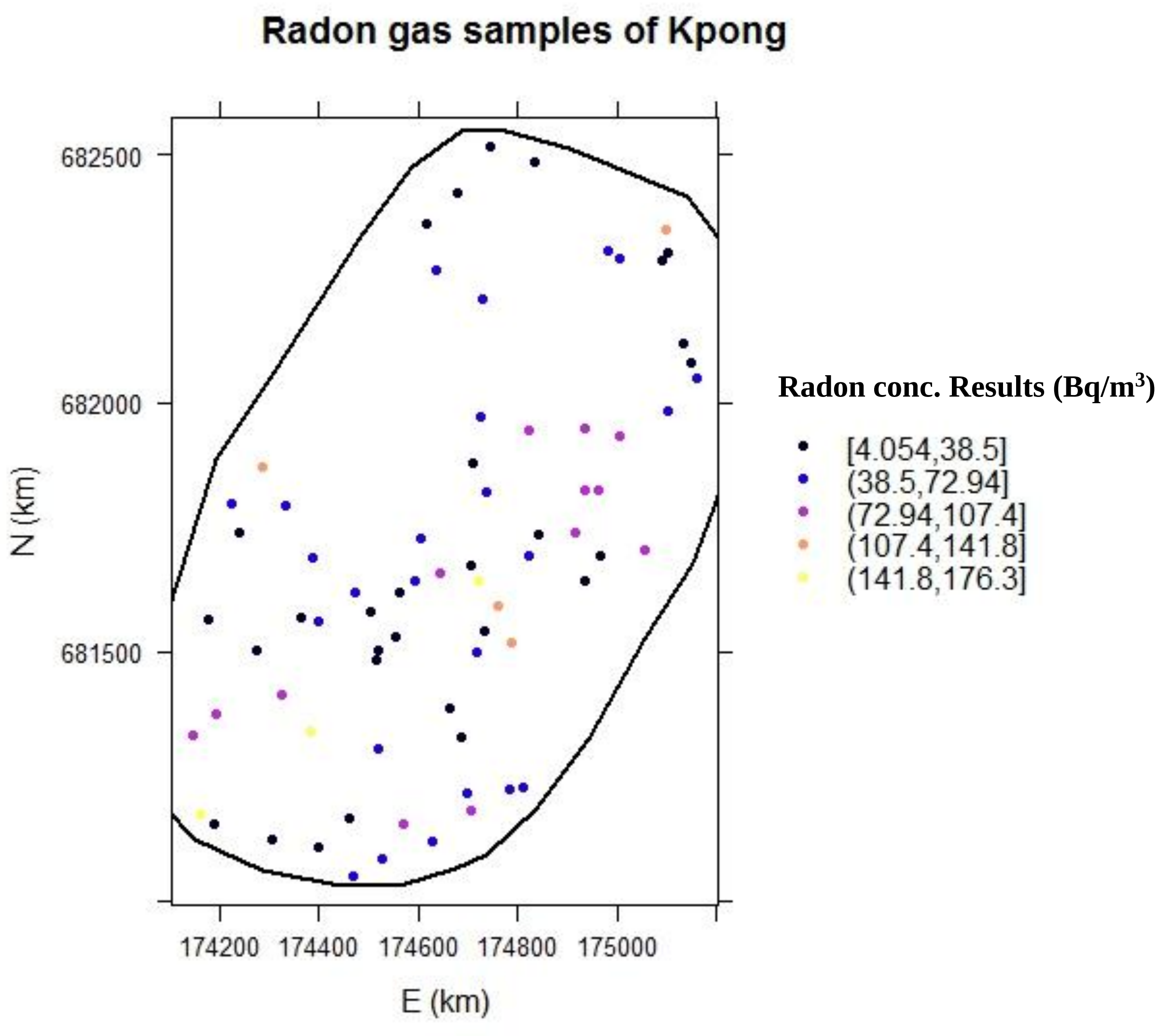


Fig. 4.6: Distribution of range of concentration within kpong

Almost all concentration levels from low to high seems to be evenly distributed within the area without any clear pattern (Fig.4.6).

