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Seasonal Radon Concentration Measurements at Sawa Lake, Samawa City-South of Iraq

**A Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master in Physics Science**

By

Ahmed Augab Sharrad

B.Sc. in Physics

Supervisor

Prof. Dr. Abdulalmeer Kazem Farhood

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

يَرْفَعُ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ

دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ

صَدَقَ اللَّهُ الْعَلِيِّ الْعَظِيمِ

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Certification

I certify that this thesis entitled “*Seasonal Radon Concentration Measurements at Sawa Lake, Samawa City-South of Iraq*” was prepared by “*Ahmed Augab Sharrad*” under my supervision at the Department of Physics, College of Science, Al-Muthanna University, as a part of the requirements of the Master degree of Science in physics.

Prof. Dr. Abdulalmeer Kazem Farhood

Supervisor

Recommendations of the Head of the Physics Department

In view of the available recommendations, I forward this thesis for debate by the examining committee.

Dr. Salah A. Hassan

Head of the Department

Abstract

In the present study, seasonal measurements of radon activity concentration were carried out for water and soil of Sawa Lake, Samawa City-South of Iraq. The measurements were conducted in two seasons, winter and spring, using RAD7 continuous radon monitoring detector manufactured by DurrIDGE company, USA.

For winter season, (85) water samples were collected from different locations; the period of assessment was two months (from December, 1st 2018 to February, 1st 2019). Radon activity concentrations were ranged from (0.085 Bq/L) to (0.965 Bq/L), while the average value was (0.322 Bq/L), the annual effective dose (AED) of inhalation was estimated and is found to be ranged from (0.000080 mSv.y⁻¹) to (0.000917 mSv.y⁻¹) with a mean value of (0.000325 mSv/y). Radon measurements during the spring season have been carried out with a period of two months (from March 1st, 2019, to April 26, 2019). Radon concentrations have been determined for (85) collected water samples and found to be in the range of (0.093±0.085 Bq/L) and (1.15±0.35 Bq/L) with an average value of (0.409±0.24 Bq/L), the annual inhalation dose in the spring season varied between (0.0000883 mSv/y) and (0.001065 mSv/y); with an average value of (0.000389 mSv/y). Physiochemical parameters such as pH, EC, TDS, resistivity, and turbidity were determined for the collected water samples during both seasons and the correlation between these parameters and radon concentrations was established.

Radon concentrations in soil gas have been measured during winter and spring seasons. A total of (30) locations around the lake in each season were chosen for in situ analyzing. RAD7 detector is used for this purpose. Radon soil gas activity concentration for the winter season is found to vary from (86.9 ± 54 Bq/m³) and (6448 ±480 Bq/m³) with an average value of (1963±267 Bq/m³). Associated annual effective dose due to inhalation has been found to be in the range of (0.000826-0.061282 mSv/y), with an average value of (0.01866 mSv/y). For the spring season, radon concentrations in soil gas varied from (40 ±50 Bq/m³) to (4970±360 Bq/m³), with a mean value of (1434.17 ±205 Bq/m³). Annual inhalation dose due to these concentrations has been estimated and is found to vary between (0.000380 mSv/y) and (0.061282 mSv/y), with an average value of (0.01363 mSv/y).



Dedication

To

My father's memory...

*My kindness Mother for her ever lovely
encouragement...*

My supportive wife for her patience...

My brothers and sisters for their limitless love...

My beloved children Ali, Lana, and Sana...

Ahmed A. Sharrad

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviation	Key
RAD7	An electronic radon in air detector
RAD H ₂ O	RAD7 accessory to determine radon concentration in water
α	Alpha radiation
β	Beta radiation
NORM	Naturally Occurring Radioactive Materials
$t_{1/2}$	Half life
PAEC	Potential Alpha Energy Concentration
SGD	Submarine Groundwater Discharge
C	Radon concentration in air
C_w	Radon concentration in water
f	Transferred efficiency of radon from water to air
v_w	Rate of water used
x_h	Ventilation rate of an air change per hour
v_h	The volume of house
k	Permeability of soil
E-PERM	Radon monitoring kit
USEPA	United States Environmental Protection Agency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
ICRP	International Commission on Radiological Protection
WHO	World Health Organization
EC	Electric Conductivity

TDS	Total Dissolved Solids
GPS	Global Positioning System
GIS	Geographical Information System
AED	Annual Effective Dose
MCL	Maximum Contamination Level
D_{inh}	Annual effective dose due to inhalation
A_{Rnw}	Radon concentration in water
C_{aw}	Ratio of radon concentration in the air to radon concentration in water
F	Equilibrium factor between radon and its products decay
I	Mean outdoor occupancy time per individuals
DCF	Dose conversion factor for radon exposure
r	Person correlation coefficient
C_{Rn}	Radon concentration in the air near the soil surface
C_{SG}	Radon activity in the soil
d	Exhalation diffusion constant
D	Eddy diffusion coefficient
SSNTDs	Solid State Nuclear Track Detectors
PMT	Photomultiplier

Chapter One

INTRODUCTION

1.1. Introduction

Radon is a chemical inert, naturally occurring, and a noble gas, without any odor or taste, produced naturally as a member of the decay series of uranium that exists in the different types of the rocks over wide the earth. It presents in water, soil and atmospheric air around us but in different amounts depending on several conditions. Radon has three isotopes: Rn^{222} (Radon), Rn^{220} (Thoron), and Rn^{219} (Actinon) that are produced by disintegration of U^{238} , U^{234} , and U^{235} , respectively. The most important isotope is (Rn^{222}) due to its long half-life (3.82 day) relative to other isotopes which allows it to migrates far from the source.

In recent decades, radon has become known as one of the effective sources of environmental hazards, the second reason for lung cancer after smoking. It contributes by more than 54% of the total natural background radiation received by the public, decays naturally by emitting alpha particles to give a series of radionuclides which in turn disintegrate by emitting several types of radiations including alpha particles. Inhalation of radon short-lived products represents a great danger to human life and it is possible to cause serious health problems. Therefore, it is essential that radon issues have been gaining increasing attention on a global scale and huge efforts are made in order to reduce or prevent health problems resulted due to such pollution. The current study represents a modest contribution to the humanity relentless pursuit of providing a safe and clean environment for the next generations.

In this work, radon pollution in Sawa Lake will be treated and discussed in details. Sawa Lake is a closed basin created naturally 2000 years ago in the Samawa dessert,

south of Iraq. The lake has no inlet or outlet, and the groundwater is the main source of the lake water that provided through three cracks or springs. Sawa Lake represents an important tourism site regarding the big numbers of people who visit it annually. Hence, it is important to study radon activity in this site to determine if it poses any kind of health hazard for the public firstly, and secondly for providing appropriate database can be used in future in case of establishing tourist or scientific facility.

The present investigation will deal with Rn-222 concentration in the lake water, different locations will be chosen in order to cover the whole water surface of the lake. RAD7 radon electronic detector provided with RAD H2O accessory will be used for this purpose. Radon measurements will be carried out seasonally and we will make a comparison between radon levels during two seasons, the winter and the spring. In addition, some physiochemical parameters will be measured for the establishment of relationships between these parameters and radon concentrations in the lake water. On the other hand, radon soil gas concentration in the lake soil also will be seasonally measured for several locations around the lake. The annual effective dose received by inhalation will be estimated due to radon activity in the lake water and soil and also for two seasons.

1.2. Radiation

Radiation is the energy that emitted as either electromagnetic radiation (waves) or particles (particle radiation). It is produced by radioactive decay, nuclear fission, fusion, hot objects, chemical reaction, and gases excited by electricity [1].

The word “radiation” was used until about 1900 to refer to electromagnetic waves. Around the beginning of that century, x-ray, electrons, and natural radioactivity were discovered and were also classified under the term “radiation”. These newly discovered types of radiation exhibited characteristics of particles, in contrast to the electromagnetic radiation, which was treated as a wave.

In 1920, de Broglie developed his theory of the duality of matter which was soon supported by electron diffraction experiments.

Today, radiation describes the whole electromagnetic spectrum, in addition to, all the atomic and subatomic particles that were discovered [2].

Radiation is usually classified into two main categories: ionizing and non-ionizing radiation, depending on the amount of energy transferred and the danger of radiation. Ionization is “the capability of radiation to take off electrons out of their orbits around atoms, leading to produce unstable electrically charged particles (ions)”. Several forms of radiation such as microwave, heat, radio waves, or visible light do not have enough energy to eject electrons from atoms and thus, are called “non-ionizing radiation” [1].

The electrons and nuclei produced by ionizing radiation may cause damage in living cells, the term radioactivity generally describes the release of ionizing radiation.

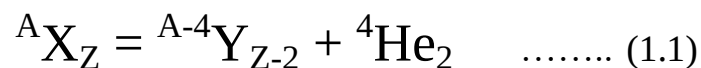
1.3. Alpha Decay and Alpha Particle

α - decay is a type of nuclear radiation in which an atomic nucleus emits an alpha particle and therefore produce a different atomic nucleus. Alpha particle is a positively charged particle with a mass number of (4) and an atomic number of (2), it is identical to

the helium-4 atom (${}^4_2\text{He}$) which consists of two neutrons and two protons and is thus heavier and slower than other decay radiations. Alpha particles do not penetrate far into a material and can be stopped quite easily. Hence, it can be stopped by a thin piece of paper or skin (a distance of penetration depends upon the energy with which they are emitted and the material type). However, due to their mass, size, and charge, alpha particles have the capability of breaking chemical bonds (and hence causing chemical or biological damages) [3].

Alpha decay of heavy nuclides (such as ${}^{238}\text{U}$, ${}^{226}\text{Ra}$, and ${}^{222}\text{Rn}$) is the most well-known sources of alpha particles. When an atom releases alpha particle during alpha decay, the atom loses four nucleons and hence the total mass number decreases by four. Because of losing two protons, the atomic number of the atom also decreases by two, leading to the transformation of the nuclei to a different element.

For nuclides of the large mass number, Alpha decay is a typical mode of decay to produce alpha particles. The decay process is [4]:



where X and Y are initial nuclide (parent) and final nuclide (daughter), respectively, A is the mass number, Z is the atomic number.

1.3.1. The Interaction of Alpha Particle with Matter

Alpha particle is regarded as a heavy charged particle (a heavy charged particle is the charged particle that has a rest mass larger than the rest mass of the electron, such as

protons, mesons, and alpha particles), where its mass is equal to four mass units [5]. Since the electromagnetic interaction extends over some distance, heavy charged particles do not have to make a direct collision with an atom. They can transfer energy by passing close by.

The interaction between heavy charged particles and matter is done by the interaction between their positive charge and the electrons' negative charge in their orbits around the atom according to Coulomb's law. Since the internal energy of an atom is quantized, therefore, only a certain amount of energy (quanta) can be transferred [6]. In general, the energy of charged particles is transferred mostly by:

- **Excitation:** raising electrons to higher energy levels by transferring energy to the atom by charged particles.
- **Ionization:** is the capability of radiation to take off electrons out of their orbits around atoms, leading to produce unstable electrically charged particles (ions).

It is becoming known that the alpha particle consists of two neutrons and two protons. On the other hand, it has no electrons, according to this, the alpha particle possesses a positive charge of (+2). This positive charge is responsible for stripping electrons from their orbits close to its path.

As the alpha particle passes to cross the material, it strips electrons from the atoms in the vicinity of its path, and its energy goes down by each interaction. In the end, the alpha particle will be stopped after it spends most of its energy [7].

Due to their short range of absorption and the limited ability to penetrate the external surface of the skin, alpha particles are not dangerous to life unless the source is

inhaled or ingested, in such case, they represent a serious risk to the human life. Because of this high mass and strong absorption, if alpha-emitting radionuclides do enter the body (upon being ingested or inhaled), alpha radiation is the most destructive form of ionizing radiation [8].

1.4. Terrestrial Radiation

Terrestrial background radiation or primordial background radiation represents the main external sources of irradiation of the human body which has been originated mainly from naturally occurring radioactive materials (NORM). NORM is “Materials which may contain any of the primordial radionuclides or radioactive elements as they occur in nature, such as potassium, uranium, and thorium, that are undisturbed because of human activities” [9]. Terrestrial naturally occurring radionuclides are common in the soil, rocks, water, and building material used for dwellings. Only those primordial radionuclides with half-lives comparable to the age of the earth, and their decay products, present in sufficient amounts to contribute significantly to population exposure [10]. These radionuclides existed at the creation of the planet. Since some of these radionuclides have very long half-lives, significant quantities of these radionuclides are still present on the earth today, but the amount of radioactivity in the soil varies widely depending on the geological process involved in the formation of the rocks and soil. These radionuclides can be categorized into two types [11]:

- (i) Singly Occuring Radionuclides such as ^{40}K , O, SiAl, Ca, ..etc.
- (ii) Decay Chains, such as ^{238}U , ^{232}Th , and ^{235}U .

Potassium (^{40}K) is the most important member of singly occurring terrestrial radionuclides, with a half-life of 1.27×10^9 years and isotope abundance of 0.0118%. It decays through β - decay to produce a stable ^{40}Ca most the time (89%). The remaining 11% of ^{40}K undergoes decay by electron capture to stable ^{40}Ar and releases a characteristic γ -ray at 1.461 MeV [12].

In contrast to potassium-40, two radionuclides of uranium and one of thorium decay to give rise to families of radionuclides which decay in three distinct series, all of them contain alpha emitters. The first decay series starts with the decay of ^{238}U and is called the uranium chain, the second one begins with ^{232}Th decay, which is called the thorium chain, while the third starts with the decay of ^{235}U , which is called the actinium chain. All of these three decay chains end up with stable isotopes of lead: ^{206}Pb , ^{208}Pb , and ^{207}Pb , respectively [13].

1.4.1. Naturally Occurring Decay Chains

Naturally occurring radionuclides disintegration occurs in three natural decay chains, headed by uranium-238, thorium-232, and uranium-235 and is called uranium, thorium, and actinium decay chain, respectively. These terrestrial radionuclides are common in soil, water, building materials, and different geological formations.

^{238}U is the most common isotope of uranium found in nature, with a relative abundance of 99%. Around 99.284% of natural uranium mass is uranium-238, which has a half-life of 4.468×10^9 years [14]. According to its natural abundance and long half-life as compared to other radioactive elements, uranium-238 produces about 40% of the radioactive heat produced within the earth [15].

^{238}U decay series begins with naturally occurring uranium-238 and terminates with stable lead-206, including several radioactive isotopes of the following elements: astatine, bismuth, lead, polonium, protactinium, radium, radon, thallium, and thorium.

Thorium is a naturally occurring, radioactive metal, small values of thorium are existent in all rocks, soil, above and under the earth, water, and planet. Thorium-232 is the most stable isotope of thorium and represents about 99% of the natural thorium. There are twenty-nine other isotopes of thorium in addition to ^{232}Th , with a mass number that ranges from 209 to 238 [16].

^{232}Th decays by alpha decay with a half-life of 1.405×10^{10} years, its decay series is “thorium chain” which finally ending in stable lead-208. The longest half-lives in it are for radium-228 and thorium-228, with values of 5.75 years and 1.91 years, respectively.

Uranium-235 presents in fewer quantities (in order of 0.7%) with a half-life of 7×10^8 years, due to this fact, it is less important with respect to the total background exposure [17]. ^{235}U is the head of the actinium decay chain, this chain starts with uranium-235 which suffers many of the disintegrations and ending with stable lead-207.

The three decay series of ^{238}U , ^{232}Th , and ^{235}U are shown in Figures (1.1), (1.2), and (1.3), respectively [18].

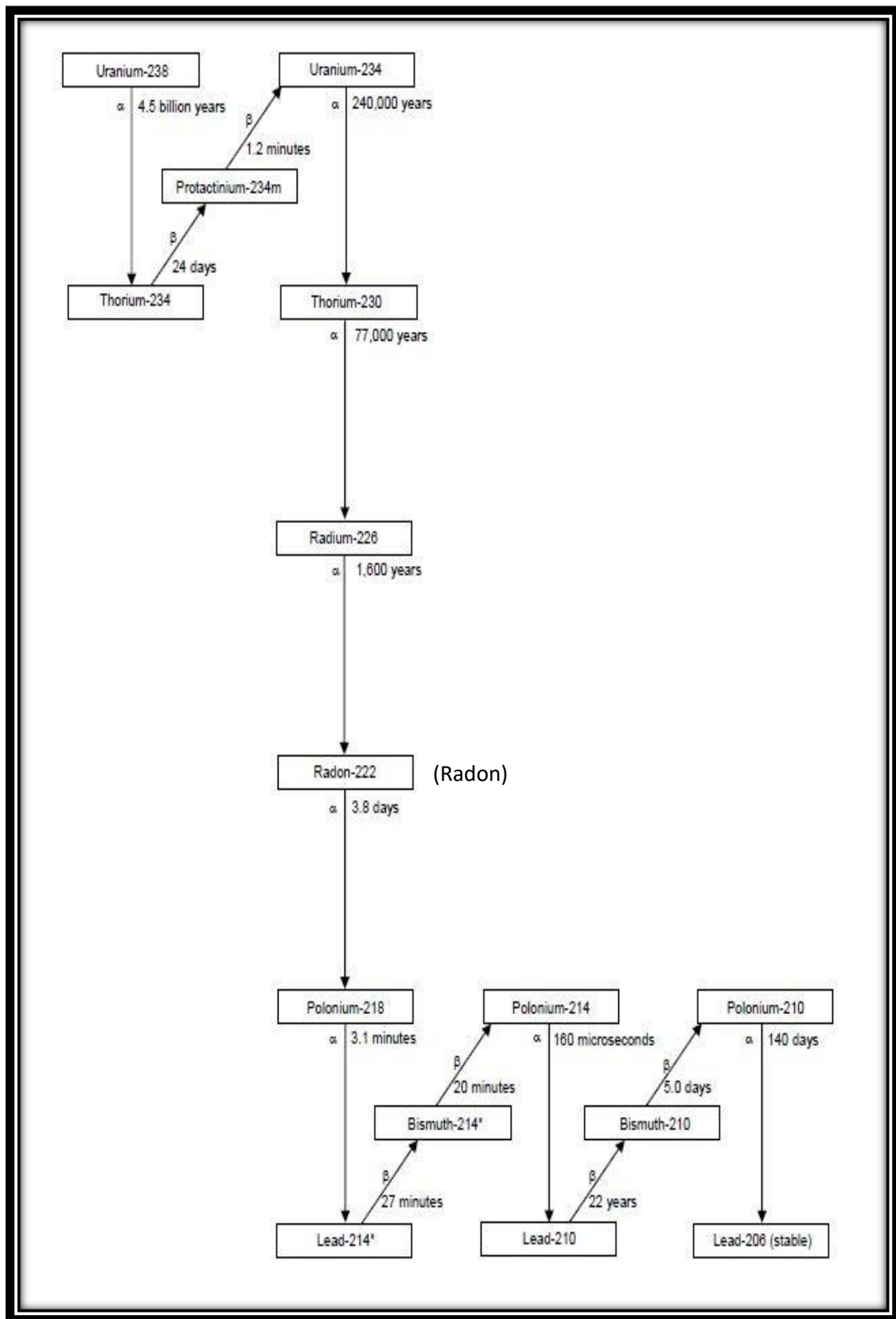


Figure (1.1): Uranium-238 decay chain.

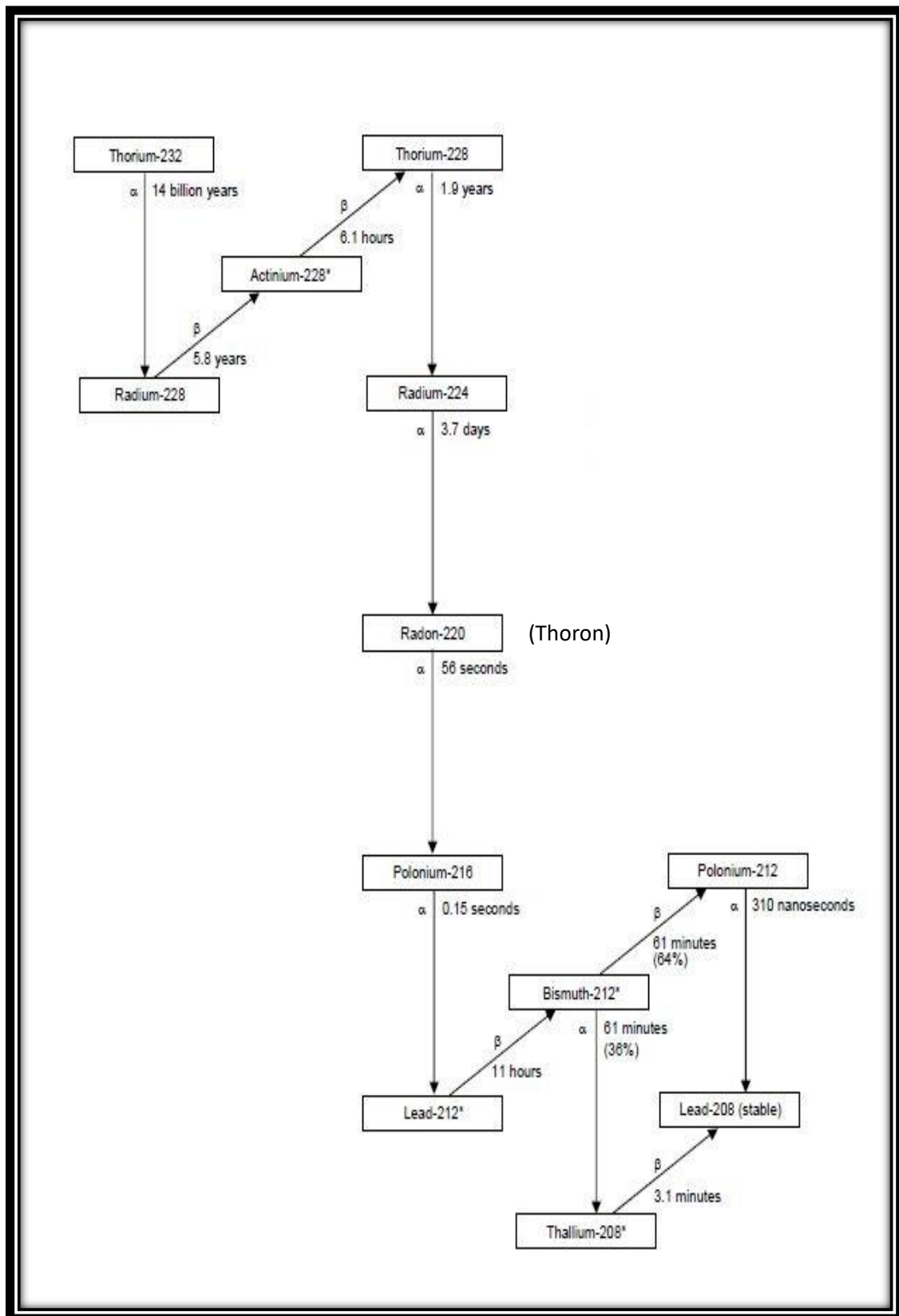


Figure (1.2): Thorium-232 decay chain.