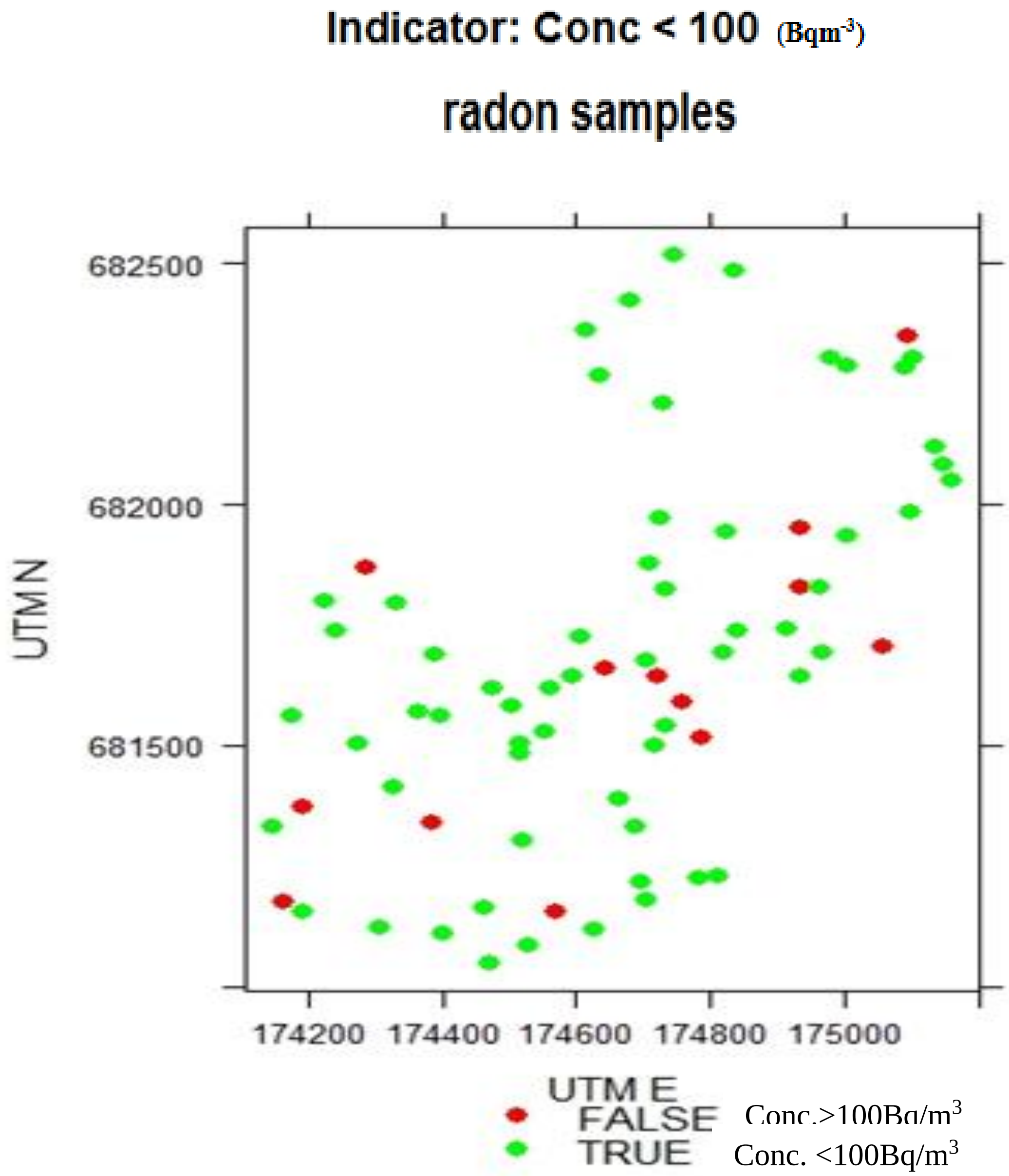
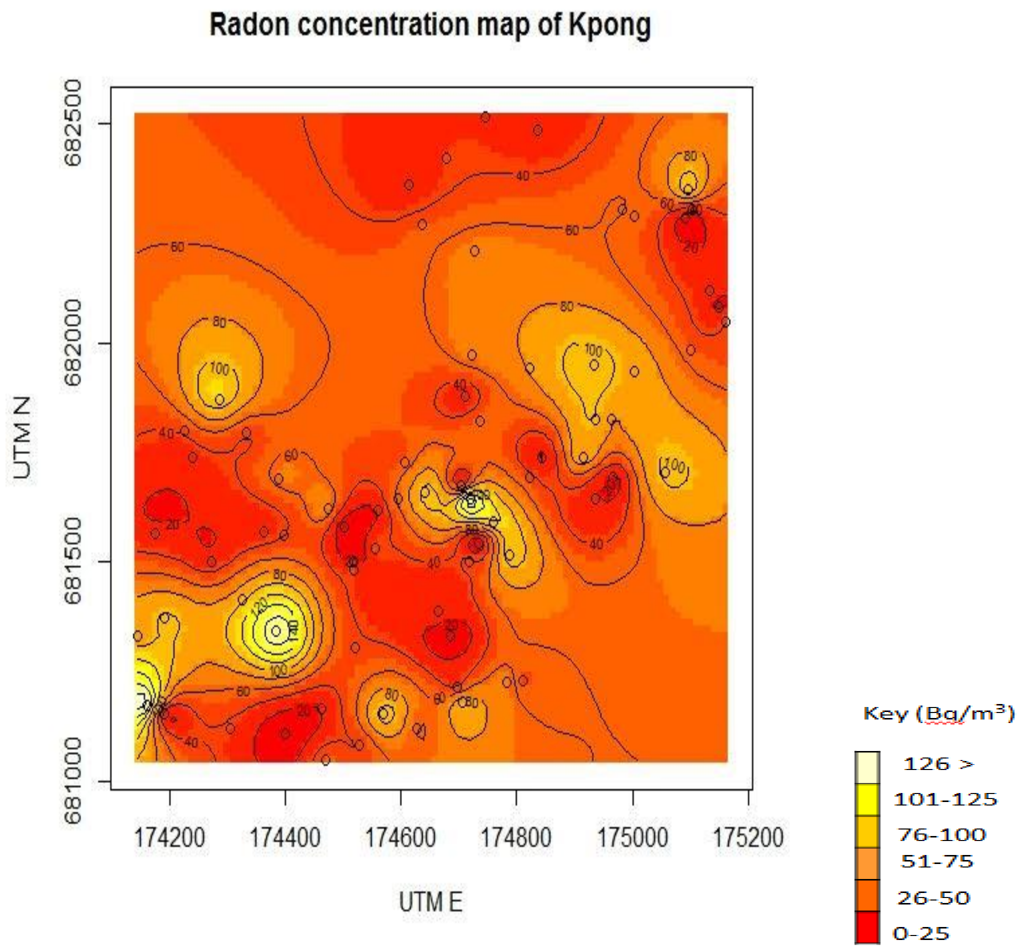


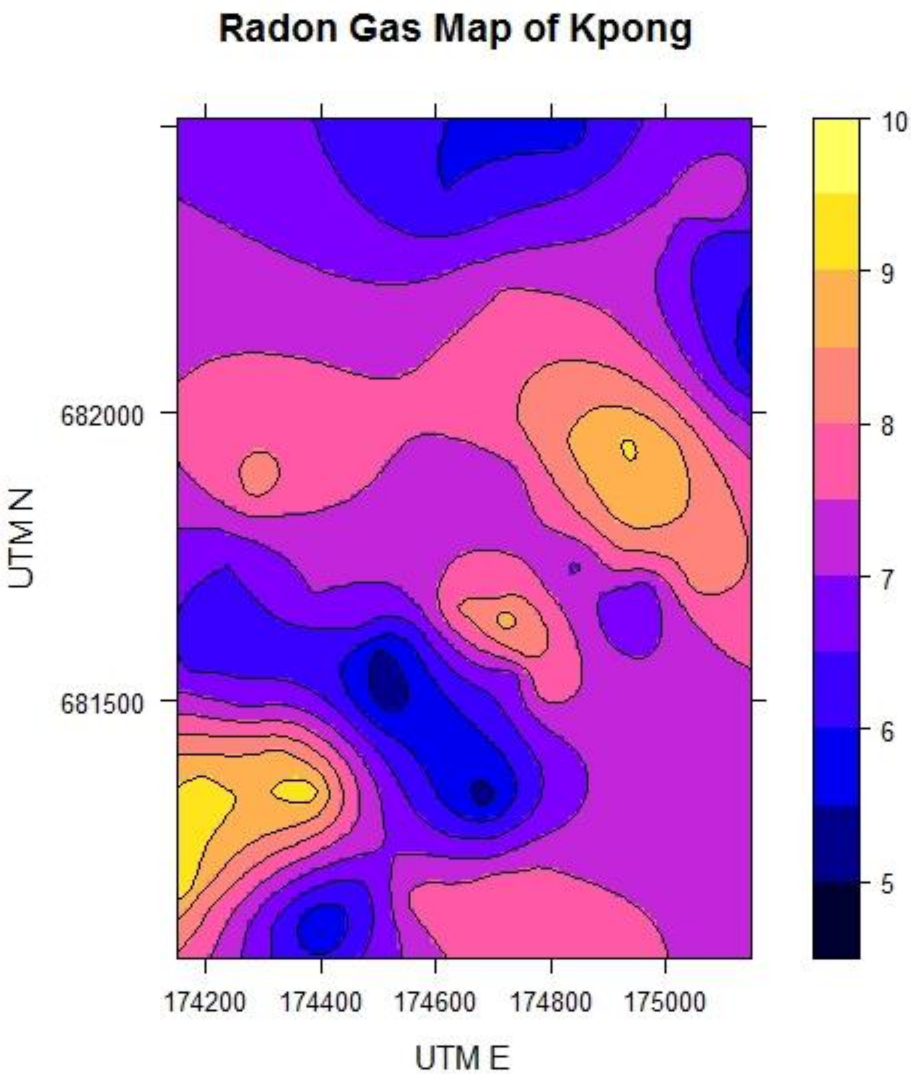
Fig 4.7: Spatial distribution of radon concentration below and above 100Bq/m^3 within the studied area.

There seem to be an even distribution of homes with Indoor radon concentrations above 100Bq/m^3 within the studied area (Fig.4.7).



Map 4.1: Map of indoor radon concentration at kpong based on Bayesian's model

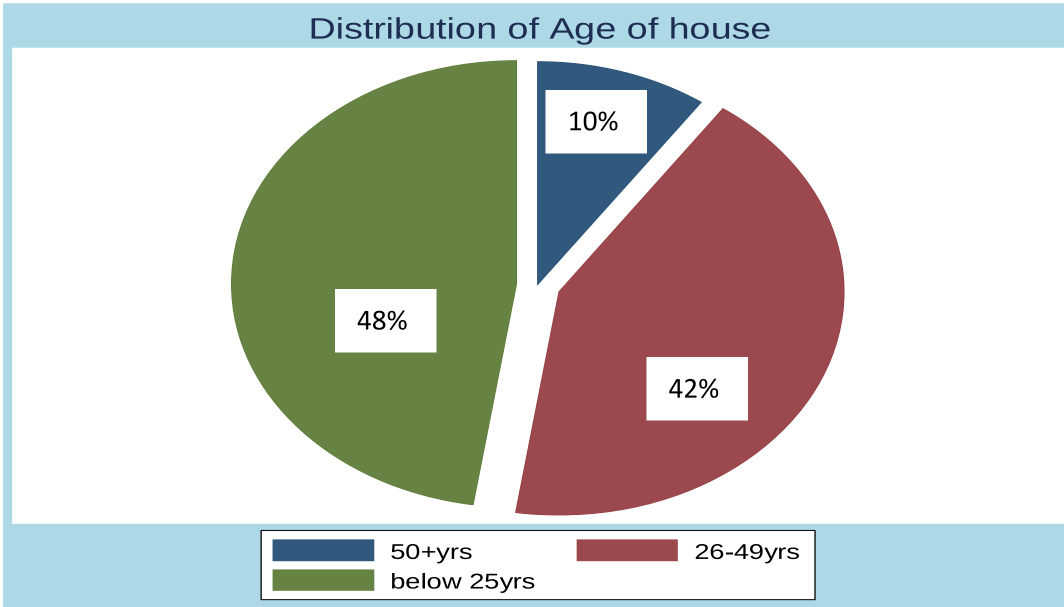
Areas with higher Indoor Radon Concentration seem to be evenly distributed within the studied area (Map.4.1).



Map 4.2: The log transformed map of indoor radon concentration at kpong using Krigging model

Areas with very low concentration (In5 Bq/m^3) are found to be within UTM E (174500-174700) and UTM N (681300-681600) (Map.4.2).

4.4 Housing Characteristics: Descriptive and statistical analysis



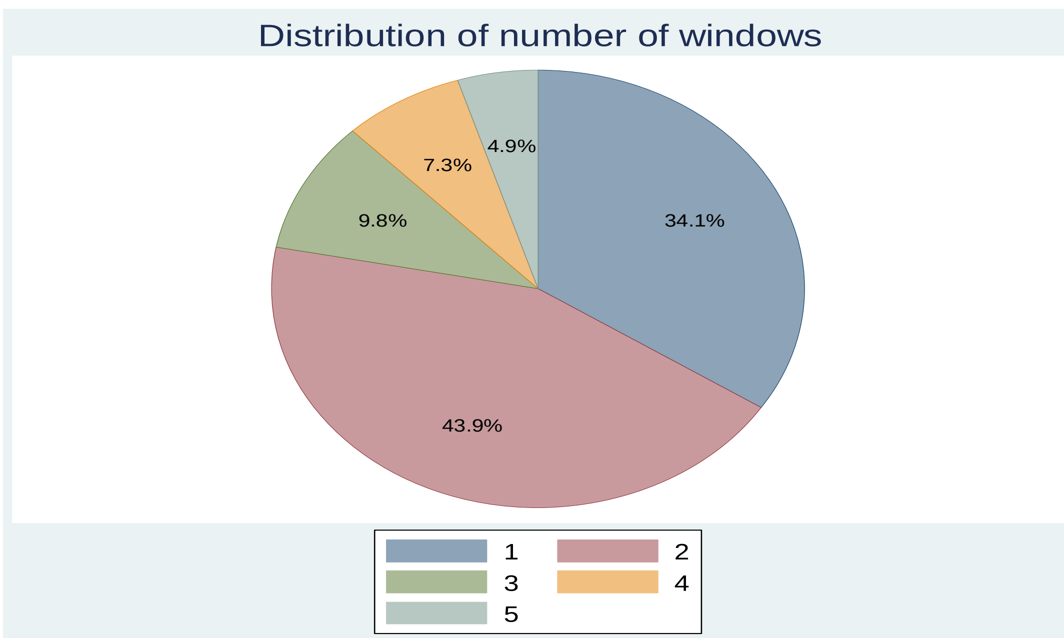


Fig 4.8: Frequency distribution of age of house and the number of windows in rooms reading were taken. ***Top*****:** Most (48%) of houses were below 25 yrs and ranges between 1 to 8yrs with a mean ± std of 28 ± 17yrs. ***Below*****:** Majority (44%) of rooms has two windows.