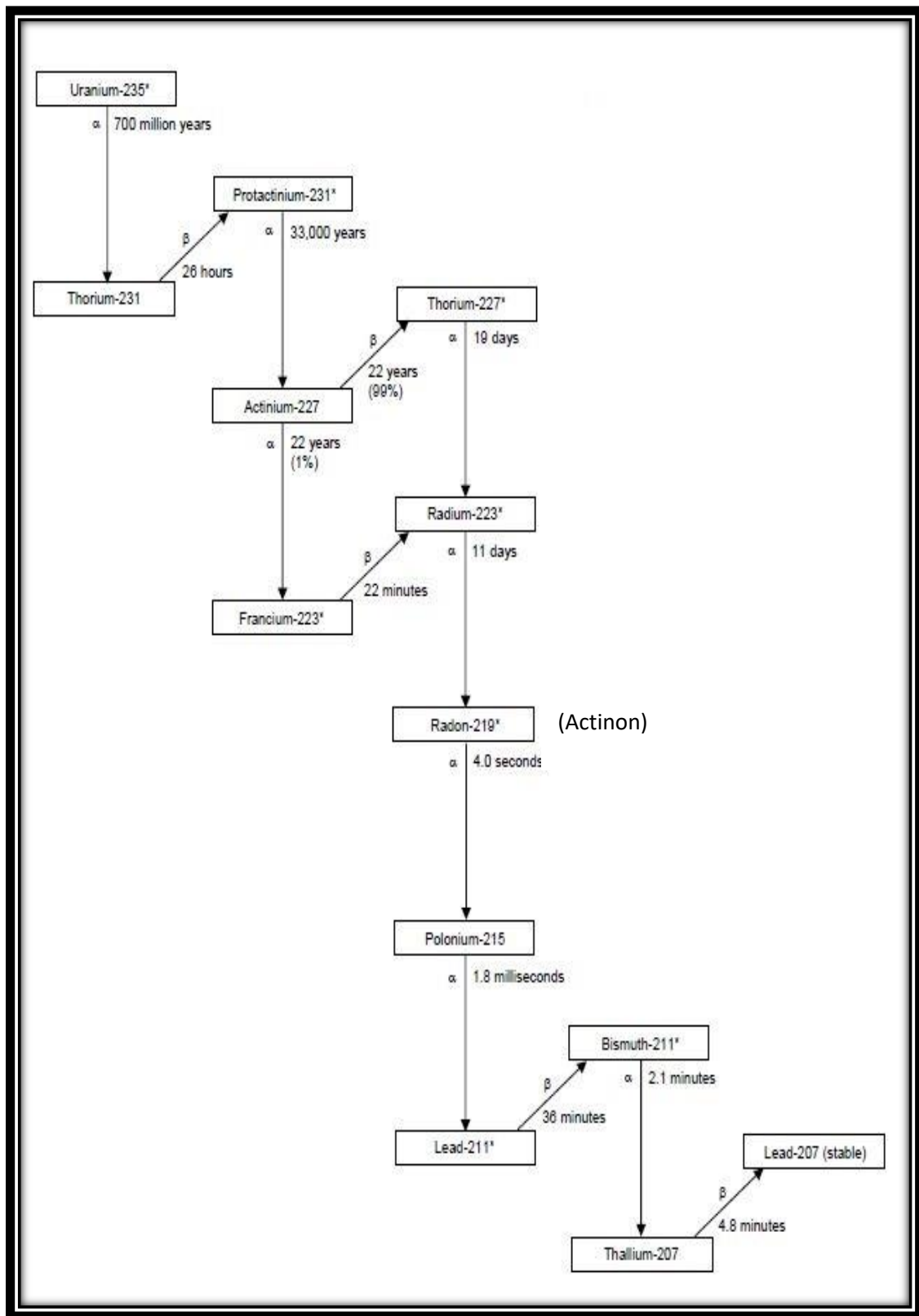


Figure (1.3): Uranium-235 decay chain.

1.5. Health Hazards of Ionizing Radiation

The exposure of human beings to ionizing radiation from natural sources of radiation is a continuing and unavoidable feature of life on the earth. For most people, exposure from natural sources exceeds that from artificial sources combined [10].

Human exposure occurs by irradiation from external sources (outside the body) and internal sources by the decay of radionuclides that taken into the body during inhalation and ingestion. Ionizing radiation can damage living cells by ionization their molecules, leading to death some of them and modifying others.

The effect of losing numbers of cells is limited or not considerable in most organs and tissues of the body. However, if the number lost is sufficiently large, there will be noticeable harm to these organs that may lead to death. Such damage takes place in individuals who are irradiated in excess of the threshold level (up to 100 Rem). Other damages may also occur in cells that are not killed but modified. Such damages are often repaired. If the repair is not ideal, the resulting modification will be transmitted to other cells and may finally give rise to cancer [19].

Radiation exposure has been associated with common forms of cancers of many organs, such as lung, thyroid gland, and breast, but not with specific organs, prostate gland for example. The main long-term evaluation of populations exposed to ionizing radiation is the study of 86,500 survivors of the nuclear bombings of Hiroshima and Nagasaki, Japan. A few hundred cancer deaths among the population studied have been revealed. Since about half of that population is still alive [20].

1.6. Radon

Radon is naturally occurring, colorless, odorless, radioactive, tasteless, and a noble gas. In fact, it is the heaviest noble gas in nature. Due to the relatively long half-life of radon and gaseous nature, radon can be regarded as a significant contributor to radioactivity in the atmosphere. Gaseous radon can be produced by soil, rocks, and construction material which contain amounts of naturally occurring uranium and thorium. Radon contributes by over 50% of the total natural radiation that human received [21], see Figure (1.4). Based on this, radon consists of a significant health hazard which leads to radon monitoring in different environments around the world. Radon occurs naturally as a product of the Uranium decay. Uranium is a naturally radioactive material found in varying quantities in all rocks, soil, bricks, and concrete. It occurs over wide the earth, especially in rocky and mountainous areas. Radon occurs as three natural isotopes: ^{222}Rn , ^{220}Rn , and ^{219}Rn , derived from three different radioactive decay chains, commencing with ^{238}U , ^{232}Th , and ^{235}U respectively.

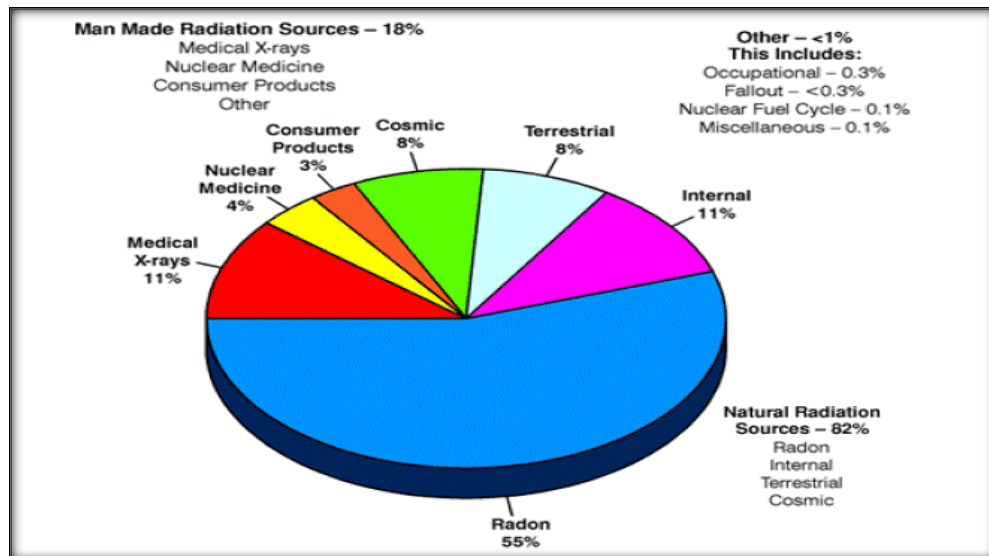


Figure (1.4): Global distribution of natural background radiation [22].

1.6.1. Physical and Chemical Properties of Radon

Radon is Radioactive, colorless, odorless, tasteless, and noble gas. Has a chemical character of (Rn) and an atomic number of (86). Figure (1.5) illustrates the atomic structure of radon.

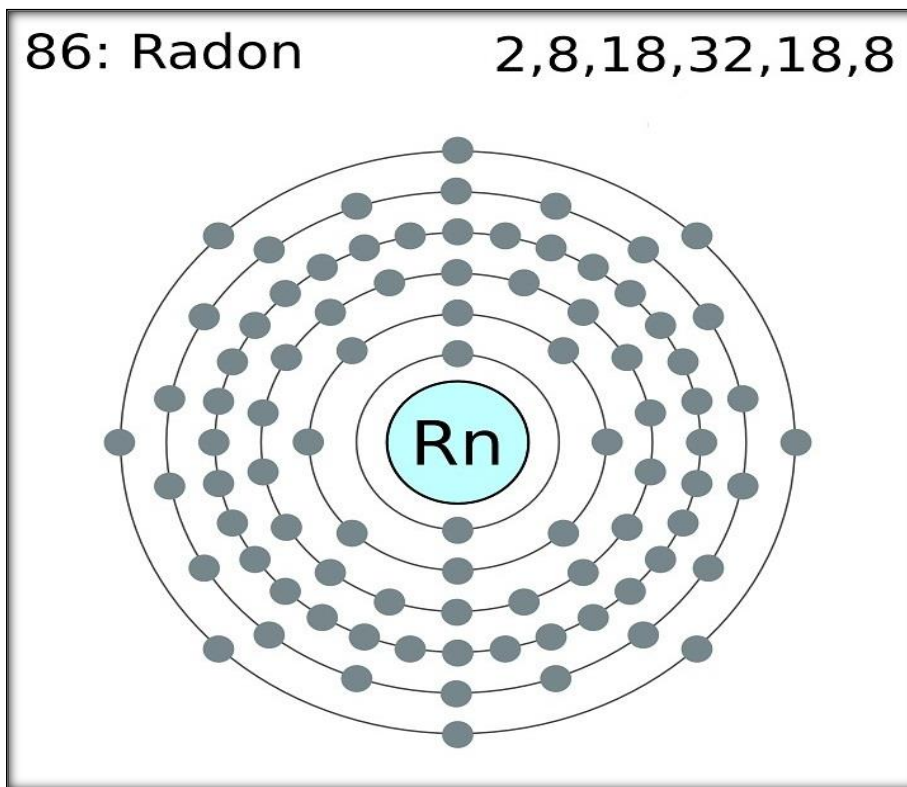


Figure (1.5): Electrons distribution of radon atom [23].

Radon can be considered as one of the natural sources of radiation. It has three naturally occurring radioactive isotopes as ^{222}Rn , ^{220}Rn , and ^{219}Rn . It is the 86th element of the periodic table and the heaviest of the noble gases along with helium, neon, argon, krypton, and xenon. Radon is chemically inert due to its stable electronic configuration $[\text{Xe}] 4f^{14}5d^{10}6s^26p^6$. It is a non-flammable gas, an alpha emitter, and needs to special equipment to detect it. Radon has a density of (9.73 Kg/m³) and its boiling and melting points are (-62 °C) and (-71 °C) respectively [24]. Also, it has the highest critical temperature and critical pressure of any other gas as shown in Table (1.1). It is a

monoatomic gas, and soluble in cold water and several organic solutions, its solubility decreases with temperature increases.

Radon transforms into a transparent liquid when it is condensed and then become a shiny solid material (has a shiny phosphoric color). When its temperature undergoes to decrease below the melting point, its color transforms to yellow and to orange when the temperature reaches (-180 °C) [25].

Table (1.1): Physical properties of radon.

Properties of Radon	
Density at 0 °C and 1 atm	9.73 gm/l
Boiling Point	-62 °C
Melting Point	-71 °C
Critical Temperature	104 °C
Critical Pressure	62 atm
The diffusion coefficient in free air Viscosity at 1 atm and 20 °C	0.1 cm ² /s
Viscosity in water at 1 atm partial pressure and 20 °C	229.0 micropoise
Solubility in various liquids at 1 atm and 18 °C:	230 cm ³ /kg water
Glycerine	0.21 cm ³ /kg liquid
Ethyl alcohol	7.4 cm ³ /kg liquid
Petroleum (liquid paraffin)	9.2 cm ³ /kg liquid
Toluene	13.2 cm ³ /kg liquid
Carbon disulfide	23.1 cm ³ /kg liquid
Olive oil	29.0 cm ³ /kg liquid

1.6.2. Isotopes of Radon

There are three important isotopes of radon which are: ^{222}Rn , ^{220}Rn , and ^{219}Rn , all of which radioactive, and each associated with natural radionuclides of ^{238}U , ^{232}Th , and ^{235}U respectively.

^{222}Rn (so-called radon), has a half-life of (3.823 days), It is the most important isotope because of his long half-life relative to the other isotopes and due to the health risk that caused by exposure to its radioactive daughters. Radon is formed by the alpha decay of Radium (^{226}Ra) which belongs to the decay chain of ^{238}U .

^{220}Rn (named thoron) is the second isotope of radon, has a shorter half-life of (55.6 seconds), produced through the decay of ^{232}Th , which is more abundant in nature than uranium, since that it has a global average concentration of 11 ppm in the earth's crust compared with that of uranium which is only 2 or 3 ppm [24]. The short half-life of thoron decreases its concentration in the environment as compared to radon (^{222}Rn) concentration.

The third isotope of radon is actinon, ^{219}Rn , with a very short half-life of (3.96 seconds), it is a member of the ^{235}U decay series. Actinon does not contribute significantly to total background radiation exposure due to the low natural abundance of the ^{235}U ore (20 times smaller than ^{238}U activity concentration) and the very short half-life [26].

Table (1.2): Radon naturally occurring isotopes.

Isotope	Common name	Half-life	Decay chain associated with
^{222}Rn	Radon	3.823 days	^{238}U
^{220}Rn	Thoron	55.6 seconds	^{232}Th
^{219}Rn	Actinon	3.96 seconds	^{235}U

1.7. Radon Decay Chain

Radon isotopes are radioactive gases that are naturally disintegrated into new products or daughters. The radon decay products or progenies are isotopes of heavy metals, such as Polonium, Bismuth, Lead, and Thallium.

These new products are unstable and decay by emitting alpha/beta particles and gamma radiation, and easily fixed to existing aerosol particles in the atmosphere. Radon isotopes are having different decay chains and therefore different products to some extent but it all ends up with stable isotopes of lead.

^{219}Rn (actinon) has a relatively low abundance in the crust, only about 0.7% [27], and because of its very short half-life (3.96 sec), it usually disappears immediately after its forming. ^{220}Rn is also not able to migrate far because it decays before reaching the earth's surface due to its short half-life (55.6 sec). Hence, the most important progenies are those have been produced by ^{222}Rn decay because of its relatively long half-life (3.82 days), therefore, it is able to travel far enough from its origin point. The decay products of ^{222}Rn and ^{220}Rn and its properties are summarized in Tables (1.3) and (1.4) [1], respectively.

Table (1.3): Properties of ^{222}Rn decay products.

Nucleus	Half-life	Energy (MeV)	Radiation type	Phase
^{222}Rn	3.82 days	5.49	α	Gas
^{218}Po	3.05 minutes	6.00	α	Solid
^{214}Pb	26.8 minutes	0.7	β	Solid
^{214}Bi	19.8 minutes	3.26,1.5,1.00	β	Solid
^{214}Po	164.3 microseconds	7.69	α	Solid
^{210}Pb	22.3 years	0.015 , 0.065 0.065	β γ	Solid
^{210}Bi	5.015 days	1.17	β	Solid
^{210}Po	138.376 days	5.30	α	Solid
^{206}Pb	Stable			Solid

Table (1.4): Properties of ^{220}Rn decay products.

Nucleus	Half-life	Energy (MeV)	Emitter	Phase
^{220}Rn	55.6 seconds	6.29	α	Gas
^{216}Po	0.15 seconds	6.79	α	Solid
^{212}Pb	10.6 hours	0.75,0.33 0.3,0.238,0.178	β γ	Solid
^{212}Bi	60.6 minutes	6.09 2.23	α β	Solid
^{212}Po	0.3 microseconds	8.78	α	Solid
^{208}Tl	3.0 minutes	1.8	β	Solid
^{208}Pb	Stable			Solid

1.7.1. ^{222}Rn Decay Products

The concentration of radon decay products is represented by the potential alpha energy concentration (PAEC). It depends on the concentration of the first three decay products (^{218}Po , ^{214}Pb , and ^{214}Bi) and the amount of polonium α energy that obtained. The behavior of Radon daughters is of high interest among scientists not only to satisfy the relationship between Radon concentration and decay product concentration but also to provide a view of decay products exposures [28]. The decay products can attach to aerosols within the atmosphere, indoor walls, furniture, and human lungs if radon is inhaled. Before attachment of decay products to aerosols, they can deposit on surfaces after radon decay. The health significance of the decay products is greatly influenced by their half-life decay modes and their behavior after decay.

1.8. Radon in water

There are two types of water on the earth: surface water and groundwater, these types can be used for household, industrial, and agriculture purposes. Since rock and soil contain radium, therefore, surface water and groundwater should contain the dissolved radon gas. Surface water such as rivers water, lakes water, and seawater, usually contains little concentrations of radon, because it escapes easily into the air, so the dwelling that depends on surface water usually do not have a radon problem from their water. In big cities, aerating the water through the municipal system also contributes to reducing radon content in the used water.

Groundwater is located beneath the ground surface in soil pore spaces and in the fractures of geologic structures. It is widely used as the main water supply for homes

and the population in many areas around the world. In addition to agriculture use. Radon-222 concentration in groundwater relies on the content of radium-226 within ambient rocks. The ^{222}Rn in water is allowed to be in approximate secular equilibrium with ^{226}Ra in underlying rocks due to the short life of ^{222}Rn with the slow migration of groundwater. It is known that the granite and in high-grade metamorphic rocks contain a high ^{226}Ra concentration and therefore the groundwater that confined within these rocks hold a high concentration of ^{222}Rn [29].

The ^{222}Rn concentration is correlated in water supplies with indoor radon levels by the most investigations, which leads to estimating of the ratio of the indoor level to water. The water level of radon to be of the order of 10^{-4} which is given by a relationship between indoor radon emanating from potable water supplies leads to the following equation [30]:

$$C = \frac{C_w f v_w}{x_h v_h} \quad \text{----- (1.2)}$$

Where: C is the concentration of radon in air, C_w is the concentration of radon in water (pCi / l), f is transferred efficiency of radon from water to air, v_w is the rate of water used (liter/hour), x_h is the ventilation rate of an air change per hour, and v_h is the volume of house = volume of air change.

The areas most likely to have problems with a groundwater content of radon are those that have high levels of uranium in the local rocks. For example, granite rocks in various regions of the United States are origins of high levels of radon in groundwater that supplies to private water supplies. In some areas, the main water supply is from

private wells and small public water works. Radon in ground water can increase radon in indoor air [31].

1.9. Radon in soil

The soil is recognized as the major source of radon in the air (at least 80%) [27], radon is formed in rocks and soil that contain ^{238}U nuclides. Uranium concentrations are depending on the rock type, In general, sedimentary rocks that consist of organic material are usually moderately enriched with metals, including uranium. Organic-rich black shales and rocks containing phosphate show the highest values, approaching 1000 ppm. Additionally, glacially-eroded debris derived from uranium-rich source rocks has been transported long distances and spreads over large areas in tills and outwash deposits [32]. Radon flows from the soil into the outdoor air and also into the indoor air in homes from the movement of gases in the soil under homes. A distribution of radon in soils has been related to geological controls in terms of its generation and migration; uranium content in bedrocks and soils influence production and the soil characteristics (including the soil moisture and permeability) control the transportation of radon. The radium and uranium contents of the soil generally reflect that of the bedrock from which the soil materials have originated due to weathering processes [33].

There are three main emanation mechanisms that transport radon from its sources in soils or rocks to the environment [24]:

- 1) Emanation from the solid phase to either gas or liquid in pore spaces by alpha recoil.
- 2) The emanation of radon relative to the gas or liquid by molecular diffusion.
- 3) The emanation of radon within soil gas or water by advection.

1.9.1. Alpha recoil

Alpha recoil is a process that transfers radon from the solid grains of the source rock into the pore space. The energy released as a result of the alpha decay of radium to radon causes the alpha particle to be fired out from the nucleus, and the newly-formed radon nucleus is fired in the opposite direction (Figure 1.6). For radon, the recoil range is about 20 to 70 nanometers and several recoil paths can be identified [34]. In the case of radium nucleus located at a depth greater than the recoil range, the produced radon progeny stills embedded in the grain. Other atoms migrate from its original grain to be trapped in the adjacent grain. On the other hand, other atoms escape from grains where it located and fired out into pore water which stops these atoms by absorbing its recoil energy. Other atoms which located within recoil range are fired out into pore air can be free to travel toward the surface and released to the atmosphere.