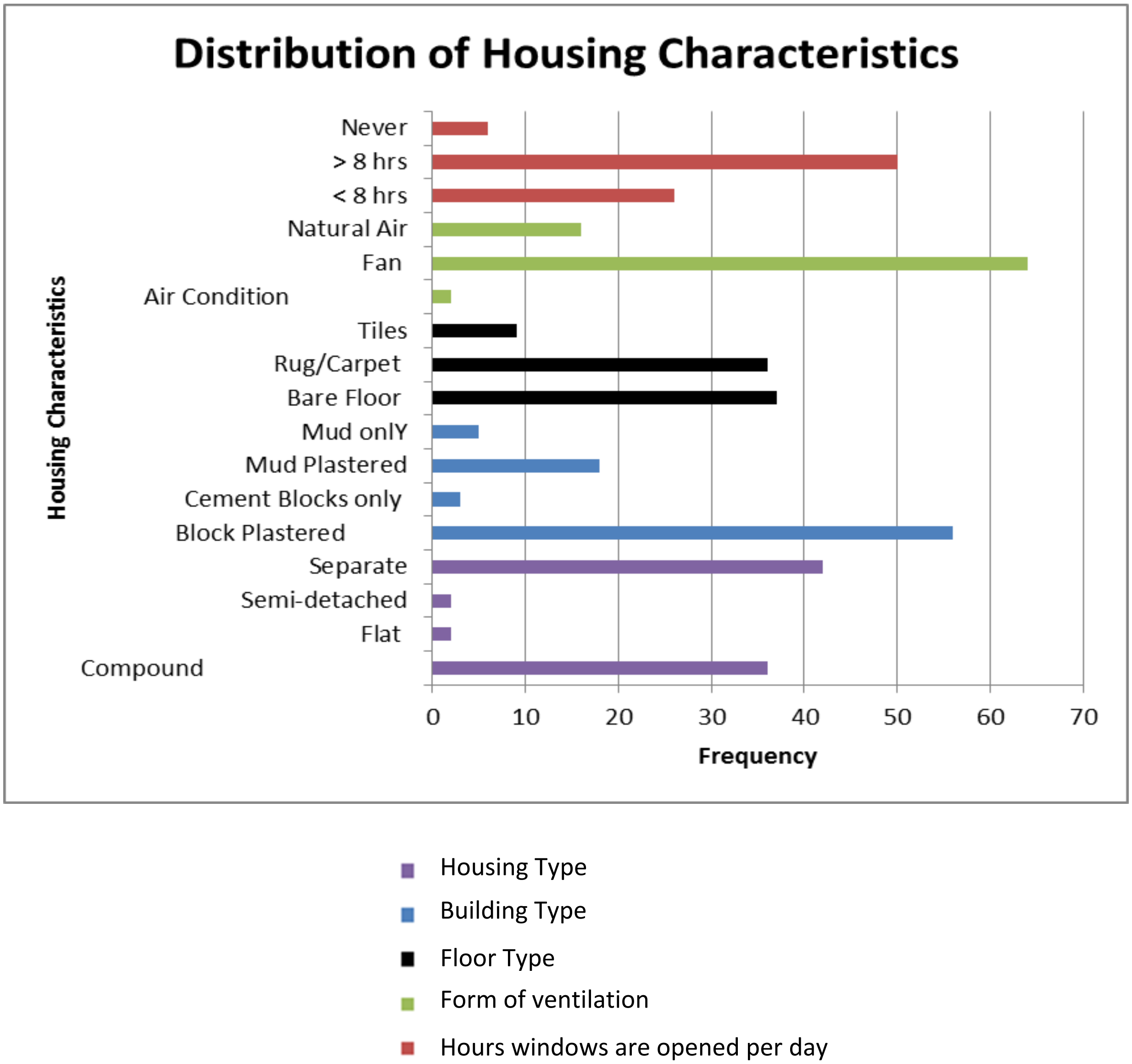
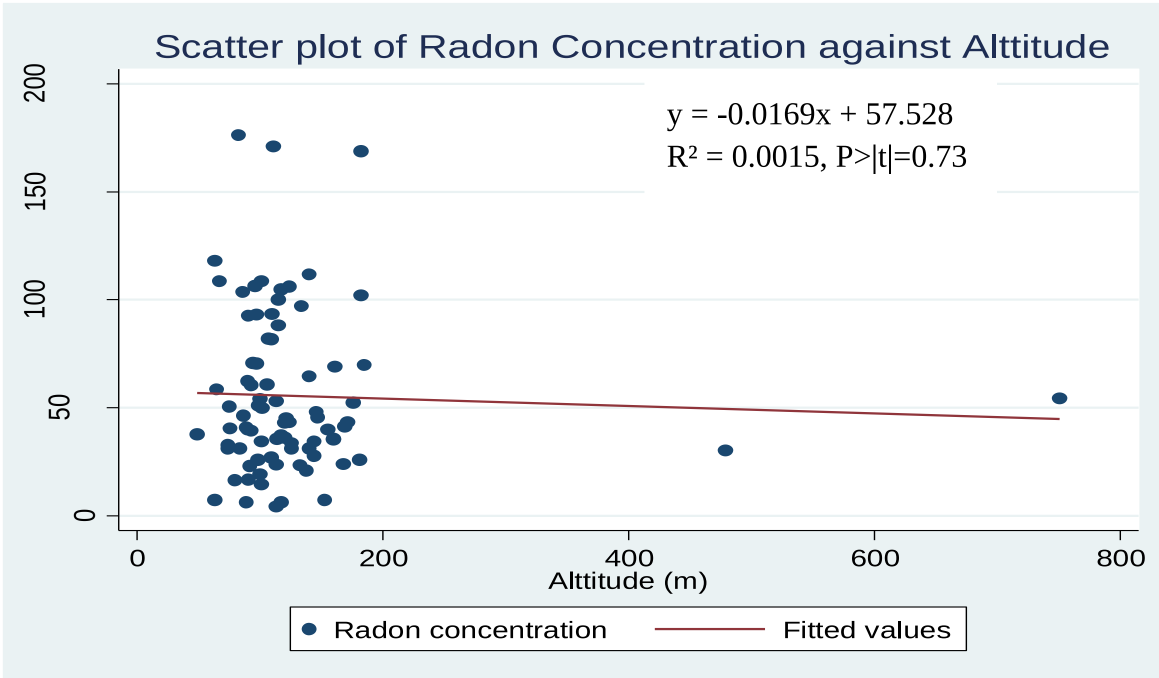


Fig.4.9: Frequency distribution of other housing types

Most (50, 63, 38, 58, and 42) of the 82 households open their windows more than 8 hours in a day, own fans, have bare floors with plastered blocks and the house are separate or they stand alone respectively (Fig.4.9).



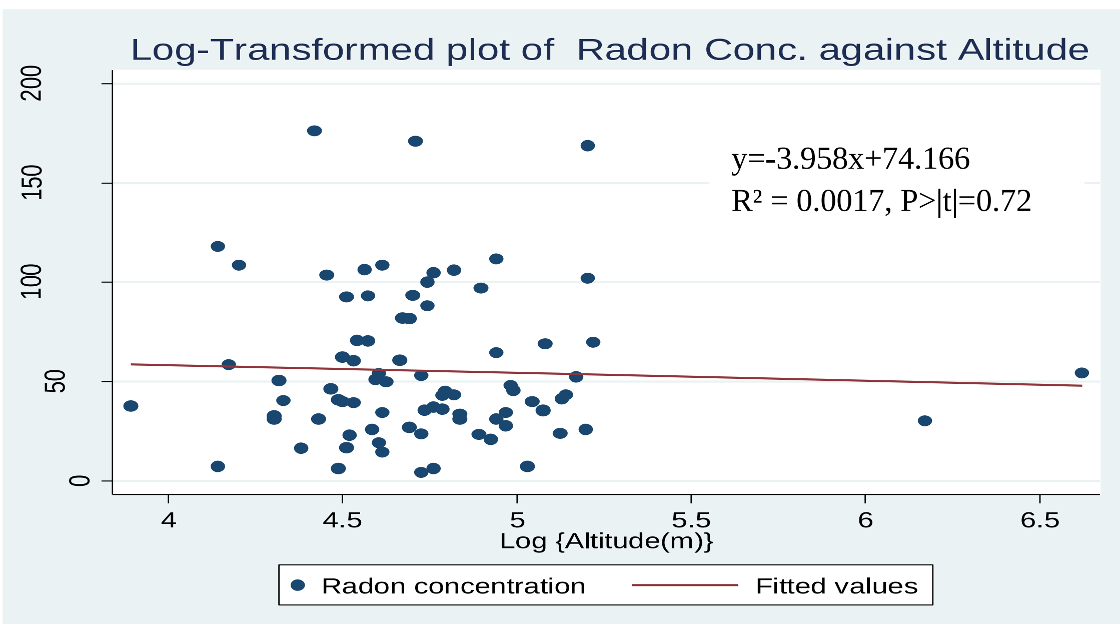


Fig.4.10: Correlation between indoor radon concentration and altitude

There is no significant relationship between radon concentration and altitude of both actual (*Top*) and adjusted (*Below*) plots (Fig.4.10).

Table 4.3: Correlation coefficients of radon concentration against housing characteristics

Housing Characteristics	Correlation coefficient	Significance level (0.050)
Building type	0.18	0.047
Housing type	0.01	0.857
Age of house	-0.02	0.944
Floor type	0.12	0.124
Ventilation type	0.10	0.200
Number of windows	0.16	0.161

All housing characteristisc show a very weak relation with radon concentration. With the exception of age of house all other housing characteristics show postive correlation with radon concentration. Based on the p. values of all housing characteristics, building type shows a significant relationship with IRC hence a good predictor of radon concentrations at 95% confidence level. With reference to houses built with blocks and plastered, mud house is a good predictor of indoor concentration; P.value 0.050 (=0.05)(Table.4.3).

With an F-Test of 1.47 at an allowable error of 5% and P.value 0.20 (>0.05), we fail to reject the null hypothesis and conclude that there is no significant relationship between radon concentration and housing characteristics. Adj.R^2 = 3.35% (only 3.35% of the variability in radon concentration is being explained by housing characteristics).

Table.4.4 Significance level of indoor radon concentration with building types

Building type	**Significant level**
Blocks only	0.639
Mud plastered	0.214
Mud house	0.050

With reference to houses built with blocks and plastered, mud house is a good predictor of indoor concentration (Table.4.4).

`CHAPTER FIVE

DISCUSSION

5.1 Description of surveyed Houses

This study was conducted at Kpong in the Eastern Region of Ghana. Participants included 112 households out of the 652 household populations; of which 82 came out valid. This study sample is the highest so far compared with other studies conducted in other areas in Ghana compiled by Yeboah (2014). But it is worth noting that these studies did not indicate the total housing population of which the samples were selected.

The summery of the participated houses included majority (48%) of buildings constructed in the early 90s to date. Houses built in this era use modern methods and improved building practices. It is not surprising that the majority (72%) of houses were built with cement blocks, only few (28%) were built with mud/earth. This is in line with the findings of the 2010 housing and population census of the municipality; cement blocks/concrete accounted for 69.7% with mud bricks/earth constituting 25.9% (GSS, 2010). Nearly two-thirds (63.9%) of all dwelling units in the Municipality are compound houses; 25.3% are separate houses and 5.2% are semi-detached houses (GSS, 2010). But with this study more than half (52%) of sampled dwelling units were separate houses; (42%) were compound houses and (2%) semi-detached. This might be due to the fact that most dwellings units were quite difficult to categorize.

5.2 Indoor radon concentration

Indoor radon exposure due to vapor invasion can lead to 22,000 deaths annually (WHO, 2009). The only way to know the presence of the naturally occurring, odorless, tasteless, and colorless gas is to test your home (EPA, 2015). In this study it was found that of the homes tested 84% resulted in detection of radon below 100 Bqm^{-3} with 16% above the recommended reference limit (100 Bq/m^3) by WHO (2009). A requirement for accurate testing requires that there is no direct air or heat blowing on the detectors once it is fixed but it is not possible to know if participants complied with this conditions which might have reduced detection and concentrations of radon in the home during screening tests.

The survey indicated that the average IRC was 57.19 ± 38.9 (Bq/m^3). The concentrations range from 4.05 - 176.27 (Bqm^{-3}) with house ZG23 recording the lowest and KT6 recording the highest. The mean value (57.19Bq/m^3) is 43% higher than the world's average IRC of 40Bq/m^3 (UNSCEAR, 2000). Compared with this study, the mean value (57.19Bqm^{-3}) is the third lowest among IRC study done in other parts of the country. While the study conducted in south eastern part of Ghana recorded 518.7 Bqm^{-3}, that of Kwabenya was 19 Bqm^{-3} (Yeboah, 2014). But it is interesting to note that the study conducted at Aburi (51.4 km from Kpong) and in the same region as the study site recorded 49.78 Bqm^{-3} which is quite close to the mean of this study. This might be due to the common bedrock formation of these two study sites. The Togo Formations (schists, quartzite and phyllites, unaltered shale and sandstone) are rocks forming the Akwapim range of hills trending northeast from the coast West of Accra through Kpong, Aburi, Anum into the Republic of Togo (Amponsah, 2002). The average IRC for the various communities ranged from 38.6-101.5 (Bq/m^3), with Tandor (community around Ensign Campus) recording the lowest and Kortokolie recording the highest. This might be due to difference in soil composition.

5.3 Correlation of indoor radon concentrations with other factors

Most studies (Jelle, 2012; Mäkeläinen et al., 2001, Kropat et al., 2014) confirm that housing characteristics have influence on the level of IRC. One of the objectives of this study was to test the hypothesis that there is a relationship between IRC and housing characteristics. In this study all housing characteristics (Housing Type, Building Type, Floor Type, Form of ventilation, age of house and number of windows) that were chosen correlated with IRC although very weak. With the exception of age of house all other housing characteristics showed postive correlation. Though there was an association, was it significant? With F-Test = 1.47 at an allowable error of 5% and P.value 0.20 (>0.05), we fail to reject the null hypothesis and conclude that there is no significant relationship between IRC and housing characteristics. Meanwhile from the multivariate analysis only 3.35% (Adj.R^2) of the variability in the IRC is being explained by the housing characteristics. On the other hand based on the p. values of all housing characteristics, building type showed a significant relationship with IRC hence a good predictor of radon concentrations at 95% confidence level.

In the same vain, altitude showed a weak negative correlation (-0.039) but it was not significant (P>|t|=0.72). Both linear correlation and log transformed graph indicated similar results.

5.4 Zoning of hazard areas

With respect to the radon map there was no clear pattern in the spatial distribution of the IRC levels in the studied area. This might be due to uncertainty like for example the house coordinates or elevation.

5.5 Determination of exposure and lifetime lung cancer risk

Using Eqns 5-7, radon exposure, effective dose and corresponding lung cancer risk in household have been estimated and summarized. The analyses indicate that the lung cancer risk increases proportionally with increasing radon exposure and IRC and vice versa. An average radon exposure in buildings was found to be 0.12 ± 0.08 (WLM/y). Effective radon dose to the lung received by dwellers was 0.71 ± 0.48 (mSv/y). Estimated average annual effective dose due to radon decay products received by inhabitants has been found lower than the upper annual dose limit of 1mSv, recommended by the ICRP (WHO, 2004).

The excess lifetime cancer risk attributed to the dwellers has range 0.03 - 1.23 (%) with an average value of 0.39 ± 0.26 (%). The estimated risks are very small as compared with the estimated risk of 2.3 for entire population from the lifetime exposure at 4pCi/l (148Bq/m^3); the action level proposed by EPA (EPA, 2003). Seemingly, the time spent by individuals in home varies widely worldwide. The occupancy factor of 0.8 (ICRP, 1993) over estimates the excess lung cancer risk in the tropical regions but may be valid for the inhabitants of the temperate zone. In the tropical regions, people spend most of their time outdoors and mainly go indoors to sleep at night hence an occupancy factor of 0.4 is suitable for such instance (Nsiah-Akoto, 2011). The low occupancy might contribute to the very low excess lung cancer risk estimated in this study.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the above study it is concluded that:

- The average indoor radon concentration at Kpong lies below the recommended level so the studied area is safe as far as radon health hazards effects are concerned. Notwithstanding, thirteen houses were found to be above the WHO recommended level hence the need for remediation for these homes.
- The estimated lung cancer risk is very small as compared with the EPA recommended estimated risk hence dwellers are safe as far as risk attributable to radon exposure is concerned.
- Though not significant, there is correlation between the selected housing characteristics and IRC. Houses constructed with mud on the other hand showed significant relation hence a good predictor of IRC at Kpong.
- The created hazard (radon) map of Kpong did not indicate any clear pattern but contributes spatially to our understanding of IRC at Kpong.