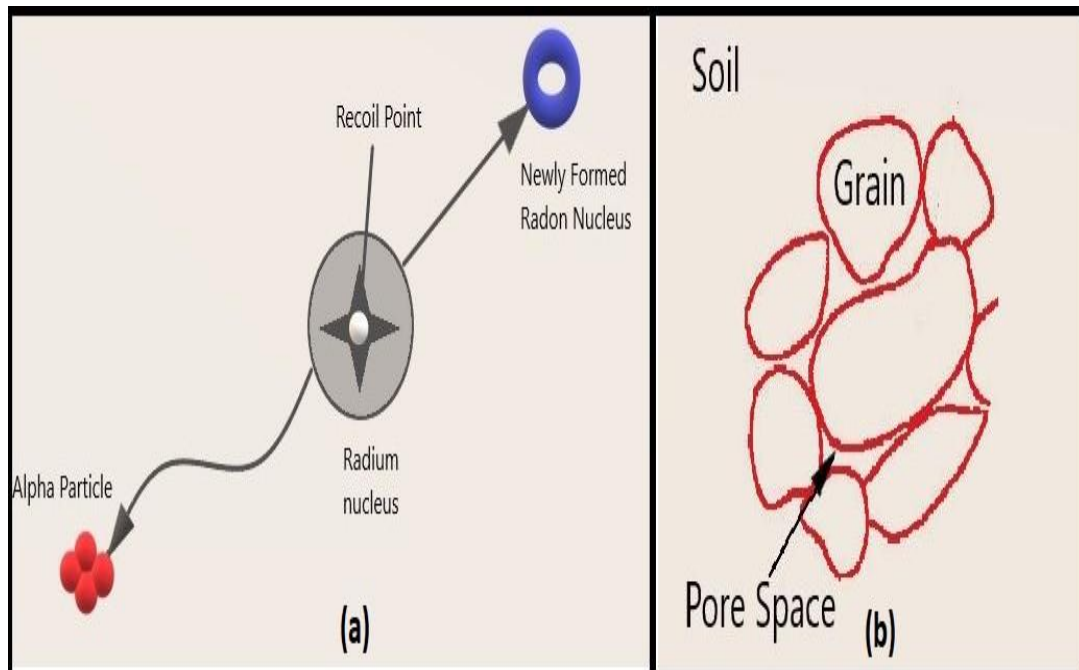


Figure (1.6): (a) Alpha recoil process.

(b) Grain and pore space.

1.9.2. Diffusion

Radon diffusion within the soil is a process identified by the radon concentration gradient across the soil structure between the radon source and surrounding ambient [35]. Radon diffusion and transport through different mediums depends on several factors. For any medium, the porosity, the permeability, and the diffusion coefficient are the parameters, which can quantify its capability to stop the flow of radon soil gas [36].

The porosity is the ratio of the air volume in a medium to its overall geometric volume. An increase of porosity will decrease the resistance to radon transport by providing more airspace in the medium for radon to migrate. The permeability is closely related to the porosity of medium, it describes to act as a barrier to gas transportation when a pressure gradient presents across it. The diffusion coefficient of medium determinates the ability of radon to travel through it when the concentration gradient is the driving force.

1.9.3. Advection

Advection either by groundwater flow or pressure driven air flow can carry radon over significantly greater distances than by diffusion alone. Transport of radon in the air, as a result to pressure gradient, is proportional to decreasing of atmospheric pressure, high wind, or significant temperature gradients between soil air and the atmosphere [37,38]. The pressure that is responsible for radon flow depends on the permeability (k) of soil where the overall mean grain size is larger than silt or fine sand, and where $k > 1 \times 10^{-12} \text{ m}^2$, below this value transport by diffusion dominates [38].

1.10. Radiological Effects of Radon to Human being

Human beings are exposed to natural background radiation all the time from the air, ground, food, building materials, the universe, and even elements inside their own bodies. But the major source of background radiation comes from radon and its decay products. Because of radon inertness and low solubility in the body fluid, radon itself does not has much of a risk to the human body, since the chance that it will decay during the short time of its presence in human lungs is small. The risk arises from the radioactivity coming from the three elements: polonium, lead, and bismuth, which are produced sequentially as a result of radon disintegration. In the microscopic scale, these elements are solid and tend to attach themselves to the dust in the atmosphere. Some of these dust particles accumulate on the lung surfaces through the air inhalation. In particular, both the polonium-218 and polonium-214, which are formed during the radon decay, emit energetic alpha-particles that can cause damage to the cells located close to the dust particles. This damage can finally lead to lung cancer. Significant health effects have been seen in uranium miners who are exposed to high levels of radon. However, studies in Europe, North America, and China have confirmed that lower concentrations of radon such as those found in the houses also confer health risks and contribute substantially to the occurrence of lung cancers worldwide [27].

1.11. Applications and Uses of Radon

Radon (^{222}Rn), the sixth member of the ^{238}U decay chain, and an inert gas has a number of properties make it an interesting and useful for several applications and uses, such as the exploration of uranium. Uranium is an important element and recognized as an excellent source of energy through its using in nuclear fission reactors. Since radon gas is one of the uranium decay products. Hence, the existence of a significant concentration of radon in a specific location is good evidence of subsurface uranium deposits presence in that location [25]. It is also used as a predictor of earthquakes and volcano, where the correlation between radon concentration variation and geological changes of earth crust is strong and observable. The strain changes occurring within the earth's surface is expected to increase the radon content in soil gas. The principle seems to be simple: Before earthquake major physical shock in a specific region, many changes taking place in the earth's crust in that region will result in small fractures which allow radon that is trapped within the ground to be released [39]. There is another use of radon monitoring near the surface of the earth over the oil and gas reservoirs as one of those cost-effective techniques used for detecting underground oil and gas bearing structures. As the gases resulting from geochemical effects of hydrocarbon in petroleum reservoirs and seeping through rocks and geological structures upwards to the surface, up flow of released gases will help to carry radon gas near the surface where its concentration is measured. So, there is an indirect relationship between the presence of radon near the surface of the earth at certain concentrations and the existence of oil and gas ores at a specific depth in the ground [27]. In addition to above, there are other uses of radon as groundwater tracer, and in prediction of geothermal energy.

1.12.Radon measurements Techniques

It is well known that radon (^{222}Rn) represents a hazard to human health. Hence, the assessment of radon concentrations in different places has been gaining increasing attention in recent several decades with the overpopulation and enhanced standards of living. Such that, many methods and devices are developed around the world for measuring radon and its progeny to determinate its contribution to the natural dose received by the population and to find remediation possibilities [40]. Techniques used for this purpose are divided into two main categories: Active and Passive techniques.

1.12.1 Active Measurement Techniques

Active techniques include sampling continuously and then active samples will be isolated and studied. These techniques need to be supplied with power through the measurement operation and usually used for short-term measurements [30]. Active techniques are employed in several instruments and devices for radon detection and measurements such as Lucas cell, and ionization chamber.

Lucas cell or scintillation cell consists of a tightly sealed metal or glass container. The interior of the cell is coated with scintillator material, usually silver activated zinc sulfide or ZnS (Ag). The sample of air is drawn in by an air pump to fill the volume of the cell. Once the cell is filled, radon products that are generated in the cell will emit alpha particles which tend to interact with the scintillator material to produce photons. These photons can be detected by the photomultiplier (PMT) and converted to electric pulses which can be counted to estimate radon concentration.

However, there are many devices adopt this technique such as alpha guard, and RAD7 radon electric detector [67]. Ionization chamber consists of two or more electrodes with an electrical field established between them. The chamber is filled with filtered air either by pumping or by diffusing. Radon and its decay products will ionize the air within the chamber by emitting α -particles. Electrons and ions that are produced as a result to ionization will be drifted toward the respective electrode by the influence of the applied voltage, and the resulting current can be measured as a function of the number of the decayed radon atoms within the chamber [30].

1.12.2. Passive Measurement Techniques

Passive techniques are those techniques which don't require to be powered through the measurement process. These techniques are more appropriate for the assessment of radon exposure over long-term measurement and can be used for scale surveys at a moderate cost [41].

1.12.2.1. Charcoal Detectors

Activated charcoal has been contained in the uncapped canister and exposed to air a period of a few days for allowing radon to be absorbed by the charcoal. Radon adsorbed on charcoal will decay and its short-lived products will be retained. The amount of radon absorbed by activated charcoal will be measured by gamma spectroscopy of the emissions from lead-214 and bismuth-214 where they emit gamma radiation of energies 352 KeV and 609 KeV respectively [42,43].

1.12.2.2. Solid State Nuclear Track Detectors (SSNTDs)

SSNTDs are cost-effective, convenient to use, sizeable since they can be produced in various sizes according to need, insensitive to light and quite robust. Such advantages make the using of SSNTDs is very common and popular especially in radon detection and measurement field [44]. SSNTDs types lie in two major classes: organic SSNTDs (CR-39, LR-115, etc.) and inorganic SSNTDs (mica, quartz, etc.) [45].

Two types of SSNTDs are commonly used for detection and measurements of radon which are CR-39 and LR-115 II. In order to measure radon concentration, a small piece of plastic (detector) enclosed in a container (Either close or open container) and exposed to the ambient atmosphere. When radon diffuses inside, the detector will be struck by alpha particles that emitted during radon decay. In this process, alpha particles ionize almost all molecules in or close to its path, such ionization leads to creating new chemical radicals and other chemical species along the path of the alpha particle. These damaged zones are called “latent tracks” [46].

After that, the detector that contains latent tracks will be exposed to a chemical aggressive solution such as NaOH or KOH and chemical reactions occur intensively along the latent track. The whole surface of the material will be etched but in a faster rate at the damaged zones and observable tracks will be formed which can be seen under an optical or an electronic microscope. The number of tracks per unit area is an indication of radon concentration in location atmosphere.

1.13. Literature Review

In the last decades, many previous studies have been conducted to estimate the radon concentration in water, soil, and others. In the following, the most important studies of radon in water and soil have been reviewed in the last two decades.

1.13.1. Radon in Water

B.S. Bajwa et al in **2005** [47] measured the levels of ^{222}Rn concentrations in the tube-wells, hand-pumps, and natural springs, in some areas of Himachal Pradesh and Punjab (India). The radon concentrations in the samples collected from hand-pump drawn groundwater have been found to be higher than the concentrations from other sources. The measured radon concentrations in these samples are varied from 1.0 ± 0.3 to 48 ± 2.2 Bq/L. The ^{222}Rn concentration in some thermal springs has also been measured and its values have been found to be quite significantly higher than from other sources of groundwater.

O. Baykara and M. Doğru (**2006**) [48] analyzed different water samples have been collected from over the North and East Anatolian Fault System for radon concentration and rate of radon exhalation using CR-39 solid-state nuclear track detector in conjunction with the closed-can technique. The measured maximum value of the radon concentration was 3319.3 Bq/m^3 . However, radon Exhalation rate in water has been found to vary from 20.2 and $470 \text{ mBq/m}^2\text{h}$. The annual effective dose also has been calculated for the water sample and the highest dose has been obtained was $14.5 \text{ }\mu\text{Sv/y}$.

H. Yalim et al (2007) [49] conducted Radon concentration in well water in the Afyonkarahisar area of Turkey and calculated the average annual dose equivalent in water. Radon concentration was found to range between 0.42 and 28.82 Bq/L and the annual effective dose was estimated to about 73.8 $\mu\text{Sv/y}$.

J. Singh et al (2008) [50] assessed radon levels in drinking water samples that taken from hand-pumps, natural sources, and wells, in upper Siwaliks of Kala Amb, Nahan and Morni Hills of Haryana and Himachal Pradesh states, India. Alpha scintillometry technique has been used for this purpose. The radon concentration has been found to vary from 0.87 ± 0.29 to 32.10 ± 1.79 Bq/L.

F. Khan et al in 2009 [51] carried out the radon levels in (72) samples of different types of water from the fault zone of Balakot and Mansehra regions, North West Frontier Province, Pakistan, using a Pylon system that based on Lucas cell for radon estimation. The result showed that the radon concentrations are in the range of 4.99 – 24.52 kBq/m³, with an average value of 15.52 kBq/m³ for all types of water.

K. Badhan et al in 2010 [52], used electronic radon monitor (Rad7) for assessment of radon contents in the groundwater of National Institute of Technology, Jalandhar, Punjab, India. Radon concentrations in drinking water of location have been found to vary from 2560 to 7750 Bq/m³ with an average value of 5143.33 Bq/m³. The PH value of water under study also has been determined and it is found in the range of 6.69 to 7.0 and the average value is found to be about 6.99. No observed correlation has been recorded between PH values and radon concentrations.

H. Idriss et al in **2011** [53] measured and mapped radon activity concentration within groundwater supplies in Khartoum State, Sudan. Water samples have been collected before and after autumn and analyzed using low-level gamma spectrometry equipped with HPGe detector. Radon concentration was found to vary from 1.58 to 345.10 Bq/L with an average value of 59.20 ± 6.60 Bq/L. Physiochemical parameters also have been determined for the water samples and no correlation was observed between radon levels and these parameters.

A. Rani et al in **2012** [54] investigated radon concentration in groundwater that taken from hand pumps over the different areas of SriGanganagar, Hanumangarh, Sikar, and Ghuru in northern Rajasthan, India. RAD7 an electronic radon monitor has been used to estimate radon concentration in groundwater. Radon levels were found to range from 0.5 ± 0.3 Bq/L to 85.7 ± 4.9 Bq/L, with an average value of 9.03 ± 1.03 Bq/L in 89% of the samples, while the calculated annual effective dose ranged from 1.34 to 229.68 $\mu\text{Sv/y}$.

A.A. Abojassim and A.R. Shitake (**2013**) [55] estimated radon levels in drinking water of 24 location in Al-Najaf city, Iraq, by using RAD7 radon detector. It is found that the radon concentrations were varied from 2.43 ± 0.879 Bq/m³ to 225.5 ± 12.657 Bq/L. the annual effective dose due to inhalation has been calculated and is found to be within the range ($0.0177 \mu\text{Sv.y}^{-1}$) to ($1.646 \mu\text{Sv.y}^{-1}$).

B.C. Shivakumara et al in **2014** [56] determined radon concentration in naturally occurring groundwater of the Mandya district, Karnataka state. India. The radon concentration in borewell water is found to be within a range of 6.44 ± 0.20 to 44.83 ± 0.54

Bq/L with an average value of 16.42 ± 0.31 Bq/L. While the total annual effective dose has been varied from 26.31 to 178.53 $\mu\text{Sv/y}$.

N. Ahmed et al from Malaysia in **2015**, used RAD7 electric radon detector to determine radon activity concentration in drinking and irrigated water samples collected from various regions Sungai Petani, Kedah, Malaysia. The maximum average value of radon concentration among the different types of water samples was found 14.7 ± 1.44 Bq/L in well water and the minimum was found 5.37 ± 0.58 Bq/L in tap water.

A. Jafir et al in **2016** [57], studied the seasonal measurements of radon in Darbandikhan Lake water resources at Kurdistan region, Iraq. The assessment includes 164 water samples collected from the lake and its different resources during the whole year, and the estimation was carried out using the electronic RAD7 detector. The average radon concentrations for spring water during spring, summer, autumn, and winter were found to be 8.21 Bq/l, 8.94 Bq/l, 7.422 Bq/l, and 8.06 Bq/l, respectively. While the average values were found to be 0.43 Bq/l, 0.877 Bq/l, 0.727 Bq/l, and 0.575 Bq/l for the lake and streams. It is observed that the radon concentration was higher in summer and lower in spring. Mean annual dose is estimated for spring water during the four seasons and it is found to be 0.022 mSv/y while for the lake with streams was 1.57 $\mu\text{Sv/y}$. In addition, some physiochemical parameters were measured and no correlation was noted between radon concentration and these parameters except for the conductivity of the spring water which reveals a strong correlation for the whole year.

V. Duggal et al in **2017** [58] measured radon concentration in 59 groundwater samples collected from Fatehabad district of Haryana, India. The measurements were

carried out by RAD7 radon electronic detector manufactured by DurrIDGE company Inc. Radon levels were found within the range of 1.4-22.6 Bq/L. 14% of the groundwater samples were above the (US EPA) recommended value for radon in water. The total annual effective for ingestion and inhalation dose was evaluated and found to vary from 14.1 to 221.8 $\mu\text{Sv/y}$.

by A. Naskar et al (2018) [59] evaluated the radon concentrations for tube-wells samples collected from 173 different locations in Bakreswar and Tantoli, Budapest, Hungary. The radon levels were observed to fluctuate widely between 3.3 and 803.8 Bq/L with an average of 106.8 Bq/L. About 42% of the samples posed radon content above the safe limit of 100 Bq/L proposed by WHO and EU. The corresponding annual effective dose was varied between 16.72 and 4079.47 $\mu\text{Sv/y}$ with an average value of 541.92 $\mu\text{Sv/y}$.

1.13.2. Radon in Soil

In 2005, J. Swakoń et al [60] investigated radon levels in the vicinity of geologic fault zones within the Krakow region in Poland and determined the impacts of such formations on radon concentration in soil using ALPHAGUARD PQ2000 PRO and CR-39 detectors. Higher radon levels were found in the study area than those documented in an earlier survey covering Krakow agglomeration. For radon, the arithmetic means concentrations values was 39 kBqm^{-3} and median 35.5 kBqm^{-3} .

S. Al-Shereideh et al (2006) [61] studied the depth dependence and seasonal variations of soil radon concentrations in different geological formations in Deir Abu-

Said District in Irbid, Jordan, using CR-39 solid-state nuclear track detector. Seasonal variation of radon at depths (10, 25, 50, 75, and 100 cm). At a depth of 100 cm, radon concentrations, in summer, varied from 6.85 kBq/m³ for Muwaqqar Chalky-Marl to 35.5 kBq/m³ for Al-Hisa Phosphatic Limestone, while in winter the range is between 4.01kBq/m³ and 24.6 kBq/m³, respectively. The highest levels of radon were found for Al-Hisa Phosphatic Limestone in both seasons at all depths. This is related to the high content of uranium of this geological formation. Eventually, study data revealed an increase of soil radon concentration with depth.

Z. Žunić et al (2007) [62] made a first radon soil gas survey in Niška Banja town, Serbia, using CR-39 SSNTDs passive detector. Radon measurements were made n 48 points at depth of 50 cm. Radon concentration levels have been found to be between 1270 and 155000 Bq/m³. Gamma dose rate and radium contents in the soil also have been measured, the high correlation between radon concentration in soil, gamma dose rate, and radium contents has been found for each point.

A. Rodriguez et al in 2008 [63] determined soil gas radon at Las Pailas geothermal area, Costa Rica, using RAD7 radon-in-air monitor. The statistical analysis of the 259 collected data showed at least four populations, with soil gas radon values determined below 140 pCi/L. Some of the anomalies are located in the intersection of formations or between them.

G. Prasad et al (2009) [64] measured soil gas radon in summer and winter using LR-115 plastic detector in the Budhakedar area of Tehri Garhwal, India. The study is conducted in order to obtain the seasonal variation of radon concentration in soil and its

correlation with the radon exhalation rate. The radon concentration in soil was found to vary from 1098 Bq/m³ to 31,776 Bq/m³ with an average value of 7456 Bq/m³ in summer and 3501 Bq/m³ to 42883 Bq/m³ with an average of 17148 Bq/m³ in winter. The radon exhalation rate also has been determined in both seasons and a weak negative correlation was found between radon concentration in soil and radon exhalation rate.

B. Singh et al in **2010** [65] determined radon concentrations in the soil for 39 locations of Northern Punjab, India, using AlphaGUARD PQ 2000 PRO detector. The soil gas radon concentration was found to vary from 0.3 to 35.8 kBq/m³. Soil temperature, pressure, and humidity also have been investigated to find out if there was a correlation between these parameters and radon in soil concentration.

A. Hasan et al [66] in **2011** measured the soil gas radon concentrations at 15 sites for different depths in the Najaf Al-Ashraf city, Iraq, using RAD7 active radon detector. The highest value of radon concentration was 9290±400 Bq/m³ for the depth of 60 cm in Al-Amir district, while the lowest value was 9±17 Bq/m³ in Al-Shoara district at a depth of 5 cm.

A. Al-hamidawi et al In **2012** [67] conducted a set of measurements of radon concentrations of soil gas in Al-Kufa City, Iraq, RAD7 electric radon meter. Radon concentration levels were measured in 20 locations for depths of 50, 100, and 150 cm. The result showed that the radon concentrations from location to another, depending on the geological formation. For 50 cm depth the soil gas radon concentrations were varied from 697.5±119.145 Bq/m³ to 8835±513.703 Bq/m³ and for depth of 100 cm, it is found

to be within the range of 178.75 ± 25.303 - 12775 ± 386.48 Bq/m³, while ranged from 41.45 ± 16.500 Bq/m³ to 9535.5 ± 712.729 Bq/m³ for 150 cm depth.

K. Szabó et al (2013) [68] studied the seasonal and daily variation of soil radon concentration in a highly permeable sandy-gravelly soil in order to understand if the temporal variation of radon soil gas concentration can affect radon potential determination. Results showed that the seasonal and daily variations of the measured radon concentration in highly permeable sandy-gravelly soil with definite seasons without obvious long transitional periods. The winter is characterized by 2.5 times higher average soil gas radon concentration with a median of 7.0 kBq/m³ than the summer with a median of 2.8 kBq/m³.

V. Duggal et al (2014) [69] investigated soil gas radon concentration in Sri Ganganagar district of Rajasthan, India. A radon survey was carried out using RAD7 radon electronic detector. Radon concentration in soil gas was conducted for different depths (10, 40, 70, and 100 cm), the radon concentration was in range of 0.09-4.25 kBq/m³ for 10 cm depth and varied from 0.15 kBq/m³ to 6.30 kBq/m³ for 40 cm depth, while it ranged between 0.50 kBq/m³ and 9.18 kBq/m³ and was 0.72-10.40 kBq/m³ for 100 cm depth.

P. Ravikumar et al (2015) [70] made a radon survey in different sites in Chitradurga district of Karnataka state, India, using RAD7 an electronic radon monitor in order to explore the pattern of geological and seasonal changes of radon concentrations in soil gas at different locations. Radon activity concentration in the soil

ranged from 0.5 to 812.9 Bq/m³ with a mean value of 93.78 Bq/m³ and 0.8 to 810.4 Bq/m³ (mean:92.84 Bq/m³) during pre- and post-monsoon seasons, respectively.

K. Hatif and M. Muttaleb (2016) [33] determined radon levels in soil at 10 districts in Hilla City, Iraq. RAD7 electronic radon in air detector has been used for radon estimation. The samples are collected from the soil at a depth of 30 cm for each location. Maximum activity of radon was 12700 Bq/m³ while the minimum radon activity was 25 Bq/m³.

A. Cucuș (Dinu) et al (2017) [71] determined soil gas radon concentrations in 5 counties of Romania, using the LUK3C device. Radon concentration in soil was found to range from 0.8 to 169 kBq/m³ with a mean value of 28.4 kBq/m³.