6.3 Recommendations

Based on the conclusions, inferences and limitations of this study, below are the recommendations:

- The inhabitants of rooms with concentration levels above $100Bq/m^3$ are advised to ensure good ventilation practices as the cost effective means of mitigation of indoor radon gas level. Occupants are again encouraged to seal opening or cracked areas in contact with soil such as spaces around bathtub, shower or toilet drains with materials that provide permanent air tight seal such as non- shrink mortar, grouts expanding foam or similar.
- The need for regulations and national policy on radon mitigation measures which will allow assessment of radon levels in households, workplaces, schools etc should be considered by Regulatory Authorities.
- The EPA of Ghana, Ghana Health Service and Radiation Protection Board of GAEC should work hand in hand to organize public forums to sensitize the general public about the related health risk to indoor radon exposure.
- To researchers alike further studies to determine and understand the correlation between IRC and housing characteristics as well as other factors such as soil radon concentrations and atmospheric factors should be considered. Again studies in other parts of the country should be encouraged to collate more data to enhance the development of radon map for Ghana to assist the identification of the radon prone areas in the country and also to help build or establish a national reference level.

REFERENCES

1. International Commission on Radiological Protection (ICRP), 1993. Protection against Radon-222 at home and at work. ICRP Publication 65, Annals of the ICRP. Vol. 23, Pergamon Press, Oxford.

2. American Cancer Society (ACS), 2016. Radon and Cancer. Retrieved from 12Q11http://www.cancer.org/cancer/cancercauses/othercarcinogens/pollution/radon on June 24, 2016.

3. National Toxicology Program (NTP), 2014. Report on Carcinogens, Thirteenth Edition: Ionizing Radiation. Accessed at http://ntp.niehs.nih.gov/ntp/roc/content/profiles/ionizingradiation on June 15, 2016.

4. Lubin, J.H., Wang, Z.Y., Boice, J.D., Xu, Z.Y., Blot, W.J., De Wang, L. and Kleinerman, R.A., 2004. Risk of lung cancer and residential radon in China: pooled results of two studies. *International Journal of Cancer*, 109(1), pp.132-137.

5. Krewski, D., Lubin, J.H., Zielinski, J.M., Alavanja, M., Catalan, V.S., William Field, R., Klotz, J.B., Létourneau, E.G., Lynch, C.F., Lyon, J.L. and Sandler, D.P., 2006. A combined analysis of North American case-control studies of residential radon and lung cancer. *Journal of Toxicology and Environmental Health*, Part A, 69(7-8), pp.533-597.

6. Darby, S., Hill, D., Deo, H., Auvinen, A., Barros-Dios, J.M., Baysson, H., Bochicchio, F., Falk, R., Farchi, S., Figueiras, A. and Hakama, M., 2006. Residential radon and lung cancer—detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14 208 persons without lung cancer from 13 epidemiologic studies in Europe. *Scandinavian journal of work, environment & health*, pp.1-84.

7. Environmental Protection Agency (EPA), 2016. Health Risk of Radon. Retrieved from https://www.epa.gov/radon/health-risk- radon on June 24, 2016.

8. International Agency for Research on Cancer (IARC), 2013. Monographs on the evaluation of carcinogenic risks to humans: Internalized α-particle emitting radionuclides, Vol. 100D-9. Accessed at http://monographs.iarc.fr/ENG/Monographs/vol100D/mono100D-9.pdf on July 2, 2016.

9. Risica, S., 1998. Legislation on radon concentration at home and at work. *Radiation Protection Dosimetry*, 78(1), pp.15-21.

10. Hamori, K.E. and Koteles, T.G., 2004. Radon level of hungarian flat (1994-2004). *Egeszsegtudomany*, 48: 283-299.

11. Demoury, C., Ielsch, G., Hemon, D., Laurent, O., Laurier, D., Clavel, J. and Guillevic, J., 2013. A statistical evaluation of the influence of housing characteristics and geogenic radon potential on indoor radon concentrations in France. *Journal of environmental radioactivity*, 126, pp.216-225.

12. Nations, U., 2008. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

13. Nsiah-Akoto, I., Fletcher, J.J., Oppon, O.C. and Andam, A.B., 2011. Indoor radon levels and the associated effective dose rate determination at Dome in the Greater Accra Region of Ghana. *Research Journal of Environmental and Earth Sciences*, 3(2), pp.124-130.

14. Environmental Protection Agency (EPA), 2012. A Citizen's Guide to Radon. Accessed at www.epa.gov/radon/pubs/citguide.html on June 24, 2016.

15. George, A.C., 2015. The history, development and the present status of the radon measurement programme in the United States of America. *Radiation protection dosimetry*, p.ncv213.

16. Choukri, A. and Hakam, O.K., 2015. Volumic activities measurements and equivalent doses calculation of indoor 222Rn in Morocco. *International Journal of Cancer Therapy and Oncology*, *3*(3).

17. Singh, S., Kumar, A. and Singh, B., 2002. Radon level in dwellings and its correlation with uranium and radium content in some areas of Himachal Pradesh, India. *Environment International*, 28(1), pp.97-101.

18. Quashie, F.K., Fletcher, J.J., Oppon, O.C., Asumadu-Sakyi, A.B., Wordson, D.A., Adjei, C.A., Amartey, E.O. and Amponsah, P., 2011. Preliminary studies on indoor radon measurements in some adobe houses in the Kassena Nankana area of the upper east region of Ghana. *Research journal of environmental and earth sciences*, *3*(1), pp.51-55.

19. World Health Organization (WHO), 2004. Radon and Health, Information Sheet. Accessed at

20. www.who.int/phe/radiation/en/2004Radon.pdf on July 28, 2016.

21. Afolabi, O.T., Falode, D., Onayade, A.A. and Tobih, J.E., 2015. Radon Risk Awareness Among University Employees Of Obafemi Awolowo Univeristy, Ile-Ife. *American Association of Radon Scientist (AARST)*, pp.1-9.

22. Cheng, W., 2016. Radon Risk Communication Strategies: A Regional Story. *Journal of environmental health*, 78(6), p.102.

23. Foster, S., Dent, A., Bryant, J., Tencza, B., Adams, E. and Dutton, N.D., 2015. Are schools safe from indoor radon?. *Journal of environmental health*, 77(10), p.38.

24. Nita, D.C., Moldovan, M., Sferle, T., ONAd, V.D. and Burghele, B.D., 2013. Radon concentrations in water and indoor air in north-west regions of Romania. *cancer*, *2*, p.3.

25. IAEA 2013, National and Regional Surveys of Radon Concentration in Dwellings, Review of Methodology and Measurement Techniques *Analytical Quality in Nuclear Applications Series No. IAEA/AQ/33*

26. World Health Organization (WHO), 2015. Radon. Retrieved from http://www.who.int/ionizing_radiation/env/radon/en/ on June 28, 2016

27. World Health Organization, 2009. WHO handbook on indoor radon: a public health perspective. World Health Organization.

28. Badoe, L.G., Andam, A. and Sosu, E.K., 2012. Measurement of radon gas level in Ashanti region and design of a radon vulnerability map for Ghana. *Research Journal of Environmental and Earth Sciences*, *4*(1), pp.76-81.

29. Amponsah, P.E., 2002. Seismic activity in relation to fault systems in southern Ghana. *Journal of African Earth Sciences*, *35*(2), pp.227-234.

30. Ghana Statistical Service (GSS), 2010. Population and Housing Census Final Report

31. Yeboah, S.M., 2014. Indoor Radon in Selected Homes in Aburi Municipality: Measurement Uncertainty, Decision Analysis and Remediation Strategy (Doctoral dissertation, University of Ghana).

32. Nations, U., 2000. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

33. World Nuclear Association, 2016. Radioactive decay in the Uranium and Thorium series. Accessed at http://www.world nuclear association on 18th October 2016.

34. International Commission on Radiological Protection (ICRP), 1993. Protection against radon-222 at home and at work. ICRP Publication 65. Annals of the ICRP 23(2).

35. Nielson, K.K., Rogers, V.C., Holt, R.B., Pugh, T.D., Grondzik, W.A. and de Meijer, R.J., 1997. Radon penetration of concrete slab cracks, joints, pipe penetrations, and sealants. *Health physics*, *73*(4), pp.668-678.

36. Nations, U., 1988. Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

37. Nero, A.V., 1988. Estimated risk of lung cancer from exposure to radon decay products in US homes: a brief review. *Atmospheric Environment (1967)*, *22*(10), pp.2205-2211.

38. Nero, A., 1989. Earth, air, radon and home. *Physics today*, *42*(4), pp.32-39.

39. Nations, U., 2006. Sources-to- effects assessment of radon in homes and workplaces. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

40. Swedjemark, G.A., Mellander, H. and Mjönes, L., 1993. Radon levels in the 1988 Swedish housing stock (No. NEI-FI--222 (V. 4).

41. Sciocchetti, G., Clemente, G.F., Ingrao, G. and Scacco, F., 1983. Results of a survey on radioactivity of building materials in Italy. *Health physics*, *45*(2), pp.385-388.

42. Groves-Kirkby, C.J., Denman, A.R., Crockett, R.G.M., Phillips, P.S. and Gillmore, G.K., 2006. Identification of tidal and climatic influences within domestic radon time-series from Northamptonshire, UK. Science of the Total Environment, 367(1), pp.191-202.

43. Miles, J., 2001. Temporal variation of radon levels in houses and implications for radon measurement strategies. Radiation Protection Dosimetry, 93(4), pp.369-375

44. Cucoş, A., Cosma, C., Dicu, T., Begy, R., Moldovan, M., Papp, B., Niţă, D., Burghele, B. and Sainz, C., 2012. Thorough investigations on indoor radon in Băiţa radon-prone area (Romania). Science of the total environment, 431, pp.78-83.

45. Hauri, D.D., Huss, A., Zimmermann, F., Kuehni, C.E. and Röösli, M., 2012. A prediction model for assessing residential radon concentration in Switzerland. *Journal of environmental radioactivity*, 112, pp.83-89.

46. Kropat, G., Bochud, F., Jaboyedoff, M., Laedermann, J.P., Murith, C., Palacios, M. and Baechler, S., 2015. Predictive analysis and mapping of indoor radon concentrations in a complex environment using kernel estimation: An application to Switzerland. *Science of The Total Environment*, *505*, pp.137-148.

47. Kropat, G., Bochud, F., Jaboyedoff, M., Laedermann, J.P., Murith, C., Palacios, M. and Baechler, S., 2014. Major influencing factors of indoor radon concentrations in Switzerland. *Journal of environmental radioactivity*, 129, pp.7-22.

48. Jelle, B.P., 2012. Accelerated climate ageing of building materials, components and structures in the laboratory. *Journal of materials science*, 47(18), pp.6475-6496.

49. Mäkeläinen, I., Arvela, H. and Voutilainen, A., 2001. Correlations between radon concentration and indoor gamma dose rate, soil permeability and dwelling substructure and ventilation. *Science of the total environment*, 272(1), pp.283-289.

50. International Commission on Radiological Protection (ICRP), 2005. Recommendations of the International Commission on Radiological Protection.

51. Environmental Protection Agency (EPA), (2016). Health Risk of Radon. Retrieved from https://www.epa.gov/radon/health-risk- radon on June 24, 2016.

52. National Council on Radiation Protection and Measurements, 1988. Measurements of radon and radon daughters in air. NCRP Report No.97.

53. Henshaw, D.L., Ross, A.N., Fews, A.P. and Preece, A.W., 1996. Enhanced deposition of radon daughter nuclei in the vicinity of power frequency electromagnetic fields. *International journal of radiation biology*, *69*(1), pp.25-38.

54. .Letourneau, E.G., Krewski, D., Choi, N.W., Goddard, M.J., McGregor, R.G., Zielinski, J.M. and Du, J., 1994. Case-control study of residential radon and lung cancer in Winnipeg, Manitoba, Canada. *American journal of epidemiology*, 140(4), pp.310-322

55. International Commission on Radiological Protection (ICRP), 1991. Recommendations of the International Commission on Radiological Protection, ICRP Publication 60. *Annals of the ICRP, Pergamon Press, Oxford*. Vol. 21.

56. National Research Council (NRC), 1988. Health risks of radon and other internally deposited alpha emitters: BEIR IV The National Academies Press 1026

57. National Research Council. 1983. Risk assessment in the federal government. Managing the process. National Academy Press, Washington, DC.

58. National Research Council (NRC), 1999. Health effects of exposure to radon: BEIR VI. Washington, DC: The National Academies Press 5499 https://www.nap.edu/ March 25, 2017

59. Mattsson, S. and Söderberg, M., 2013. Dose quantities and units for radiation protection. In Radiation Protection in Nuclear Medicine (pp. 7-18). Springer Berlin Heidelberg.

60. National Institutes of Health (NIH), 1994. Radon and lung cancer risk: A joint analysis of 11 underground miners studies. Bethesda, MD: National Institutes of Health; NIH publication no. 94-3644.

61. STATE, U., 1992. Indoor radon and radon decay product measurement device protocols. Environmental Protection Agency (EPA) Office of Air and Radiation 6604J, EPA 402-R-92-004

62. Fleischer, R. L., Price, P. B. and Walker, R. M., 1975. Nuclear Tracks in Solids: Principles and Applications, University of California Press, Berkeley.

63. Tommasino, L., 1997. Track registration: Etching and counting methods for nuclear tracks. *Radon Measurements by Etched Track Detectors-Applications in Radiation Protection, Earth Sciences. Edited by ILIC RADOMIR ET AL. Published by World Scientific Publishing Co. Pte. Ltd., 1997. ISBN# 9789812830197, pp. 129-141*

64. Nsiah-Akoto, I., Andam, A.B., Amponsah, P.E. and Hood, C.O., 2013. The radon health hazards education in Ghana. *Elixir Geoscience*, *56*, pp.13399-13401.

65. Data Protection Act, 1998. Data protection principle. Accessed at http://www.opsi.gov.uk/acts/acts1998/19980029.htm on 1/ 02/2017

66. Environmental Protection Agency, EPA 2003. 400-R-03-003. U.S. Environmental Protection Agency, Washington, DC 20460

APPENDIX

Part 1. Participant Information

Introduction

I am from Ensign College of Public Health in Kpong. I am conducting a study that involves research to investigate indoor radon levels in Kpong to help provide measures to reduce the risk caused by Radon inhalation. I will be explaining all about the study to you and you will also receive a copy of the leaflet that explains all about this research study that you are being asked to join in. Please take all the time you need to read it carefully. You may ask me any questions about anything you do not understand at any time. You are a volunteer. You can choose not to take part and if you join, you may quit at any time. There will be no penalty if you decide to quit the study.