P. Huynh Nguyen et al in 2018 [72] determined radon concentration in soil and radium content in the soil of 20 locations in Ho Chi Minh City, Vietnam. Radon concentration in soil gas was determined in depth of (10-100 cm) of loam, sandy soil, and clay soil samples in the rainy season, using RAD7 Active radon detector. Mean value of radon concentration was 28.6±2.0 Bq/kg in clay soil and 31.2±2.5 Bq/kg in loam soil, while it was 30.7±2.0 Bq/kg in sandy soil. an unclear linear relation was observed between radon concentration in soil gas and radium contents in soil. In addition to, a strong positive correlation was found between soil gas radon concentration and a pH of the soil, leading to conclude that the pH level of the soil to be considered as an indirect dynamic parameter influencing the migration of radon in soil.

1.14. Objectives and Scopes

The major reason behind studying Sawa Lake is back to being the lake an important and unique tourist attraction because of several characteristics that are not found in other lakes, where hundreds of people and tourists travel there annually to in holidays and vacations, especially during the winter and spring seasons. Therefore, our study aims to:

Determination of radon activity concentration in the lake water during two seasons, winter and spring. Find out if there is seasonal fluctuation regarding measured radon concentrations in different seasons. Estimating of annual effective dose due to inhalation associated with radon content in the lake water. In addition, assessment of several physiochemical parameters such as EC, TDS, resistivity, pH, and turbidity for the lake water in order to establish the relationship between these parameters and radon concentration in water. In addition to above, measuring of radon concentration in soil gas in different locations in the soil surrounding the lake during two seasons, winter and spring. Discover if there is seasonal variation for the measured radon concentrations in soil gas. And Calculating annual inhalation dose associated with radon soil gas activity.

Chapter Two

EXPERIMENTAL METHODS

2.1. Introduction

This chapter deals with the instruments and materials used in this work, including a brief review of each one, description of the study area and the processes that took place in present work in order to provide as much information as possible, these processes: sampling methods for both water and soil, radon concentrations measurements for both water and soil, and determination of physiochemical parameters for the water samples.

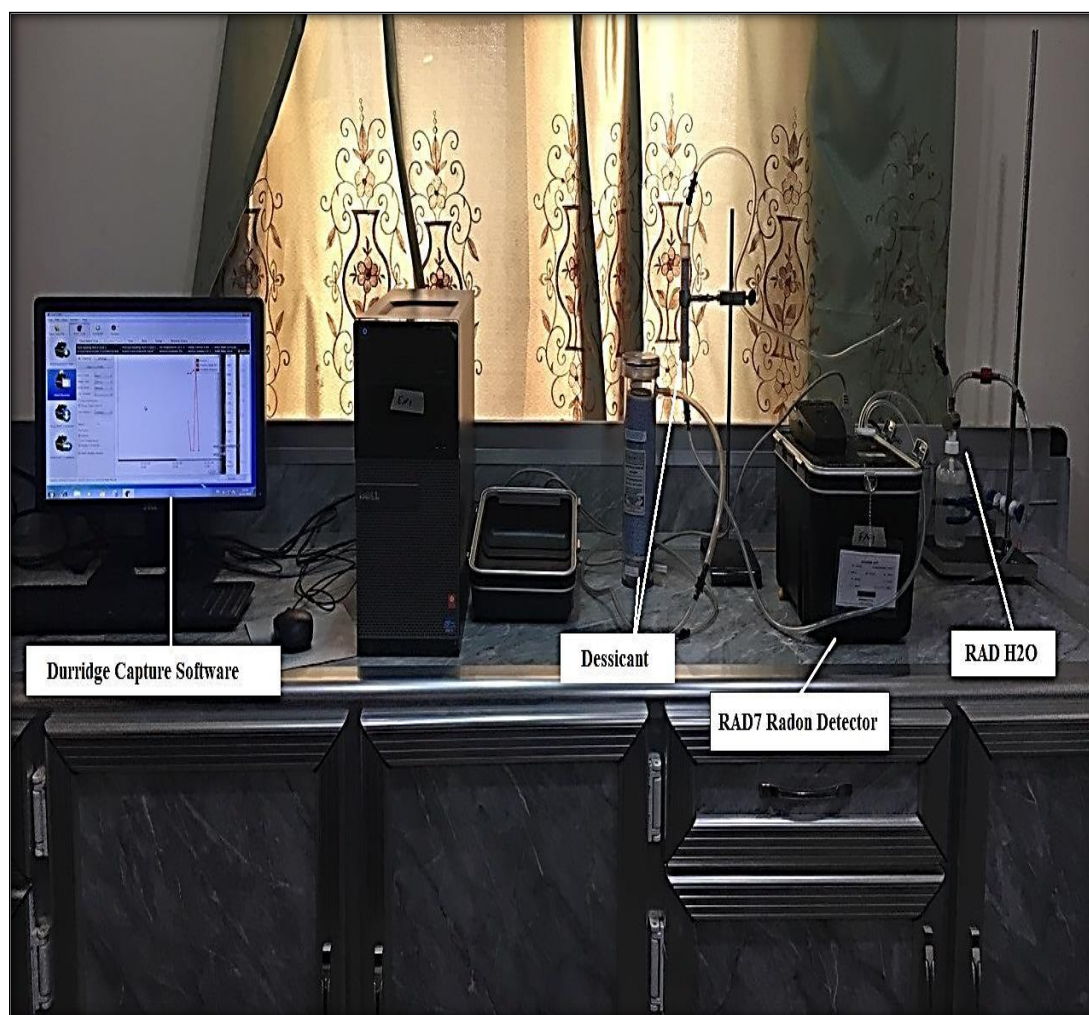


Figure (2.1): Lab setup.

2.2. RAD7 Electronic Radon Detector

There are many devices and instruments used to detect and measure radon which employ different techniques due to the conditions of using, as mentioned in the previous chapter. RAD7 an electronic radon detector manufactured by DurrIDGE Company Inc., USA, has been used in the present study. The external structure of RAD7 consists of a plastic case with an upper control interface that contains keypad, an infra-red LED, LCD screen, an air outlet, inlet ports, and computer serial port, as shown in Fig. (2.2).

The interior of the equipment consists of a hemispherical chamber with a volume of (0.7 L) as can be seen in Fig. (2.3). The internal surface of the chamber is coated with an electrical conductor which can be changed with a high voltage power supply.

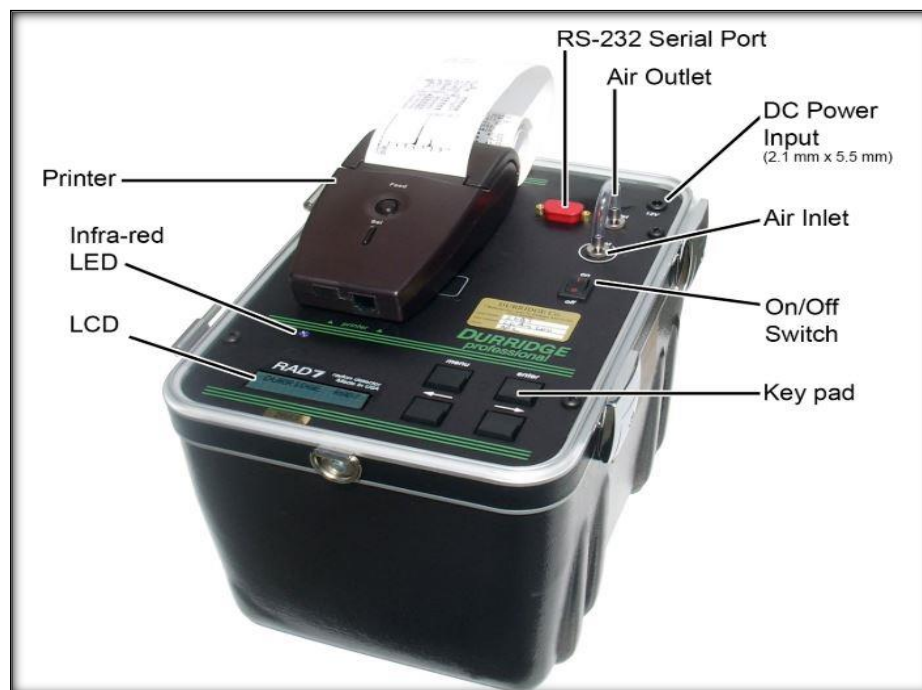


Figure (2.2): RAD7, An electronic radon detector [73].

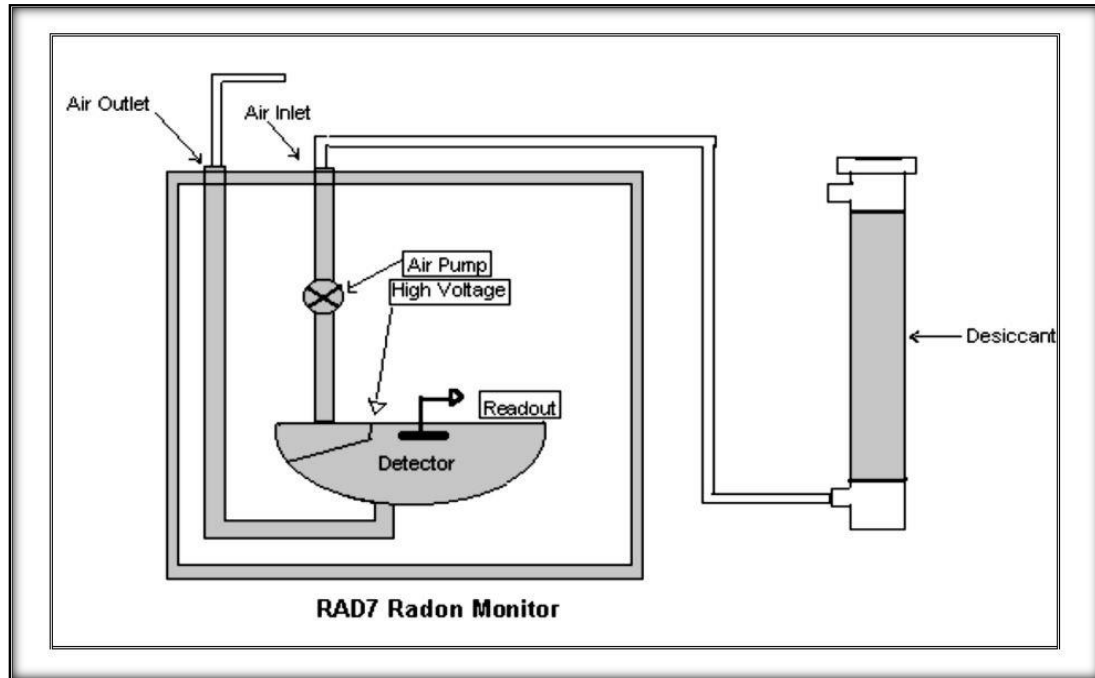


Figure (2.3): Scheme of RAD7 device [69].

The hemispherical chamber contains a solid-state detector (silicon) in the center, which works on converting the alpha radiation produced by the decay of radionuclides (e.g. ^{218}Po and ^{214}Po) into an electrical signal. One advantage of the silicon detector is the fact it can electronically determine the quantity of energy associated with the produced alpha particles. In this way, the specific radionuclide can be identified, polonium-218 with alpha radiation of 6.00 MeV or polonium-214 with alpha radiation of 7.69 MeV [74].

The RAD7 device is based on an electrostatic collection of positively charged alpha particles that formed within its chamber by the radon products, the device can be used for radon or thoron measurements in the air, water, and soil. It has a high radon sensitivity within a measurement range extending from 4 up to $4 \times 10^5 \text{ Bq/m}^3$ [75].

2.2.1. RAD7 Principal Work

Radon is radioactive gas, decay by the emitting alpha particle to give a series of radionuclides that disintegrate also by emitting alpha particles, as well as beta and gamma radiation. The RAD7 measuring process is based on detecting alpha particles produced from the disintegration of radon and its products using a solid-state alpha detector (usually silicon), and then converting alpha radiation directly to an electrical signal.

The internal sample cell is filled with air that carries radon or its progenies by a pump which pulls air in through inlet filter (with a porosity of 4.5 μm). Before that, the humidity of atmosphere within the cell must be reduced to less than 10% using a desiccant connected with the instrument through a closed loop, the desiccant contains Calcium Sulfate Granules as dryers. Humidity reducing is necessary to prevent the attraction of ions with water molecules inside the chamber, which affect the sensitivity of the instrument [73].

Once the chamber is filled with air, radon and radon products decay begins and alpha particles with characteristic energies due to each decay (e.g. ^{222}Rn , ^{218}Po , or ^{214}Po) are released within the cell. These positively charged alpha particles are drifted to move toward the silicon detector by the influence of the electric field that created through the chamber as a result of applying a potential of about 2000-2500 Volts between the chamber and detector. The detector converts alpha particles directly to an electric signal, the electrical signal recorded from the decay of the radionuclide is then amplified, filtered, and then stored according to its strength, and then the detector produces a

spectrum which contains several peaks, each one of these peaks represents the concentration of a specific radionuclide.

RAD7 detector provides several options to execute a number of measuring operations, several protocols and modes can be applied in order to estimate radon or thoron in different mediums (e.g. air, water, and soil).

2.2.2. RAD7 Cumulative Spectrum

The detector produces an electrical signal for each alpha particle formed by the decay of radionuclides that accumulates on the detector surface. This signal is intensified electronically and transformed into a digital signal. The microprocessor stores the energy level of the signal and produces the spectrum, as illustrated in Fig. (2.4).

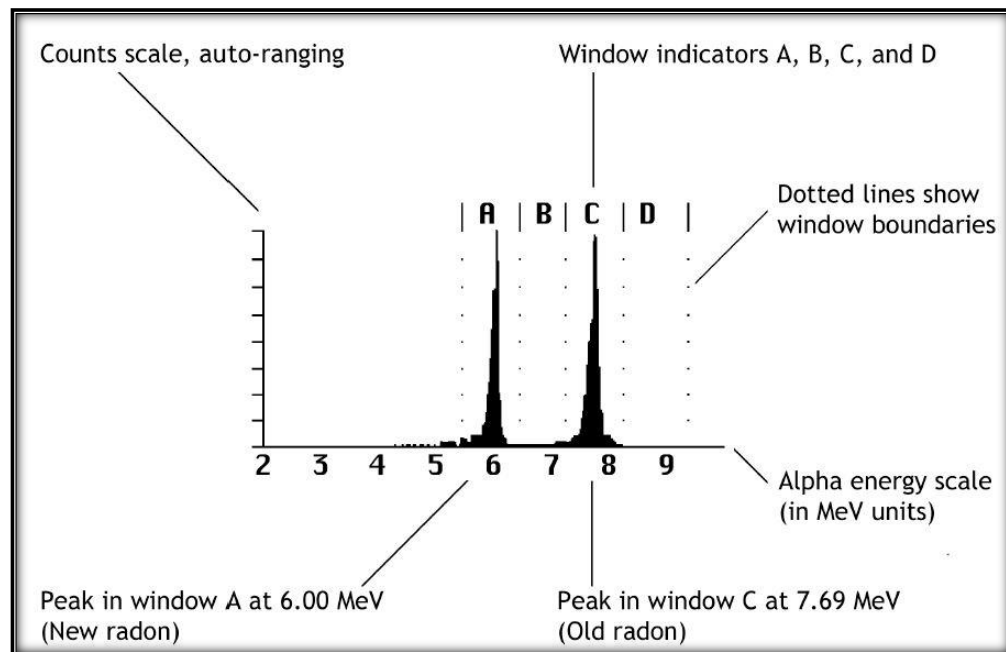


Figure (2.4): RAD7 cumulative spectrum [73].

The RAD7 divides the spectrum's 0 to 10 MeV energy scale into a series of 200 individual counters, each representing a 0.05 MeV channel. Whenever the RAD7 detects an alpha particle, it increments one of these 200 counters by one [73].

The cumulative spectrum includes 8 windows or energy range, sorted alphabetically from A to H. Windows A-D are separated while windows E-H are added together to form window O. The functions of windows A, B, C, and D as follows :

- (i) **Window A:** The total counts of alpha particles from polonium-218 decay with an energy of 6.00 MeV.
- (ii) **Window B:** The total counts of alpha particles from polonium-216 decay with an energy of 6.78 MeV.
- (iii) **Window C:** The total counts of alpha particles from polonium-214 decay with an energy of 7.69 MeV.
- (iv) **Window D:** The total counts of alpha particles from polonium-212 decay with an energy of 8.78 MeV.

It is obvious that windows A and C derive the radon concentration, since both ^{218}Po and ^{214}Po are radon products, while windows B and D derive the thoron concentration. Window O counts for the noise in the system that did not go into the major windows A, B, C, and D.

2.2.3. Background and Associated Problems

Background in a radon detector refers to spurious counts that occur even in the absence of radon. The background can arise from the properties of the instrument or its

components, other forms of radiation in the instrument's environment, or contamination of the instrument. The RAD7's design makes it much less susceptible to the background than other radon monitors, but one should still be aware of the background in the RAD7 to avoid mistakes. The following list gives possible sources of background in the RAD7 [73]:

- (i) **Short-lived Radon and Thoron Daughters:** These are the most likely contributors to affect the background in the RAD7, radon and thoron products continue to produce counts even after radon and thoron have been removed from the chamber which causes confuse to the result when trying to measure a low radon level after a high level.
- (ii) **Adsorbed Radon Gas:** arise from the absorbed radon into the internal structure of RAD7, inside the tubing, and on desiccant granules, which can inter inside the sample cell.
- (iii) **Intrinsic Background:** It is due to the material of RAD7 construction that contains a very low quantity of alpha emitters, causing counts corresponding to the concentration of (0.02 pCi/L) which is low enough to neglect.
- (iv) **Long-lived Radon Products:** An energy of 5.3 MeV arise due to alpha particles emitted by ^{210}Pb (with a half-life of 22 years) that deposited on the detector after many years of use.
- (v) **Contamination by Radon, or Thoron Producing Solid:** When ^{228}Th or ^{226}Ra are trapped in filters or inlet hoses, they may produce radon or thoron that carried into the instrument. Especially certain dusty solid may contain enough of these isotopes.

2.3. RAD7 Accessories

2.3.1. RAD H₂O

The RAD H₂O (DURRIDGE Company Inc., USA) is an accessory to the RAD7 that manufactured to measure radon in water over a wide range of concentrations (from less than 10 pCi/L to 400 kpCi/L). The accessory is capable to measure radon in water within an hour of sampling, The RAD H₂O makes use of standard, pre-set protocols, built into the RAD7, which furnish a direct reading of the radon concentration in the water sample itself [76].

The RAD-H₂O method employs a closed loop aeration scheme whereby the air volume and water volume are constant and independent of the flow rate. The air recirculates through the water and continuously extracts the radon until a state of equilibrium develops. The RAD-H₂O system reaches this state of equilibrium within about (5) minutes, after which no more radon can be extracted from the water. The extraction efficiency, or percentage of radon removed from the water to the air loop, is very high, typically 99% for a 40 mL sample and 94% for a 250 mL sample. The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90%. Since the extraction efficiency is always high, we see little or no temperature effect on the overall measurement [77]. Fig. (2.5) shows the RAD H₂O accessory.

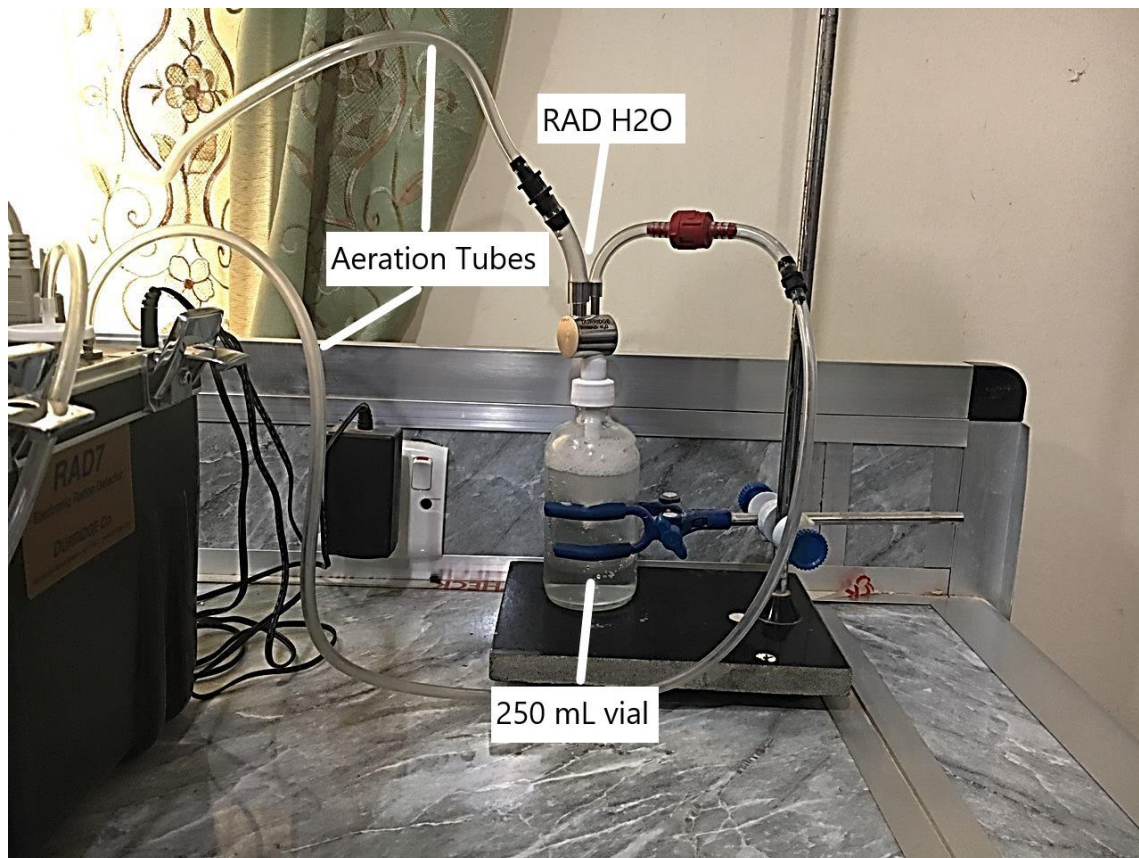


Figure (2.5): RAD H₂O accessory.

2.3.2. Soil Gas Probe

Radon in soil gas measurements required special care and practicing, it is important to make sure that the sample is not exposed to the outside air. This can be done by using the hardened steel soil gas probe supplied by DURRIDGE Company Inc., USA (Fig. 2.6). It is one of the RAD7 accessories used for measuring radon soil gas with high efficiency. The soil probe is stainless steel rod (0.5 inch diameter) with a central hollow (0.25 inch diameter) that extends along the probe, soil gas probe is hammered to the required depth below the soil surface creating a channel through which soil gas may flow upward, another end of the probe is connected to the RAD7 (through a desiccant and dust filter) by pushing the plug-in connector into the probe [78].