Why you are being asked to participate

You have been asked to take part in this study because you live in Kpong in the Lower Manya Krobo Municipality of Eastern Region. Specifically, I am interested in measuring the level of Radon; a radioactive gas in the homes of people and in all I plan to ask such people to participate in the study.

Procedures

If you agree to be part of the study, a trained project staff will ask you a series of survey questions alone for approximately 5 – 10 minutes. A Radon Detector would be placed on the wall of either your bedroom or hall or both. Your responses will be recorded electronically on a laptop by the study staff. As a participant, if you agree to participate in this study, data from your responses may be used as part of my investigation of identifying the level of radon in the household of participates and their level of exposure, which has a potential of leading to Lung Cancer.

Risk and Benefits

I anticipate minimal or no risk to you. There may be direct benefit to you for being in the study; in the sense that if your home is identified to record high radon level beyond that recommended by World Health Organisation(WHO) of $100 Bq/m^3$, the nececessary remediation methods will be provided for your home.

Confidentiality

All data will be de-identified and will be kept private. Your identifiable data such as house Number or Contact Number will not be used in documents, reports, or publications related to this research.
I will keep all documents secured and under locked.

When typing your survey responses into the computer, all data will be entered without any information that will make it possible for your identity to be known. The information you provide will be kept strictly confidential and will be available only to persons related to the study. (myself and my supervisors) The Office of Ethical Review Board of Ensign College may also have access to study records upon their request.
Your responses will not be shown to other participants or community members. The original survey forms will be deleted once data entry is complete.

Voluntariness and Withdrawal
Your participation in the study is completely voluntary and you reserve the right not to participate, even after you have taken part, to withdraw. This is your right and the decision you take will not be disclosed to anyone. If you join the study, you can change your mind later. You can choose not to take part and you can quit at any time. There will be no negative consequences if you choose not to participate in the study. Please note however, that some of the information that may have been obtained from you without identifiers, before you chose to withdraw, may be used in analysis reports and publications.

Cost/Compensation
Your participation in this study will not lead to you incurring any monetary cost during or after the study.

Who to contact
This study has been approved by the Institutional Review Board of Ensign College. If you have any concern about the conduct of this study, your welfare or your rights as a research participant or if you wish to ask questions, or need further explanations later, you may contact me. Doris Kitson-Mills (0240455938) of Ensign College of Public Health, or My supervisor Dr. Simon Sovoe (0246099870) You may also contact the Adminitrator of the Institutional Ethics Committee of the Ensign College of Public Health at (+233245762229).

Thank you.

Do you have any questions?

<u>Part 2. CONSENT DECLARATION</u>

"I have read the information given above, or the information above has been read to me. I have been given a chance to ask questions concerning this study; questions have been answered to my satisfaction. I now voluntarily agree to participate in this study knowing that I have the right to withdraw at any time without affecting future health care services"

Left thumbprint of participant

Name of **participant** _______________________________________

Signature of **Participant** ____

Date: / / 2016

Name of **witness** ____

Signature of **witness** ____

Date: / / 2016

Name of **investigator** ____

Signature of **investigator** ____

Date: / / 2016

Indoor Radon Assessment Survey

Record Identifiers

Monitor ID [ ] Time placed [ ] Date placed [ ]

Area Monitered [ ] Time removed [ ] Date removed [ ]

House Cordinates

Latitude [ ] Longitude [ ] Altitude [ ]

House number [ ]

Contact Numbers

Cell 1 [ ] Cell 2 [ ]

Demographic Information

Occupants in Room [ ]

Occupant 1

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 2

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 3

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 4

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 5

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 6

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 7

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

Occupant 8

Age [ ] Sex Female Years of Occupancy [ ] Occupation [ ] Edu. Level None

House Characteristics

Construction Year [ ] Form of Ventilation [Air Condition]

Room Tested [Hall] No_ of Windows [None] Foundation Type [Concrete]

Floor Type [Bare Floor] Building Type [Cement Blocks only]

Housing Type [Flat]

Knowledge on Radon

Have you heard of Radon? [Yes] If Yes what is it? [ ]

Do you think Radon can cause asthma? [Yes]

Do you think Radon can cause cancer? [Yes]

Lifestyle and History on cancer

How long do you open your windows in a day? [Never]

Do you keep water in your room? [ ]

Do you or any of the occupants smoke? [ ]

If yes how many? [ ]

Have you or any of your family member has cancer before? [ ]

If yes what cancer was it? [ ]

ENSIGN COLLEGE OF PUBLIC HEALTH - KPONG

OUR REF: ECOPH/DO/EL/ SDT045 /01
YOUR REF:
Tel: +233 245762229
Email: info@ensign.edu.gh
Website: www.ensign.edu.gh

P. O. Box AK 136
Akosombo
Ghana

August 9, 2016

The Traditional Leadership
Kpong

Dear Sir/Madam,

<u>INTRODUCTORY LETTER- DORIS KITSON-MILLS</u>

We write to respectfully introduce to you **Mrs. Doris Kitson- Mills** (Student Identification number **15100045**) a first year student of the Master of Public Health (MPH) degree program of the Ensign College of Public Health.

Ensign College of Public Health (ECOPH) is accredited by the National Accreditation Board (NAB) of Ghana and affiliated to the Kwame Nkrumah University of Science and Technology (KNUST) and collaborating with the University of Utah in the USA for the delivery of the programme. The College is located at Kpong on the main Tema- Akosombo Highway.

As part of her graduation requirements, Mrs. Kitson-Mills is writing a project work on: **Analysis of indoor Radon levels in some selected household in Kpong.** She will like to obtain some history about the community and be permitted to have access to the community for the work.

We would be grateful if you kindly accede her any assistance she may require.

Should you require any further clarification please contact the undersigned.

Respectfully yours,

Dr. Christopher N. Tetteh
Dean of the College

ENSIGN COLLEGE OF PUBLIC HEALTH - KPONG

OUR REF: ECOPH/DO/EL/ SDT045 /02
YOUR REF:
Tel: +233 245762229
Email: info@ensign.edu.gh
Website: www.ensign.edu.gh

P. O. Box AK 136
Akosombo
Ghana

August 9, 2016

The Municipal Director of Health Services
Lower Manya Krobo Municipal
Eastern Region

Dear Sir/Madam,

INTRODUCTORY LETTER- DORIS KITSON-MILLS

We write to respectfully introduce to you **Mrs. Doris Kitson- Mills** (Student Identification number **15100045**) a first year student of the Master of Public Health (MPH) degree program of the Ensign College of Public Health.

Ensign College of Public Health (ECOPH) is accredited by the National Accreditation Board (NAB) of Ghana and affiliated to the Kwame Nkrumah University of Science and Technology (KNUST) and collaborating with the University of Utah in the USA for the delivery of the programme. The College is located at Kpong on the main Tema- Akosombo Highway.

As part of his graduation requirements, Mrs. Kitson-Mills is writing a project work on: **Analysis of indoor Radon levels in some selected household in Kpong.** She will like to obtain some history about the community from your directorate and be permitted to have access to the community for the work.

We would be grateful if you kindly accede her any assistance she may require.

Should you require any further clarification please contact the undersigned.

Respectfully yours,

Dr. Christopher N. Tetteh
Dean of the College