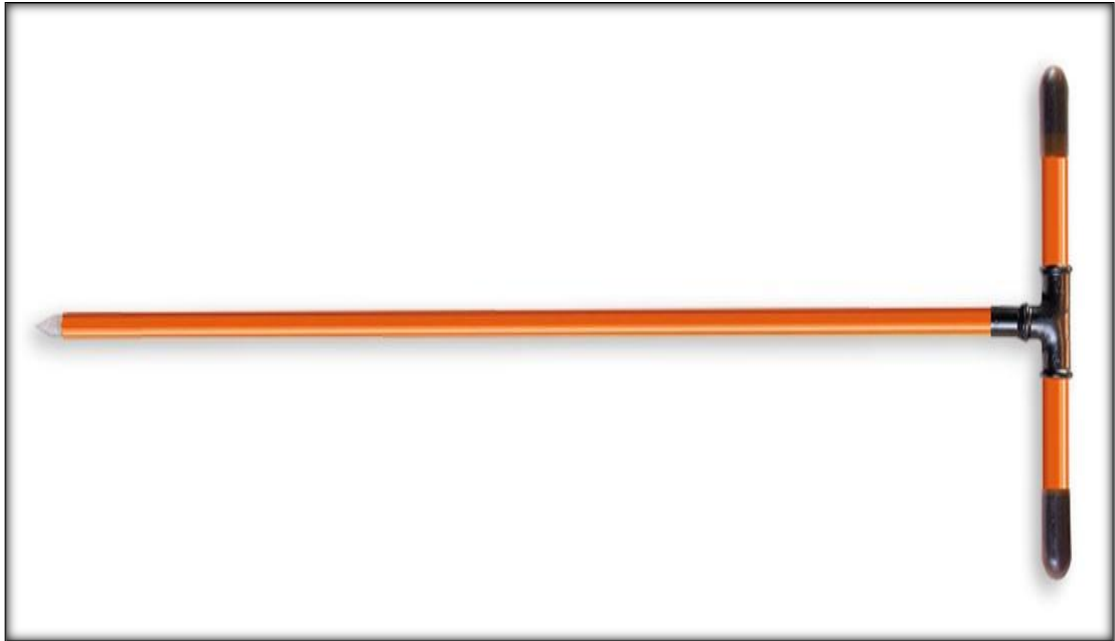


Figure (2.6): Soil gas probe [78].

2.3.3. DurrIDGE Capture Software

Capture software (version 5.6.8) an application that provided by DURRIDGE Company Inc., USA (Fig. 2.7) which is able to download data from RAD7 and save it on the computer (up to 1000 runs), has the ability to display advanced graphs of radon data, showing the cumulative spectrum of radon products, scheduling the RAD7 runs and sorting it by date and time, and offer full control of RAD7 processes. In addition, applying the humidity correction on the resulted concentrations in case the humidity has gone up (over 10 %) during the measuring process [78].

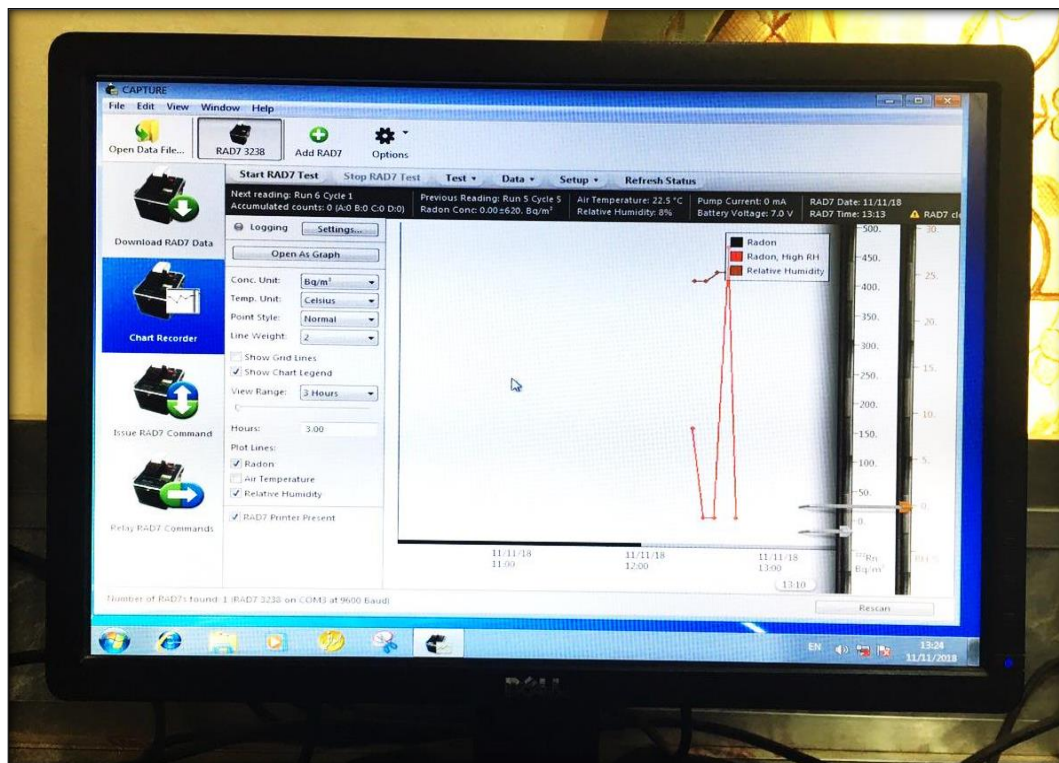


Figure (2.7): Capture software.

2.4. Physiochemical Parameters Estimation Instruments

The physiochemical parameters determination of water samples is carried out using a set of electronic instruments as follows:

2.4.1. HI 2300 EC/TDS Bench Meter

The conductivity (EC) of an aqueous solution is a measure of its ability to carry an electrical current by means of ionic motion. The conductivity invariably increases with increasing temperature. It is affected by the type and number of ions in the solutions and by the viscosity of the solution itself. Both parameters are temperature dependent. [79].

Total dissolved solids (TDS) are the inorganic salts and the slight quantities of organic materials exist in solution in water. These solids include calcium, potassium

carbonate, sodium, magnesium, hydrogen carbonate, sulfate, nitrate anions, and chloride [80].

HI 2300 EC/TDS bench meter is an electronic instrument manufactured by HANNA Instruments Inc., USA, as shown in Fig. (2.8). Used to measure electric conductivity (EC) and the total dissolved solids (TDS) for the collected water samples. The instrument is equipped with a probe enclosed by a thin plastic cover that can be inundated in water to measure the electric conductivity and TDS directly, the probe is provided with platinum sensors to offer versatility over typical Amperometric designs [79].

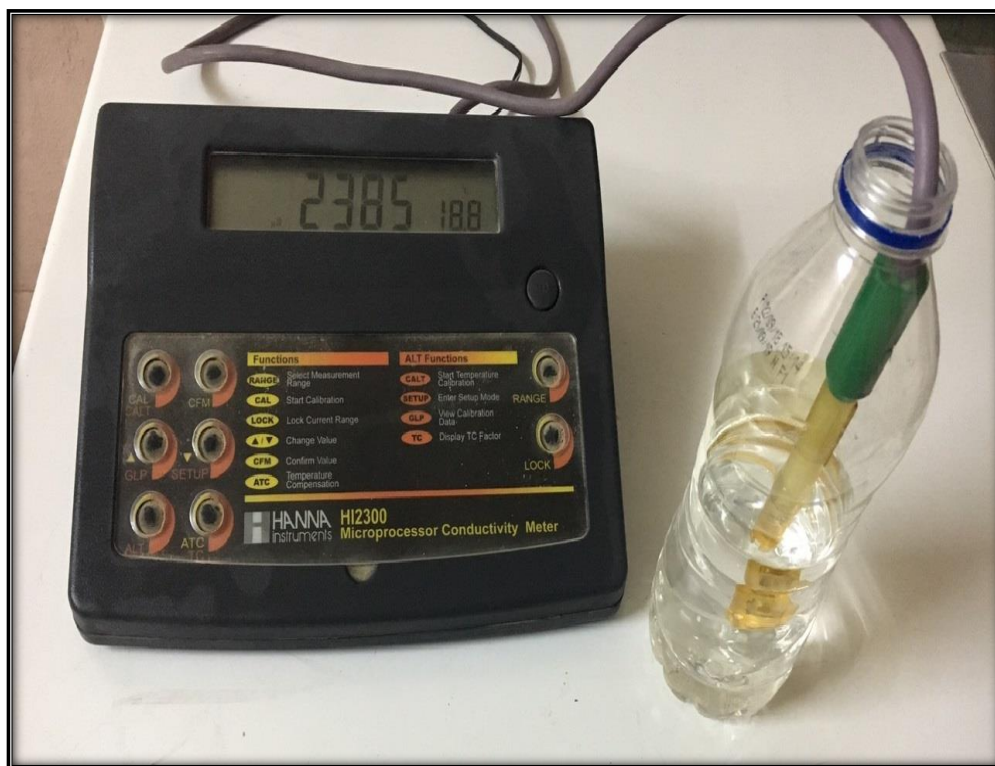


Figure (2.8): HI 2300 EC/TDS bench meter.

2.4.2. LP 2000 Microprocessor-based Bench Turbidity Meter

Turbidity is an optical property of water, scattering and absorbing of the light rather than transmitting in a straight line, caused by suspended and dissolved materials such as clay, silt, organic materials, plankton, and other microscopic organisms [81].

LP 2000 microprocessor-based bench turbidity meter instrument manufactured by HANNA Instruments Inc., USA, has been used to measure the turbidity values for the water samples, as illustrated in Fig. (2.9).



Figure (2.9): LP 2000 microprocessor-based bench turbidity meter.

LP 2000 used to determine the turbidity of water. The meter covers the 0 to 1000 NTU range, it is housed in a plastic lightweight case with an upper interface contains LCD digital screen, covered vial where the sample being measured placed and four control bottoms.

The working principle of the instrument is by passing a beam of IR (Infra-Red) with a wavelength of 890 nm through a water sample placed within the measuring vial, the high emission of IR beam from the LED lighting source reduces the interference caused by colored samples to a minimum. The interior of the equipment is provided with a sensor positioned at 90° with respect to the direction of the IR beam, see Fig. (2.10). The amount of light scattered by suspended particles within the sample is detected by the sensor and the microprocessor converts such reading to NTU values [82].

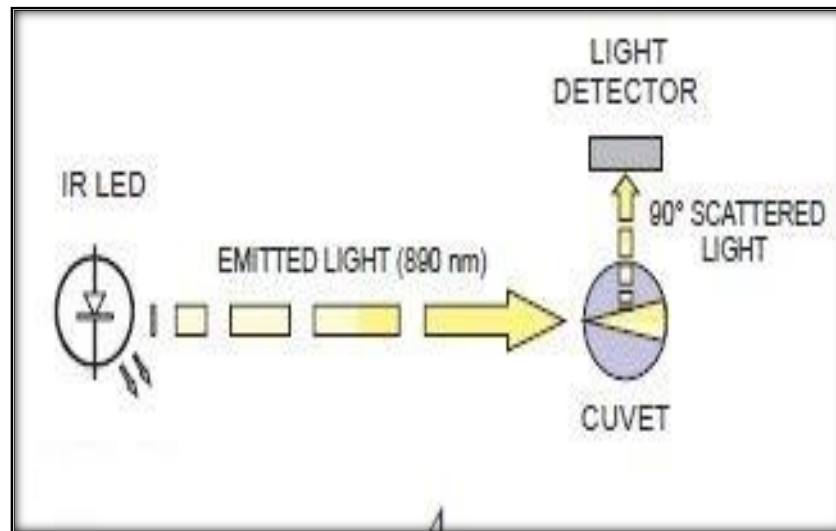


Figure (2.10): LP 2000 principle work [82].

2.4.3. HI 98127 Waterproof PH Tester

The term (PH) is commonly used to measure the activity of hydrogen ion in the aqueous solutions. The PH values of collected water samples have been determined using HI 98127 PH testing kit manufactured by HANNA Instruments Inc., USA. As shown in Fig. (2.11).

The tester is housed in a rugged plastic case that completely sealed against the humidity expect the stainless steel temperature sensor that left exposed. The reading can be shown directly during the measuring by a digital LCD screen. The meter is provided with a rechargeable battery and equipped with internal PH measuring electrode.



Figure (2.11): HI 98127 waterproof pH tester.

2.5. Memmert Heating and Drying Oven

After each measuring process, the 250 ml vials that are filled with a sample need to be washed with pure filtered water and dried to avoid old water residues in the vials which would affect the radon content in the new sample. Memmert heating and drying electric oven (Germany) as shown in Fig. (2.12) is used to dry the RAD H₂O vials after

being washed. Another use is that for drying the calcium sulfate grains that contained in the desiccant and used to dry the air passes through it.



Figure (2.12): Memmert heating and drying oven.

2.6. Global Positioning System (GPS)

The Global Positioning System (GPS) as shown in Fig. (2.13) is a space-based satellite navigation system created by US governorate for military purposes at the beginning [83], and was made later freely accessible to the civilian usage. The GPS provides location, time and velocity information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS

satellites [84]. GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map [85].



Figure (2.13): The GPS receiver.

2.7. Study area

Sawa Lake is closed basin with no surface water discharge. It is located in the eastern edge of the western desert of Iraq, (25 km) to the west of Samawa City, the capital of AL-Muthanna Province, (270 km) south of Baghdad, the capital of Iraq,

approximately between longitudes (44° 59' 13") - (45° 11' 68") east and the constituencies of latitudes (31° 17' 24") – (31° 20' 17") north, (Fig. 2.14 and 2.15).



Figure (2.14): Sawa Lake.

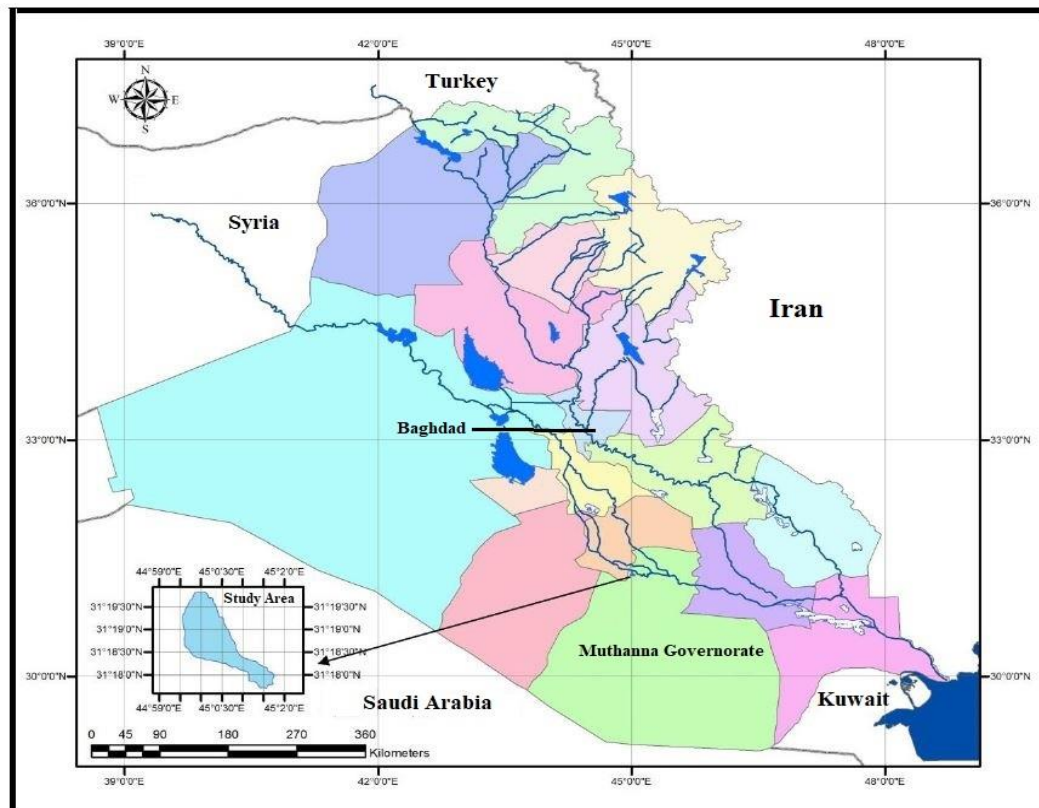


Figure (2.15): Iraq map shows the location of Sawa Lake [86].

The lake area is (10 km²) with an average length of (5 km) and a width of (2 km) [87]. Its depth varies slightly between (3 m) and (5.5 m) [88] with a very shallow depth at some places of the lake beach (ranged from 20-50 cm). The lake elevation is 16 m above the sea level [86], and it is surrounded by a salt edge composed mainly of gypsum that rises by 2.8 m above the lake surface and 18.5 m above the sea level [89]. The lake has no inlet or outlet, with no surface resources feeding it with water. Groundwater represents the main source of the lake water which flows through springs in the middle of the lake. These springs are provided with groundwater by the Euphrates aquifer through a system of cracks and joints. The salinity of the lake water is higher than the Euphrates river as a result of excessive evaporation [90].

2.7.1. Geology of Sawa Lake

The geological effects governed the creation of Sawa Lake in the region about (10,000) years ago [91,92]. Tectonically, the lake is situated as a part of the western desert, at the boundary between the stable shelf (Salman subzone) and the unstable shelf (Samawa-Nassirya subzone). The uplift of the western desert block was formed by fault systems called Abu-Jir Fault, this fault represents a large influence on the hydrological setting of the studied area. The region is covered by recent alluvial and dune sediments with thickness varies from (1m) to (10 m), there are three geological formations located under these sediments: Rus Formation consists anhydrite, limestone, and dolomite which deposited in lagoon environment. Dammam Formation is consisting of karstified limestone, dolomite limestone, nodules chert with chalky and marly limestone which deposited in the shallow neritic environment [91].

Geology is considered as an essential factor in the determination of the quality of water. The Sawa Lake site is structurally and tectonically distinct. It locates on the eastern side of the Salman subzone near the western side of the Mesopotamian Plane. By this location, it appears to be situated on the intersection of the Abo-Jir Fault zone and the Samawa lineament. The intersection of these faults formed the area often relatively unstable. The fault planes formed secondary permeability, allowing deep-water ascension upwards. In addition, the structural situation, the stratigraphic column is another factor played a major role in the processing of the lake formation. The geological formations beneath the lake are aquifers such as ErRadhuma, Dammam, and Euphrates Formations. The recharge areas of the aquifers that beneath the lake are from adjacent highlands and the piezometric pressure raises the water upward to fill the lake depression [92].

2.7.2. Origin and Quality of Sawa Lake Water

Sawa Lake is supplied with water mainly by groundwater merge between the deep and shallow aquifers beneath the lake; especially the Euphrates, Dammam, and Er Radhuma through a system of joints and cracks [93]. It is believed that Sawa Lake is of marine origin water due to the mixing of Dammam Formation water (meteoric and rich with CaSO_4) with Euphrates Formation water (marine origin) [92]. The hydrogeochemical index (Cl/HCO_3) of the lake water is very high compared to inland water and close to that of seawater which reflect the effect of seawater. Nevertheless, other processes (diagenesis) could give the same result in addition to the interaction between groundwater and marine origin sediments of area (fossil water). It is suggested that the sawa water is survived mixing between fresh and groundwater [94]. The high

value of salinity characterizes the lake water, the reason behind that maybe is the strong evaporation process due to the high temperature in the region [90,91]. The increasing in lake water salinity was accompanied by a slow rise in ionic exchange, which indicates a cationic exchange that increases the hardness of this water [94]. Because of the high salinity of the lake water. Additionally, the high amounts of TDS and dissolved sulfate compounds, the lake water have an unlikable taste and unsuitable for human consumption or for irrigation use.

2.7.3. Climate of Sawa Lake

An arid climate is dominant in the lake environment, dry and hot summer, cold winter, and pleasant spring and fall. The highest minimum and maximum temperature range between (27.6 – 44.6) °C. The mean annual rainfall is (110 mm), and the highest value of evaporation occurred during July (506 mm) with the lowest value occurring in January (89 mm). The wind blowing in the study area most of the year is N-W winds and speed of 4.9 m/s [92].

2.8. Sampling Method and Radon Measurements in Water

The major source of error in the measurements radon levels in water generally back to the mistakes happened during the samples collection. Hence, getting good samples requires care and practice [73]. Because of the radon content in the water is simply escapes from the samples, the sample must be kept with no contact with air.

In order to estimate radon concentration of Sawa Lake water, (170) water samples have been collected from (85) different locations at the lake during two seasons (winter

and spring), 85 samples for each season and two samples for each location. Samples locations coordinates are documented using the Global Positioning System (GPS) during the collection and used later to draw a map shows the samples locations on the lake (Fig. 2.16). Plastic bottles with a capacity of (1.5 L) have been used for samples collection, as shown in Fig. (2.17). The bottles are filled completely with water at depth of (20-30 cm) and sealed tightly underwater surface to make sure there is no contact between the sample and air, and there is no headspace in the bottle, and then each sample is provided with a label shows the number of the sample and the date of collection. After collection, the samples are brought to the laboratory for measuring of radon concentration, the measurements are taken place at the same day of collection or at next day to avoid any delay which would lead to dilute the radon concentration in the water and hence make the using of time correction factors become necessary. In addition, the RAD7 monitor is capable to assess the radon level in water within three hours of collection.

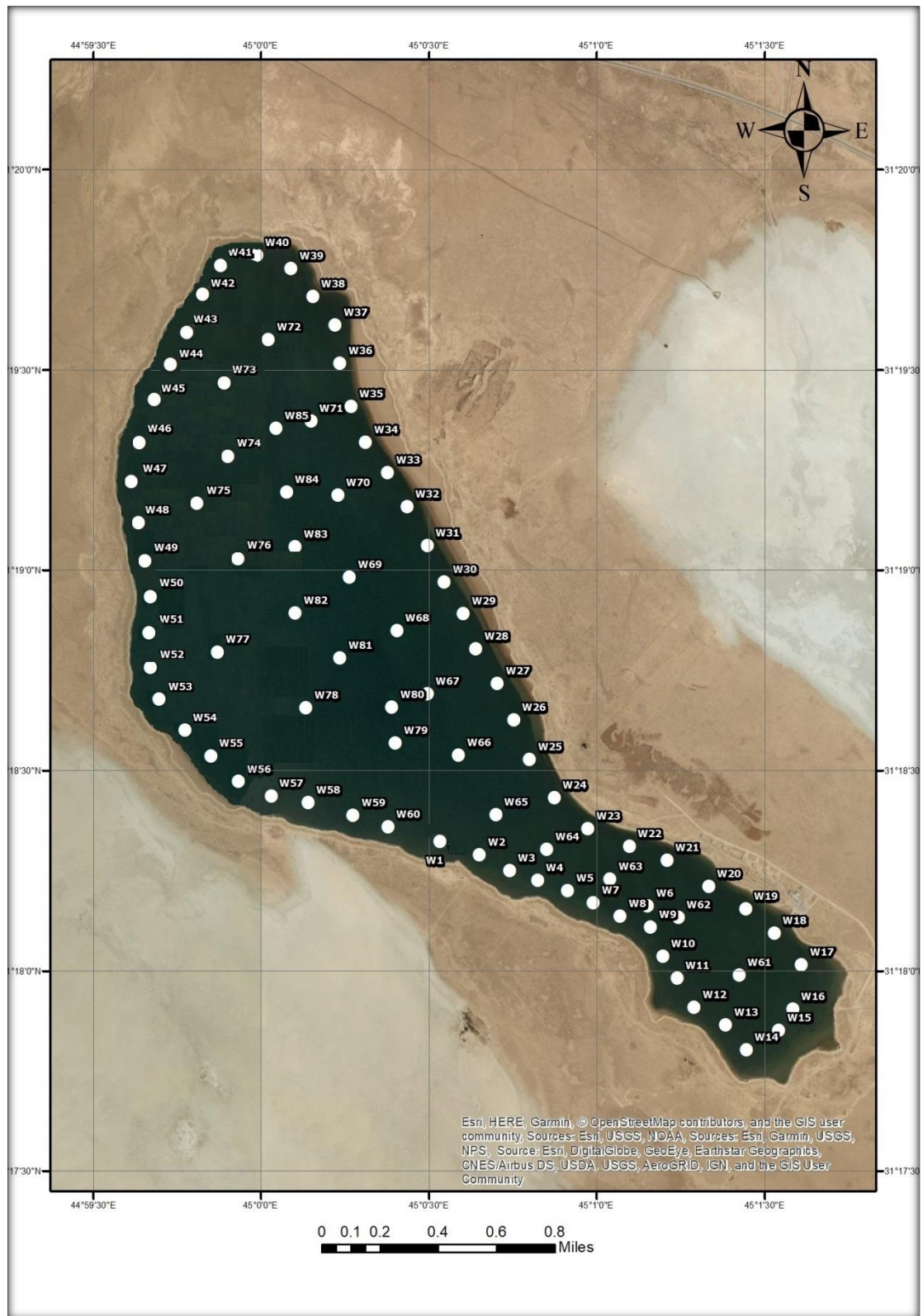


Figure (2.16): The locations of water samples in the lake.



Figure (2.17): Sample collection cans.

The RAD7 protocol used for measuring radon in water is (Grab), with (wat-250 ml) mode, which allows RAD7 to determine the radon concentration in (250 ml) vial connected to the RAD H₂O instrument. The RAD7 aerates the sample by pumping the air through a closed loop for five minutes for extracting the radon content in the sample, the closed loop carries radon into the cell sample of the RAD7. This is followed by five minutes waiting for reaching the equilibrium, after which the counting period begins. The counting period consists of five cycles with five minutes for each cycle, and five minutes waiting between each cycle and another. Hence, the sample measurement time is about one hour. Fig. (2.18) shows the procedure of radon measurement in the water.

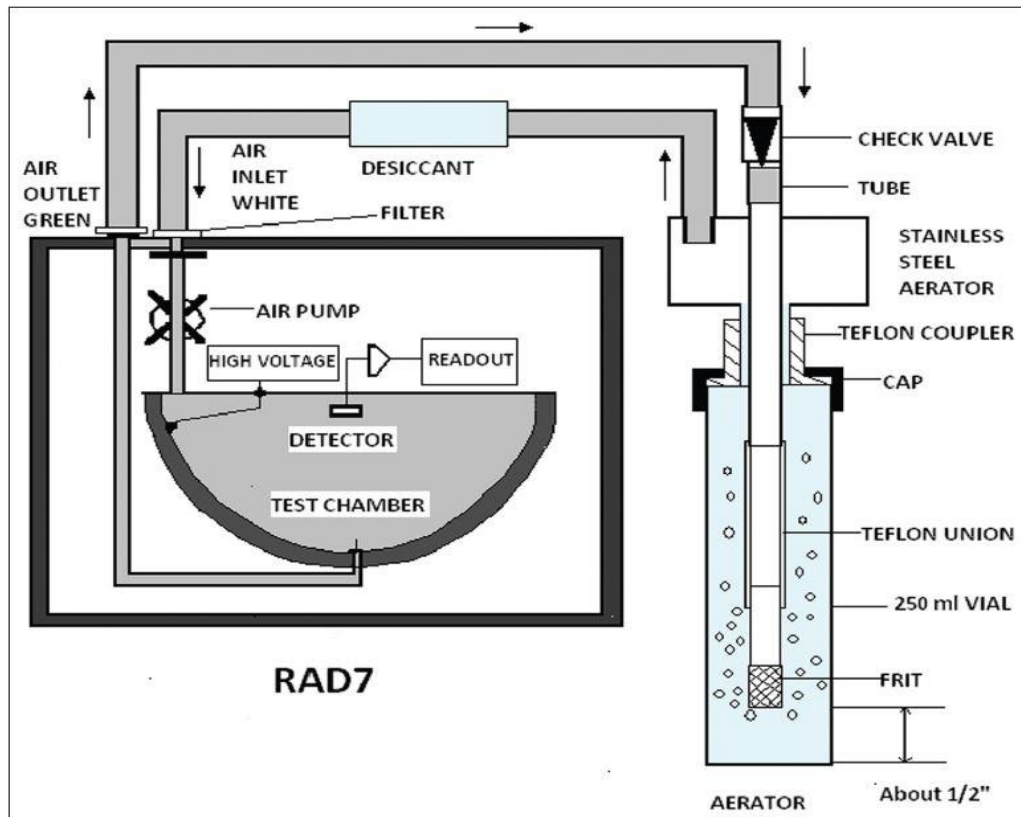


Figure (2.18): Schematic diagram of radon measurement in water [95].

2.9. Sampling Method and Radon Soil-gas Measurement

In order to measure radon concentration in Sawa Lake soils, 60 sampling points for 30 locations of soil around the Lake were in situ analyzed during two seasons, with an average of twice for each location, as shown in Fig. (2.19). The samples are taken at the depth of (30 cm) undersurface using soil gas probe which is one of the RAD7 accessories (Fig 2.20). The undersurface of the soil consists of hard rock which made the probe penetrating a little of difficult, and most of the time it is be needed to use a hard iron rod and hummer to get the required depth. Another problem that is the presence high quantities of water within the soil that fill the sniffer tip of the probe which would

affect the radon measurement, the small water pump was used with a tiny tube to decrease the water content in the sampling hole.

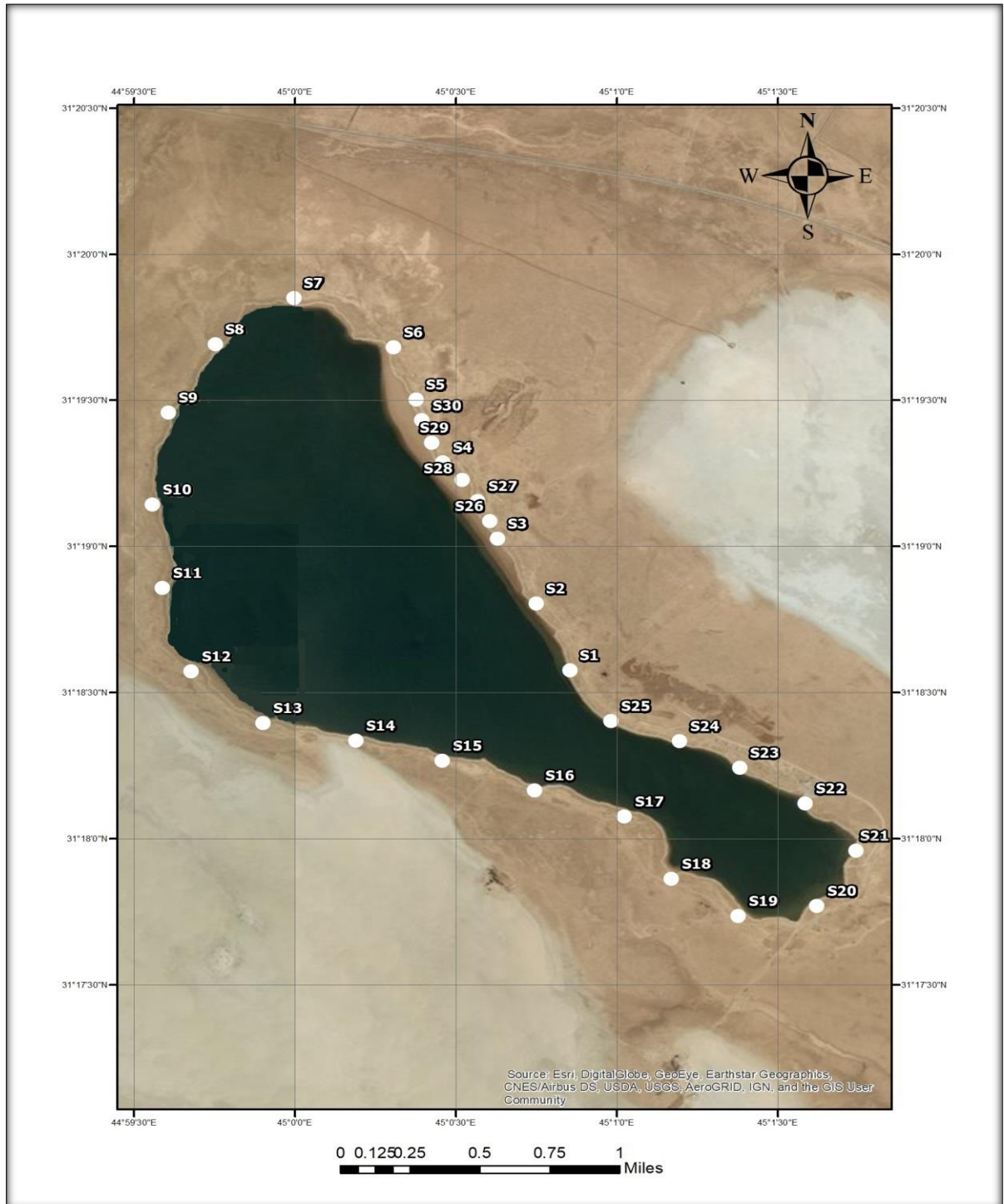


Figure (2.19): Locations of soil sampling points around the lake.



Figure (2.20): Radon soil-gas in situ measurements.

Geographical Information System Mapping Technology (GIS) was used to draw the map that shows the sampling points locations using Geographical coordinates that were obtained using (GPS) for all samples during measurements. In order to measure the radon levels in the lake soil, the free end of soil gas probe was connected to inlet port of RAD7 through a desiccant a dust filter and desiccant for decreasing the humidity of the air that is sniffed from the sampling point through the hammered end of the probe. The RAD7 protocol used is (Grab) with (Sniff) mode that allows radon assessment in the soil. After the purging process (which takes usually 15 minutes), the RAD7 begins sniffing air from the sample for five minutes, outlet port left free for air exhalation. And then, the RAD7 waits for another five minutes for reaching the equilibrium between radon and its products. Measurement process of radon products consists of five cycles,

five minutes for each cycle with five minutes waiting between every two cycles. Fig. (2.21) shows the scheme of radon measurements in the soil.

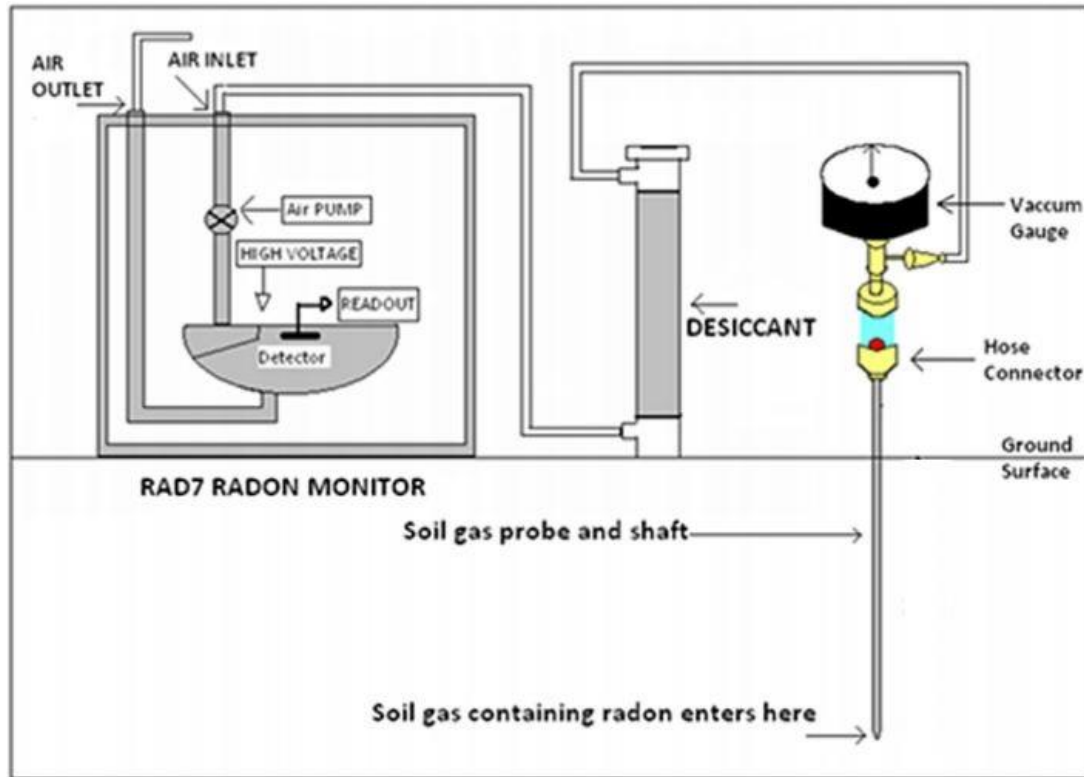


Figure (2.21): Schematic diagram of radon soil-gas measurement [69].

Chapter Three

RESULTS AND DISCUSSION

3.1. Introduction

In the present study, radon concentration of Sawa Lake water and soil has been seasonally determined and the radon concentrations in two seasons have been compared. The annual effective dose associated with the radon concentration of both water and soil was calculated. Several physiochemical parameters of the lake water were measured and the relationship between these parameters and the radon concentration of water has been established. This chapter will be devoted to review and discuss the results that are obtained during the work.

3.2. Radon Activity Concentrations in the Lake Water

Radon concentration of the lake water was measured using RAD7 an electronic radon detector. The total of (85) water samples were collected from different locations at the lake (at depth of 20 cm under the lake surface) in order to cover the whole area of the lake and brought to the laboratory for analysis. The measurements of radon in water were carried out during two seasons, winter and spring, on average of twice for each location. Samples locations at the surface of the lake water were documented using GPS and GIS, Table (3.1) illustrates the locations of collected water samples.

Table (3.1): Locations of water samples.

No.	Sample	Location		No.	Sample	Location	
		latitude	longitude			latitude	longitude
1	W1	N 31° 18.321'	E 45° 00.531'	44	W44	N 31° 19.509'	E 44° 59.729'
2	W2	N 31° 18.289'	E 45° 00.649'	45	W45	N 31° 19.423'	E 44° 59.676'
3	W3	N 31° 18.250'	E 45° 00.739'	46	W46	N 31° 19.323'	E 44° 59.636'
4	W4	N 31° 18.226'	E 45° 00.822'	47	W47	N 31° 19.222'	E 44° 59.621'
5	W5	N 31° 18.200'	E 45° 00.911'	48	W48	N 31° 19.120'	E 44° 59.629'
6	W6	N 31° 18.163'	E 45° 01.150'	49	W49	N 31° 19.026'	E 44° 59.655'
7	W7	N 31° 18.170'	E 45° 00.988'	50	W50	N 31° 18.938'	E 44° 59.671'
8	W8	N 31° 18.137'	E 45° 01.068'	51	W51	N 31° 18.847'	E 44° 59.670'
9	W9	N 31° 18.108'	E 45° 01.159'	52	W52	N 31° 18.759'	E 44° 59.672'
10	W10	N 31° 18.036'	E 45° 01.195'	53	W53	N 31° 18.678'	E 44° 59.697'
11	W11	N 31° 17.981'	E 45° 01.238'	54	W54	N 31° 18.601'	E 44° 59.771'
12	W12	N 31° 17.909'	E 45° 01.288'	55	W55	N 31° 18.536'	E 44° 59.849'
13	W13	N 31° 17.865'	E 45° 01.382'	56	W56	N 31° 18.472'	E 44° 59.933'
14	W14	N 31° 17.803'	E 45° 01.444'	57	W57	N 31° 18.437'	E 45° 00.027'
15	W15	N 31° 17.850'	E 45° 01.541'	58	W58	N 31° 18.420'	E 45° 00.139'
16	W16	N 31° 17.903'	E 45° 01.582'	59	W59	N 31° 18.387'	E 45° 00.273'
17	W17	N 31° 18.015'	E 45° 01.608'	60	W60	N 31° 18.359'	E 45° 00.377'
18	W18	N 31° 18.094'	E 45° 01.527'	61	W61	N 31° 17.990'	E 45° 01.422'
19	W19	N 31° 18.155'	E 45° 01.442'	62	W62	N 31° 18.134'	E 45° 01.241'
20	W20	N 31° 18.211'	E 45° 01.332'	63	W63	N 31° 18.228'	E 45° 01.038'
21	W21	N 31° 18.276'	E 45° 01.208'	64	W64	N 31° 18.303'	E 45° 00.850'
22	W22	N 31° 18.311'	E 45° 01.096'	65	W65	N 31° 18.390'	E 45° 00.698'
23	W23	N 31° 18.354'	E 45° 00.972'	66	W66	N 31° 18.538'	E 45° 00.587'
24	W24	N 31° 18.432'	E 45° 00.872'	67	W67	N 31° 18.691'	E 45° 00.494'
25	W25	N 31° 18.527'	E 45° 00.798'	68	W68	N 45° 00.494'	E 45° 00.403'
26	W26	N 31° 18.627'	E 45° 00.751'	69	W69	N 31° 18.983'	E 45° 00.262'
27	W27	N 31° 18.717'	E 45° 00.703'	70	W70	N 31° 19.187'	E 45° 00.228'
28	W28	N 31° 18.804'	E 45° 00.639'	71	W71	N 31° 19.372'	E 45° 00.147'
29	W29	N 31° 18.892'	E 45° 00.601'	72	W72	N 31° 19.575'	E 45° 00.021'
30	W30	N 31° 18.970'	E 45° 00.544'	73	W73	N 31° 19.469'	E 44° 59.888'
31	W31	N 31° 19.061'	E 45° 00.493'	74	W74	N 31° 19.286'	E 44° 59.902'
32	W32	N 31° 19.159'	E 45° 00.433'	75	W75	N 31° 19.168'	E 44° 59.812'
33	W33	N 31° 19.244'	E 45° 00.375'	76	W76	N 31° 19.032'	E 44° 59.932'
34	W34	N 31° 19.320'	E 45° 00.310'	77	W77	N 31° 18.796'	E 44° 59.869'
35	W35	N 31° 19.409'	E 45° 00.266'	78	W78	N 31° 18.657'	E 45° 00.132'
36	W36	N 31° 19.517'	E 45° 00.233'	79	W79	N 31° 18.568'	E 45° 00.398'
37	W37	N 31° 19.612'	E 45° 00.219'	80	W80	N 31° 18.658'	E 45° 00.388'
38	W38	N 31° 19.684'	E 45° 00.153'	81	W81	N 31° 18.780'	E 45° 00.233'
39	W39	N 31° 19.753	E 45° 00.088'	82	W82	N 31° 18.893'	E 45° 00.101'
40	W40	N 31° 19.786'	E 44° 59.986'	83	W83	N 31° 19.058'	E 45° 00.100'
41	W41	N 31° 19.763'	E 44° 59.876'	84	W84	N 31° 19.196'	E 45° 00.075'
42	W42	N 31° 19.684'	E 44° 59.824'	85	W85	N 31° 19.355'	E 45° 00.043'
43	W43	N 31° 19.595'	E 44° 59.773'				

Radon concentration results in Bq/l for the water samples collected during the winter season are shown in Table (3.2). Radon variation of water samples is illustrated in Fig. (3.1).

Table (3.2): Radon concentrations of water samples during the winter season.

No.	Sample	Radon concentration (Bq/L)					Mean concent.(Bq/L)
		1	2	3	4	5	
1	W1	0.154±0.74	0.155±0.75	0.154±0.74	0.155±0.75	0.155±0.75	0.154±0.14
2	W2	0.154±0.74	0.00±0.55	0.00±0.55	0.464±0.93	0.00±0.55	0.124±0.12
3	W3	0.00±0.55	0.311±0.85	0.311±0.85	0.777±1.1	0.156±0.75	0.311±0.20
4	W4	0.00±0.55	0.00±0.55	0.00±0.55	0.311±0.84	0.311±0.84	0.124±0.12
5	W5	0.154±0.74	0.155±0.75	0.311±0.84	0.155±0.75	0.00±0.55	0.154±0.14
6	W6	0.154±0.74	0.309±1.2	0.461±0.92	0.464±0.93	0.430±0.54	0.363±0.25
7	W7	0.311±0.84	0.154±0.74	0.308±0.84	0.619±1.0	0.560±0.94	0.356±0.23
8	W8	0.311±0.84	0.00±0.55	0.311±0.84	0.155±0.75	0.311±0.84	0.216±0.16
9	W9	0.461±0.92	0.155±0.75	0.154±0.74	0.00±0.55	0.00±0.55	0.154±0.14
10	W10	0.00±0.55	0.464±0.93	0.154±0.74	0.464±0.93	0.318±0.62	0.351±0.24
11	W11	0.461±0.92	0.154±0.74	0.308±0.84	0.00±0.55	0.615±0.95	0.384±0.19
12	W12	0.463±0.92	0.615±0.91	0.769±1.06	0.308±0.84	0.511±0.74	0.532±0.29
13	W13	0.150±0.74	0.619±0.11	0.461±0.92	0.155±0.75	0.00±0.6	0.278±0.19
14	W14	0.154±0.75	0.461±0.93	0.523±0.82	0.308±0.83	0.151±0.72	0.319±0.17
15	W15	0.511±0.73	0.755±1.03	0.614±0.84	0.455±0.74	0.311±0.82	0.529±0.28
16	W16	1.07±1.11	0.541±0.93	0.181±0.82	0.181±0.82	0.908±1.10	0.576±0.28
17	W17	0.154±0.72	0.155±0.72	0.308±0.84	0.155±0.72	0.00±0.62	0.181±0.15
18	W18	0.00±0.63	0.374±0.83	0.562±0.91	0.188±0.73	0.379±0.82	0.301±0.22
19	W19	0.00±0.62	0.00±0.62	0.179±0.72	0.181±0.72	0.544±0.93	0.181±0.15
20	W20	0.00±0.61	0.184±0.72	0.183±0.72	0.00±0.61	0.186±0.72	0.111±0.11
21	W21	0.182±0.73	0.552±0.93	0.369±0.82	0.368±0.82	0.372±0.82	0.368±0.22
22	W22	0.187±0.74	0.188±0.75	0.376±0.82	0.378±0.82	0.190±0.75	0.264±0.19
23	W23	0.545±0.92	0.365±0.84	0.00±0.61	0.183±0.74	0.184±0.74	0.255±0.18
24	W24	0.00±0.63	0.731±1.00	0.364±0.83	0.367±0.83	0.368±0.83	0.336±0.19
25	W25	0.347±0.82	0.176±0.73	0.353±0.82	0.00±0.62	0.357±0.82	0.246±0.18
26	W26	0.245±0.72	0.00±0.62	0.326±0.81	0.328±0.81	0.255±0.72	0.231±0.17
27	W27	0.370±0.82	0.372±0.82	0.741±1.03	1.49±1.24	1.65±1.24	0.924±0.36
28	W28	0.365±0.84	0.734±1.03	0.368±0.84	0.923±1.3	0.371±0.84	0.552±0.21
29	W29	0.328±0.82	0.416±0.84	0.792±1.08	0.912±1.31	0.563±0.93	0.602±0.23
30	W30	0.524±0.92	0.872±0.95	0.891±0.96	1.21±1.19	0.618±0.96	0.823±0.32
31	W31	0.437±0.86	0.748±0.91	1.51±1.33	1.07±1.13	0.691±1.00	0.891±0.33
32	W32	0.364±0.82	0.283±0.75	0.612±0.91	0.835±1.03	0.523±0.91	0.523±0.27
33	W33	0.427±0.85	0.513±0.91	1.23±1.24	0.914±1.08	0.467±0.85	0.711±0.28
34	W34	0.00±0.63	0.719±1.0	0.358±0.84	0.903±1.10	0.181±0.74	0.432±0.24
35	W35	0.185±0.74	0.00±0.62	0.188±0.82	0.189±0.82	0.00±0.62	0.113±0.11
36	W36	0.00±0.61	0.359±0.84	0.180±0.74	0.181±0.74	0.182±0.74	0.181±0.15
37	W37	0.186±0.72	0.188±0.73	0.00±0.62	0.192±0.73	1.14±1.14	0.341±0.22
38	W38	0.539±0.93	0.912±1.13	0.549±0.93	0.368±0.84	0.184±0.84	0.511±0.26
39	W39	0.185±0.74	0.186±0.74	0.370±0.82	0.187±0.74	0.187±0.74	0.223±0.17

40	W40	0.245±0.72	0.00±0.62	0.326±0.81	0.328±0.81	0.255±0.72	0.231±0.17
41	W41	0.308±0.84	1.08±1.23	0.154±0.73	1.24±1.26	0.309±0.84	0.637±0.23
42	W42	0.356±0.84	0.181±0.75	0.361±0.84	0.181±0.75	0.363±0.84	0.288±0.22
43	W43	0.367±0.84	0.599±0.93	0.00±0.62	0.376±0.84	0.473±0.93	0.363±0.23
44	W44	0.384±0.81	0.294±0.74	0.812±1.12	0.728±1.00	0.335±0.81	0.511±0.26
45	W45	0.255±0.72	0.293±0.74	0.518±0.91	0.714±1.01	0.371±0.82	0.431±0.24
46	W46	0.324±0.81	0.581±0.92	1.92±1.46	1.36±1.23	0.643±0.96	0.965±0.38
47	W47	0.472±0.86	0.791±1.09	1.24±1.25	1.02±1.17	0.574±0.92	0.819±0.32
48	W48	0.238±0.74	0.426±0.84	0.658±0.93	1.07±1.19	0.769±1.07	0.632±0.24
49	W49	0.357±0.82	0.274±0.74	0.362±0.82	0.592±0.92	0.316±0.81	0.381±0.21
50	W50	0.175±0.72	0.236±0.74	0.183±0.72	0.00±0.62	0.176±0.72	0.154±0.14
51	W51	0.243±0.74	0.248±0.74	0.146±0.71	0.185±0.72	0.00±0.62	0.164±0.15
52	W52	0.193±0.71	0.198±0.71	0.258±0.75	0.171±0.71	0.00±0.62	0.164±0.15
53	W53	0.156±0.71	0.155±0.71	0.00±0.62	0.153±0.71	0.00±0.62	0.092±0.11
54	W54	0.00±0.61	0.152±0.71	0.152±0.71	0.163±0.72	0.152±0.71	0.123±0.12
55	W55	0.173±0.72	0.146±0.72	0.215±0.74	0.115±0.72	0.115±0.72	0.152±0.14
56	W56	0.124±0.72	0.124±0.72	0.00±0.62	0.118±0.72	0.112±0.72	0.095±0.11
57	W57	0.145±0.74	0.236±0.75	0.116±0.72	0.00±0.62	0.119±0.72	0.123±0.12
58	W58	0.167±0.72	0.155±0.72	0.00±0.62	0.162±0.72	0.124±0.72	0.121±0.12
59	W59	0.346±0.82	0.213±0.75	0.329±0.81	0.123±0.71	0.238±0.75	0.249±0.18
60	W60	0.187±0.73	0.218±0.74	0.00±0.62	0.129±0.72	0.109±0.72	0.128±0.12
61	W61	0.175±0.73	0.178±0.74	0.00±0.62	0.177±0.74	0.355±0.84	0.177±0.14
62	W62	0.177±0.74	0.358±0.84	0.00±0.62	0.214±0.81	0.173±0.74	0.184±0.15
63	W63	0.214±0.81	0.184±0.73	0.385±0.84	0.00±0.62	0.196±0.75	0.195±0.15
64	W64	0.548±0.91	0.00±0.61	0.185±0.81	0.186±0.81	0.374±0.81	0.259±0.17
65	W65	0.179±0.72	0.00±0.62	0.184±0.74	0.174±0.72	0.181±0.74	0.143±0.13
66	W66	0.182±0.75	0.549±0.93	0.365±0.84	0.184±0.74	0.368±0.83	0.329±0.21
67	W67	0.181±0.74	0.00±0.62	0.182±0.81	0.363±0.82	0.733±1.00	0.292±0.18
68	W68	0.184±0.75	0.512±0.91	0.176±0.74	0.256±0.75	0.167±0.72	0.259±0.18
69	W69	0.366±0.82	0.222±0.74	0.335±0.84	0.361±0.82	0.555±0.91	0.369±0.19
70	W70	0.354±0.82	0.581±0.91	0.398±0.84	0.723±1.00	0.745±1.00	0.560±0.26
71	W71	0.274±0.75	0.456±0.84	0.123±0.72	0.437±0.84	0.389±0.82	0.335±0.23
72	W72	0.167±0.72	0.00±0.62	0.228±0.74	0.226±0.74	0.184±0.74	0.161±0.14
73	W73	0.308±0.82	0.311±0.82	0.311±0.82	0.00±0.62	0.311±0.82	0.288±0.18
74	W74	0.155±0.72	0.00±0.62	0.173±0.72	0.153±0.72	0.164±0.72	0.129±0.12
75	W75	0.548±0.91	0.368±0.82	0.366±0.81	0.366±0.81	0.368±0.82	0.403±0.22
76	W76	0.181±0.72	0.184±0.72	0.184±0.72	0.554±0.91	0.185±0.81	0.258±0.17
77	W77	0.00±0.62	0.126±0.72	0.126±0.72	0.00±0.61	0.174±0.74	0.085±0.11
78	W78	0.145±0.72	0.00±0.62	0.239±0.74	0.156±0.72	0.162±0.74	0.141±0.13
79	W79	0.366±0.82	0.184±0.72	0.184±0.72	0.00±0.62	0.00±0.62	0.147±0.13
80	W80	0.00±0.62	0.257±0.74	0.311±0.82	0.198±0.74	0.00±0.62	0.153±0.14
81	W81	0.137±0.72	0.278±0.75	0.511±0.91	0.539±0.91	0.217±0.74	0.336±0.18
82	W82	0.265±0.74	0.00±0.62	0.358±0.81	0.492±0.84	0.198±0.82	0.262±0.17
83	W83	0.00±0.62	0.527±0.91	0.275±0.75	0.257±0.74	0.091±0.71	0.231±0.16
84	W84	0.172±0.73	0.431±0.84	0.123±0.72	0.00±0.62	0.214±0.81	0.188±0.15
85	W85	0.273±0.75	0.374±0.82	0.364±0.82	0.647±0.92	0.00±0.62	0.331±0.18
Mean Value							0.323±0.19
Permissible Value [96]							11.1 Bq/L

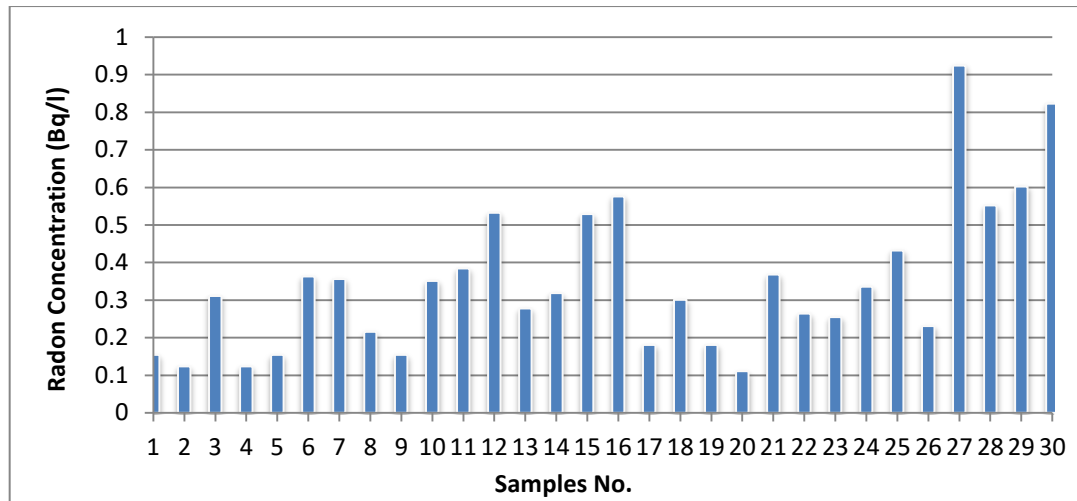


Figure (3.1): Radon variation of water samples during the winter season.

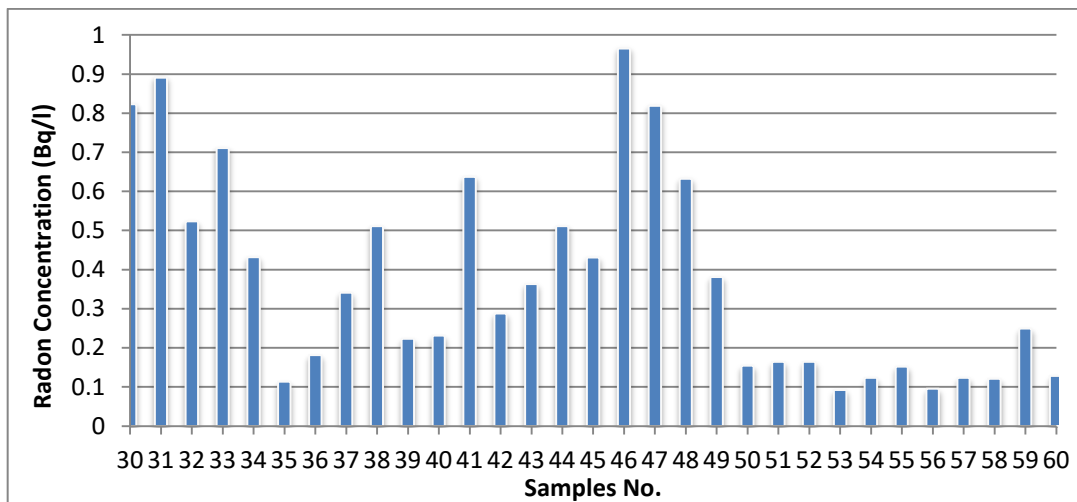


Figure (3.1): Continued

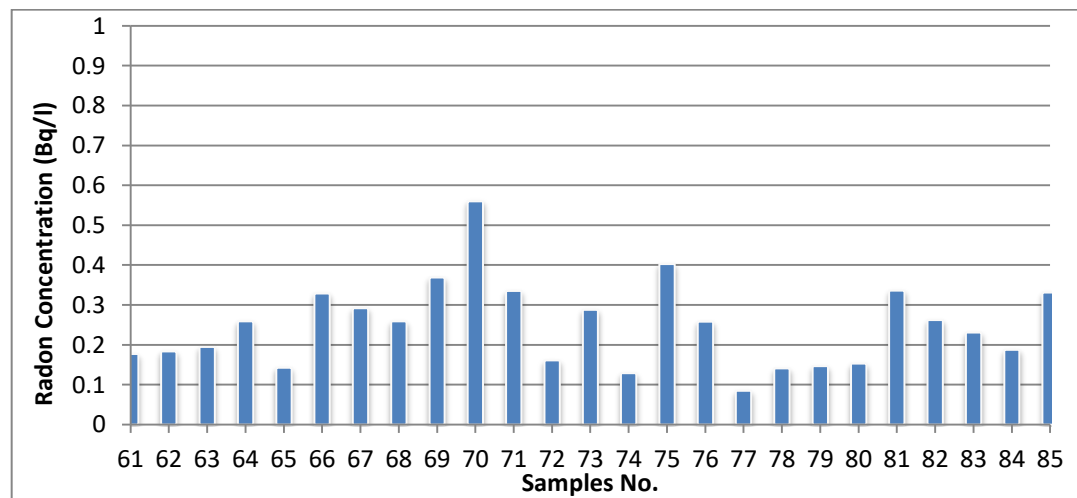


Figure (3.1): Continued

Table (3.2) shows the achieved radon concentrations in the lake water determined using RAD7, on average of five runs for each sample with a final mean value. From the table, it can be seen that the radon activity in water samples shows high variation, where concentrations values ranged from the smaller value of $(0.085 \pm 0.11 \text{ Bq/L})$ for sample (W77) to the highest one of $(0.965 \pm 0.38 \text{ Bq/L})$ for sample (W46) with an average value of $(0.322 \pm 0.19 \text{ Bq/L})$. The higher concentrations of radon in the lake water are recorded for samples W27, W28, W29, W30, W31, W32, and W33. The minimum radon concentrations can be observed from the Table (3.2) in the samples W76, W77, and W78, which are located at the east side of the lake.

During the spring season, water samples are collected from the same previous locations and analyzed with the same strategy, the obtained radon concentrations for this season are summarized in Table (3.3) which shows the reading of the device runs as well as the mean value of radon concentration (in Bq/L) for each sample. Radon concentration measured in spring is found to be in the range of (0.093 Bq/L) and (1.15 Bq/L) with an average value of (0.409 Bq/L) . The maximum radon concentrations are obtained from the samples W27, W28, W29, W30, W31, W32, W33, W34, and W35 collected from the northeastern side of the lake. While the minimum concentrations were observed for samples W20 and W77. The measured radon levels in water exhibited observable variation as shown in Fig. (3.2).

Table (3.3): Radon concentration of water samples during the spring season.

No.	Sample	Radon concentration (Bq/L)					Mean concent.(Bq/L)
		1	2	3	4	5	
1	W1	0.155±0.74	0.156±0.75	0.156±0.75	0.156±0.75	0.156±0.75	0.155±0.03
2	W2	0.00±0.61	0.622±1.01	0.156±0.75	0.00±0.62	0.00±0.62	0.156±0.26
3	W3	0.155±0.74	0.311±0.84	0.311±0.84	0.156±0.75	0.156±0.75	0.218±0.85
4	W4	0.00±0.61	0.00±0.62	0.311±0.84	0.311±0.84	0.156±0.75	0.156±0.15
5	W5	0.309±0.84	0.00±0.62	0.311±0.84	0.311±0.84	0.156±0.75	0.217±0.13
6	W6	0.155±0.74	0.466±0.93	0.466±0.93	0.466±0.93	0.311±0.84	0.373±0.13
7	W7	0.464±0.92	0.622±1.01	0.311±0.84	0.156±0.75	0.156±0.75	0.342±0.20
8	W8	0.309±0.84	0.156±0.75	0.622±1.01	0.311±0.84	0.466±0.93	0.373±0.17
9	W9	0.309±0.84	0.00±0.62	0.00±0.62	0.156±0.75	0.156±0.75	0.124±0.13
10	W10	0.309±0.84	0.156±0.75	0.622±1.01	0.466±0.93	0.622±1.01	0.435±0.23
11	W11	1.08±1.18	1.09±1.19	0.311±0.84	0.622±1.01	0.466±0.93	0.714±0.35
12	W12	0.464±0.92	0.777±1.07	0.777±1.07	0.622±1.01	0.466±0.93	0.621±0.15
13	W13	0.619±1.00	0.156±0.75	0.466±0.93	0.777±1.07	0.622±1.01	0.528±0.23
14	W14	0.464±0.92	0.311±0.84	0.156±0.75	0.311±0.84	0.466±0.93	0.342±0.13
15	W15	0.714±1.01	0.778±1.03	0.608±0.98	0.834±1.11	0.611±1.00	0.709±0.35
16	W16	0.928±1.13	0.311±0.84	0.622±1.01	0.311±0.84	0.622±1.01	0.559±0.25
17	W17	0.00±0.61	0.311±0.84	0.156±0.75	0.156±0.75	0.466±0.93	0.218±0.17
18	W18	0.464±0.92	0.311±0.84	0.156±0.75	0.311±0.84	0.466±0.93	0.342±0.13
19	W19	0.00±0.61	0.156±0.75	0.156±0.75	0.00±0.62	0.622±1.01	0.187±0.25
20	W20	0.00±0.61	0.00±0.62	0.466±0.93	0.00±0.62	0.00±0.62	0.093±0.20
21	W21	0.309±0.84	0.156±0.75	0.466±0.93	0.466±0.93	0.156±0.75	0.311±0.15
22	W22	0.155±0.74	0.311±0.84	0.156±0.75	0.00±0.62	0.311±0.84	0.186±0.13
23	W23	0.155±0.74	0.311±0.84	0.311±0.84	0.311±0.84	0.311±0.84	0.281±0.69
24	W24	0.155±0.74	0.00±0.62	0.777±1.07	0.156±0.75	0.466±0.93	0.311±0.12
25	W25	0.309±0.84	0.156±0.75	0.311±0.84	0.311±0.84	0.466±0.93	0.311±0.11
26	W26	0.309±0.84	0.156±0.75	0.466±0.93	0.622±1.01	0.311±0.84	0.373±0.17
27	W27	0.773±1.07	1.4±1.29	0.933±1.13	0.777±1.07	1.710±1.39	1.12±0.48
28	W28	0.568±0.98	0.671±1.05	0.938±1.13	1.09±1.18	0.541±0.98	0.761±0.37
29	W29	0.418±0.91	1.13±1.18	0.823±1.11	0.556±0.98	0.556±0.98	0.669±0.16
30	W30	0.773±1.07	0.466±0.93	1.56±1.34	0.933±1.13	1.56±1.34	1.06±0.48
31	W31	0.773±1.07	0.933±1.13	1.24±1.24	1.24±1.24	0.622±1.01	0.963±0.47
32	W32	0.835±1.11	0.678±1.05	0.916±1.12	0.932±1.13	0.546±0.98	0.781±0.34
33	W33	1.55±1.34	0.622±1.01	1.24±1.24	0.622±1.01	0.622±1.01	0.931±0.43
34	W34	0.464±0.92	0.777±1.07	0.777±1.07	0.622±1.01	0.466±0.93	0.621±0.15
35	W35	1.08±1.18	0.777±1.07	0.933±1.13	0.622±1.01	0.777±1.07	0.838±0.37
36	W36	0.281±0.84	0.454±0.92	0.281±0.84	0.569±0.98	0.181±0.76	0.353±0.18
37	W37	0.384±0.88	0.777±1.03	1.11±1.18	0.587±0.98	0.282±0.82	0.628±0.15
38	W38	0.534±0.98	0.812±1.10	1.41±1.32	0.914±1.12	0.823±1.11	0.898±0.38
39	W39	0.00±0.62	0.212±0.78	0.00±0.62	0.182±0.76	0.181±0.76	0.115±0.12
40	W40	0.281±0.82	0.311±0.84	0.185±0.76	0.311±0.84	0.416±0.91	0.301±0.11
41	W41	0.464±0.92	0.933±1.13	1.24±1.24	0.933±1.13	0.546±0.95	0.823±0.37
42	W42	0.347±0.82	0.374±0.84	0.262±0.76	0.592±0.92	0.316±0.81	0.378±0.13
43	W43	0.384±0.84	0.394±0.84	0.738±1.00	0.922±1.13	0.435±0.92	0.574±0.41
44	W44	0.245±0.82	0.633±1.02	0.633±1.02	0.912±1.13	0.821±1.11	0.648±0.15
45	W45	0.464±0.92	1.09±1.19	0.311±0.84	0.622±1.01	0.933±1.13	0.684±1.09
46	W46	0.619±1.00	1.09±1.19	1.4±1.29	1.09±1.19	1.56±1.34	1.15±0.35
47	W47	0.661±1.02	1.18±1.24	0.912±1.13	1.63±1.35	0.611±1.00	0.998±0.45
48	W48	0.928±1.13	0.156±0.75	0.00±0.62	0.933±1.13	0.622±1.01	0.528±0.43
49	W49	0.356±0.84	0.193±0.72	0.618±1.01	0.614±1.01	0.361±0.84	0.428±0.21
50	W50	0.346±0.82	0.213±0.75	0.329±0.81	0.123±0.71	0.238±0.75	0.249±0.18

51	W51	0.309±0.84	0.00±0.62	0.211±0.76	0.00±0.62	0.156±1.34	0.135±0.14
52	W52	0.387±0.84	0.118±0.72	0.129±0.72	0.00±0.62	0.119±0.72	0.151±0.16
53	W53	0.153±0.72	0.165±0.72	0.00±0.62	0.122±0.72	0.124±0.72	0.113±0.11
54	W54	0.365±0.84	0.168±0.72	0.00±0.62	0.00±0.62	0.455±0.92	0.198±0.25
55	W55	0.226±0.81	0.00±0.62	0.385±0.84	0.00±0.62	0.186±0.74	0.159±0.18
56	W56	0.154±0.74	0.155±0.74	0.154±0.74	0.155±0.74	0.155±0.74	0.155±0.26
57	W57	0.267±0.72	0.00±0.62	0.00±0.62	0.123±0.72	0.124±0.72	0.103±0.11
58	W58	0.446±0.92	0.184±0.82	0.185±0.82	0.086±0.68	0.474±0.92	0.275±0.19
59	W59	0.186±0.74	0.181±0.74	0.174±0.72	0.256±0.78	0.00±0.62	0.159±0.16
60	W60	0.264±0.78	0.345±0.84	0.557±0.92	0.261±0.74	0.324±0.82	0.351±0.18
61	W61	0.384±0.84	0.178±0.72	0.376±0.84	0.256±0.76	0.263±0.76	0.291±0.19
62	W62	0.361±0.84	0.00±0.62	0.137±0.72	0.332±0.82	0.283±0.79	0.223±0.17
63	W63	0.373±0.82	0.00±0.72	0.446±0.91	0.574±0.92	0.334±0.82	0.345±0.15
64	W64	0.448±0.91	0.468±0.92	0.283±0.84	0.389±0.86	0.368±0.82	0.391±0.18
65	W65	0.198±0.74	0.275±0.76	0.371±0.84	0.00±0.62	0.124±0.72	0.194±0.16
66	W66	0.534±0.92	0.271±0.76	0.662±1.01	0.215±0.72	0.428±0.92	0.422±0.21
67	W67	0.156±0.72	0.223±0.74	0.00±0.62	0.243±0.74	0.184±0.74	0.161±0.16
68	W68	0.311±0.82	0.408±0.92	0.418±0.92	0.00±0.62	0.118±0.72	0.251±0.17
69	W69	0.284±0.75	0.394±0.84	0.912±1.12	0.628±1.00	0.273±0.76	0.498±0.23
70	W70	0.464±0.92	0.466±0.93	0.777±1.07	0.156±0.75	1.09±1.19	0.590±0.35
71	W71	0.186±0.74	0.182±0.74	0.00±0.62	0.475±0.92	0.633±1.01	0.295±0.19
72	W72	0.00±0.62	0.312±0.82	0.344±0.82	0.292±0.76	0.311±0.82	0.252±0.17
73	W73	0.537±0.92	0.227±0.72	0.383±0.82	0.316±0.81	0.316±0.81	0.356±0.18
74	W74	0.267±0.74	0.215±0.72	0.00±0.62	0.326±0.82	0.00±0.62	0.162±0.16
75	W75	0.286±0.76	0.395±0.84	0.912±1.12	0.627±1.00	0.346±0.81	0.513±0.41
76	W76	0.273±0.75	0.164±0.72	0.316±0.81	0.00±0.62	0.214±0.72	0.193±0.16
77	W77	0.155±0.74	0.00±0.62	0.156±0.75	0.00±0.62	0.156±0.75	0.093±0.085
78	W78	0.284±0.76	0.412±0.86	0.115±0.72	0.456±0.46	0.00±0.62	0.253±0.17
79	W79	0.00±0.62	0.251±0.74	0.258±0.74	0.593±0.92	0.168±0.74	0.254±0.17
80	W80	0.315±0.82	0.527±0.91	0.275±0.75	0.00±0.62	0.00±0.62	0.223±0.16
81	W81	0.435±0.91	0.619±1.00	0.237±0.74	0.806±1.10	0.271±0.75	0.274±0.18
82	W82	0.256±0.74	0.558±0.92	0.492±0.91	0.923±1.13	0.628±1.00	0.571±0.43
83	W83	0.357±0.84	0.318±0.82	0.427±0.91	0.00±0.62	0.424±0.90	0.305±0.15
84	W84	0.263±0.75	0.392±0.86	0.227±0.72	0.317±0.82	0.389±0.86	0.318±0.16
85	W85	0.915±1.13	0.563±0.92	0.246±0.74	0.334±0.84	0.192±0.84	0.450±0.21
Mean Value							0.389±0.24
Permissible Value [96]							11.1 Bq/L

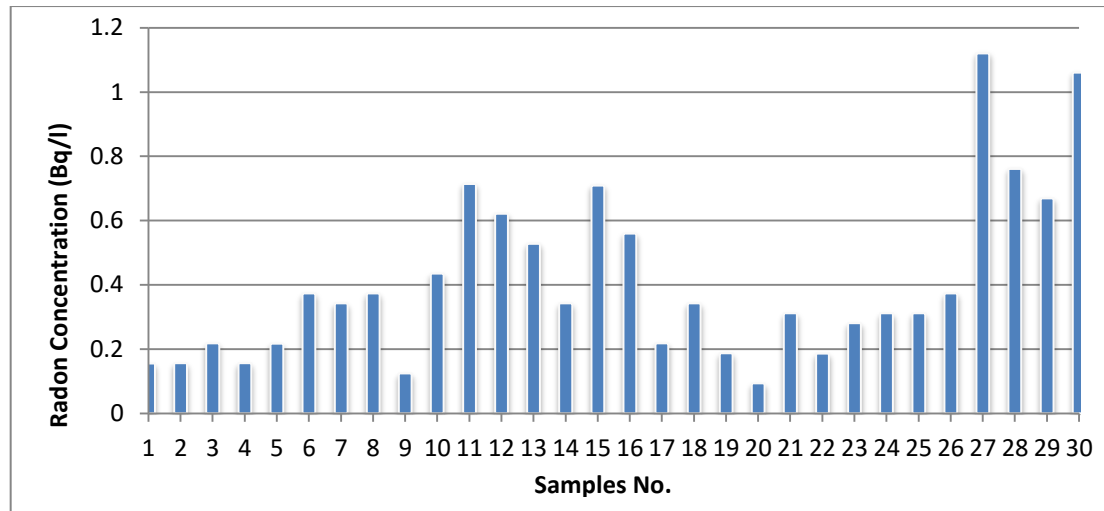


Figure (3.2): Radon variation of water samples during the spring season.

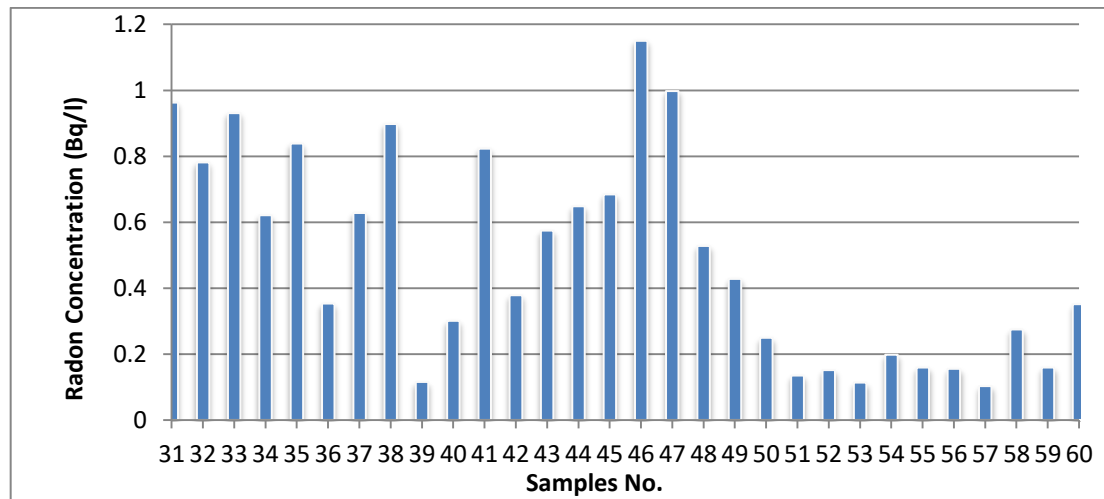


Figure (3.2): Continued

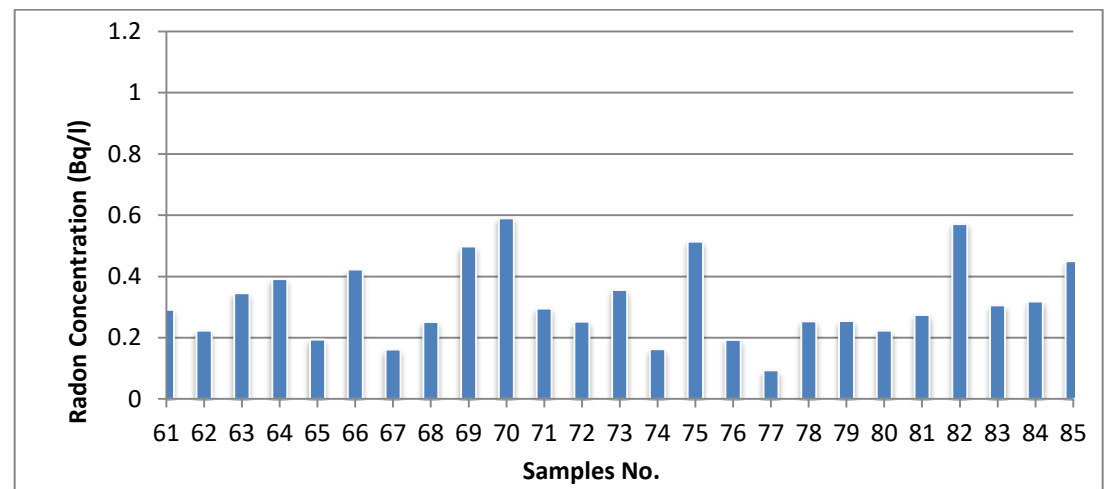


Figure (3.2): Continued

From Table (3.2) and Table (3.3), it is observed that all analyzed samples pose radon concentrations much lower than those proposed by international organizations, since the higher value of radon concentration obtained in winter was (0.965 ± 0.38 Bq/L), as well that is measured in spring was (1.15 ± 0.35 Bq/L), these values is very well below from the maximum contaminant level (MCL) of (11.1 Bq/L) that proposed by United States Environmental Protection Agency (EPA) [96], or (20 Bq/L) reported by World Health Organization (WHO) [97]. The low level of radon concentration in the lake could be ascribed to the contact of water with the air which allows much radon to escape [56].

The water samples which recorded high radon concentration relative to other samples in both seasons are located in the same region, the northeastern side of the lake. The reason behind this, that is the region lies in the vicinity of springs which feed the lake with water, and hence the radon activity is higher when compared to other locations of water samples. The other possible reason may be these locations are located in the direction of the wind that blowing in the north-west direction most of the year which contributes to drift water continuously toward these locations, or may be, the high activity in the mentioned area is due to dominant geological conditions.

However, as mentioned above, the observed wide spatial variations in the radon concentrations distribution in the present study probably attributed to the local geology, radionuclides such as uranium and radium dissolved in water and hydrogeological conditions at the aquifer [98]. It is worthy to mention that the spatial fluctuation of radon concentration in water is mainly attributed to the transport of radon from bedrock to water and mobilization of groundwater [99]. The concentration variability as a function of the sampling sites reflects the geological complexity of the studied area and the

petrophysical parameters (^{226}Ra average content, ^{222}Rn emanation rate of the bedrock, fracture surface in effective contact with the interstitial fluids) [100].

Generally, from the measured concentrations in both seasons, it is clear that radon activity level in water is higher for spring as compared to that obtained in winter. Since the maximum concentration in spring was (1.15 ± 0.35 Bq/l) with an average value of (0.409 ± 0.24 Bq/l), while the higher concentration recorded in winter was (0.965 ± 0.38 Bq/l) with an average value of (0.322 ± 0.19 Bq/l). The higher radon concentration in spring may be due to the increase in water discharge rate of the springs as noticed in the spring season that can be explained due to the increase of groundwater level as a result to intense rainfall in late winter and early spring. The rainfall impact on radon activity concentration in the lake was observed. The induced rainfall increase radon concentration in springs water. On the other hand, the higher radon activity in the spring season may be back to the rising of the lake water level which helps to confine more quantity of radon since the shallow water is more weathered than a deeper one. Several previous studies that treated the relationship between radon concentration and rainfall reported a positive correlation between radon activity and rainfall or increase in water level [101–104]. On the other hand, radon gas concentration varies due to factors such as temperature, air pressure, humidity and changes in ground layers. As a result, radon gas concentration in the seasons are different [105]. Fig. (3.3) shows a comparison between radon concentrations of water samples during two seasons.

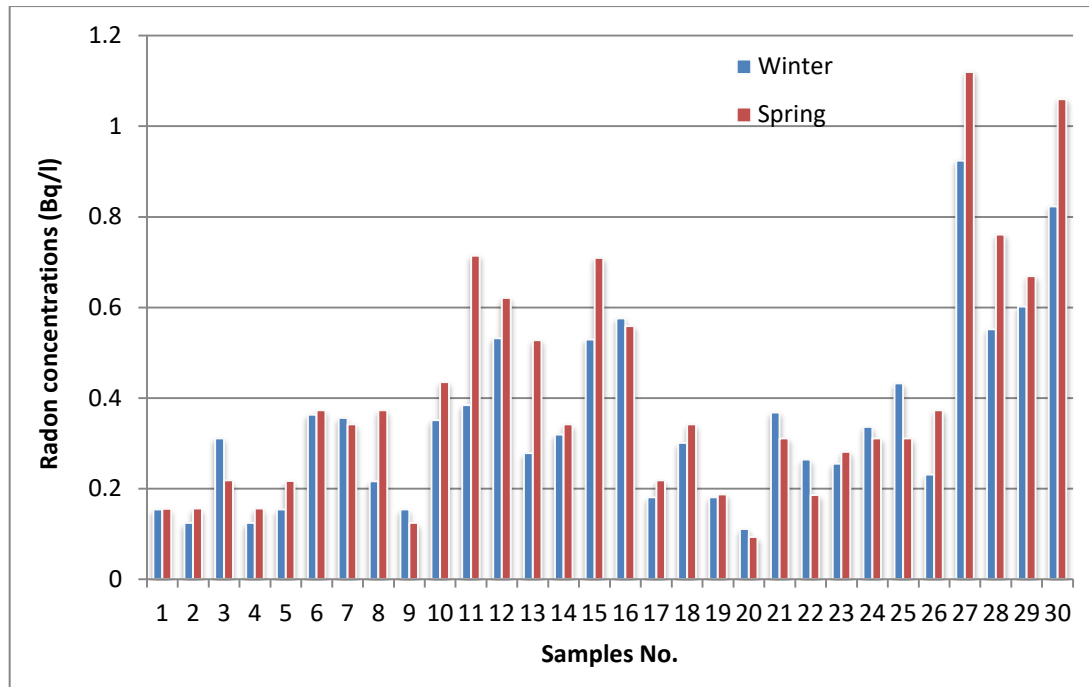


Figure (3.3): Comparison of radon concentration for two seasons.

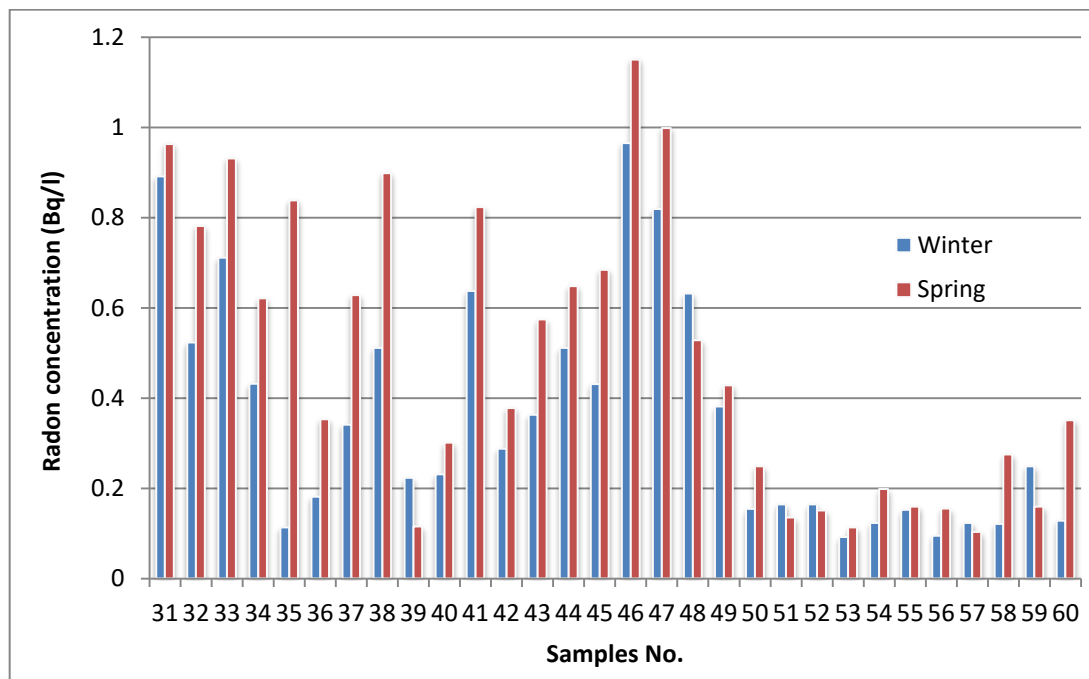


Figure (3.3): Continued

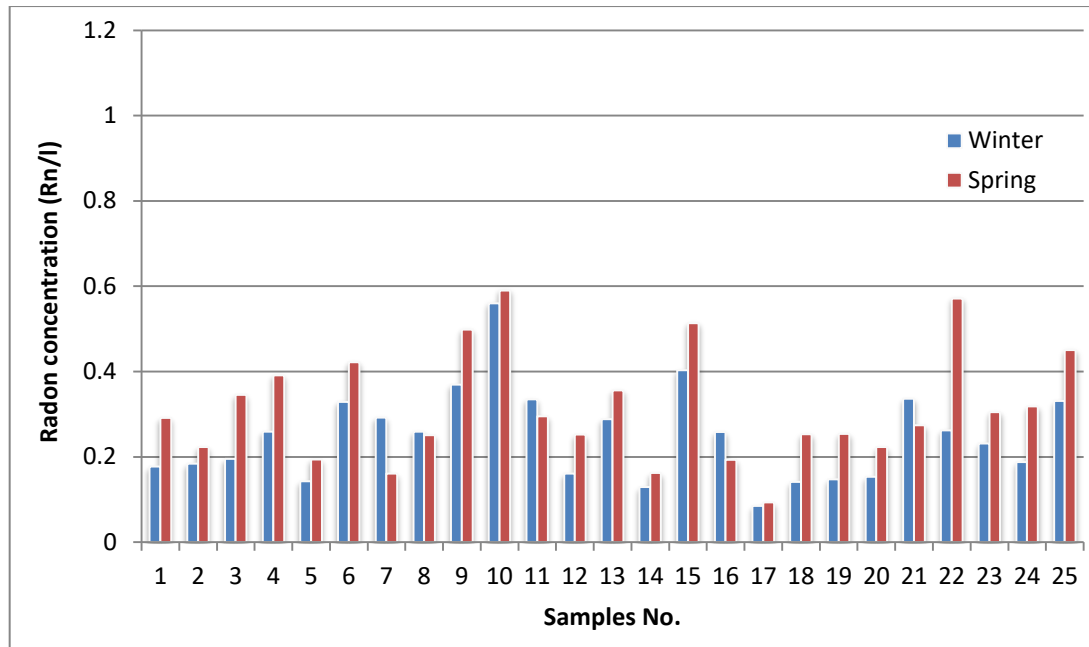


Figure (3.3): Continued

However, in the scope of the above results, the mean value of radon concentration in Sawa Lake water obtained from the present study was compared with the values reported by the other studies carried out in Iraq and the nearest countries are summarized in Table (3.4).

Table (3.4): Local and regional studies on the measurements of radon in underground, wells, and basin water.

No.	Country	Location	Radon (Bq/l)		Mean (Bq/L)	Reference
			Low	High		
1	Iraq	Darbandakhan Lake	0.27	36.07	18.17	[56]
2	Iraq	Basra Province	0.174	2.050	1.112	[106]
3	Iraq	Aucashat City	8.02	11.7	9.86	[107]
4	Iraq	Babylon Province	1.70	5.83	3.765	[108]
5	Iraq	Hashyimia City	52	113	82.5	[109]
6	Iraq	Karbala Province	2.156	4.112	3.134	[110]
7	Iraq	Al-Hindiyah City	9.169	13.573	11.371	[111]
8	Iraq	Kirkuk City	0.108	5.630	2.869	[112]
9	Iraq	Kufa City	0.267	5.662	2.964	[113]

10	Iraq	Najaf City	0.317	5.010	2.663	[114]
11	Iraq	Nineveh Province	17.4	36.1	26.75	[115]
12	Iraq	Sulaimany Province	1.184	7.589	4.386	[116]
13	Iraq	Dhi-qar Province	0.355	0.681	0.518	[117]
14	Jordan	Jordan Valley	0.28	44.31	22.295	[118]
15	Turkey	Yalova Lake	0.21	5.82	3.015	[119]
16	Saudi Arabia	Qassim Area	0.76	4.69	2.725	[120]
17	Oman	Oman and UAE borders	0.2	17	8.6	[121]
18	Lebanon	North Lebanon	0.91	49.6	25.255	[122]
19	Iran	Jooshan Spa	35	130	82.5	[123]
20	Iraq	Sawa Lake	0.085	1.15	0.617	Present study

From the table, the lowest radon concentration was (0.085 Bq/L) that we obtained in the present study as compared with other studies in the table, while the highest value was (130 Bq/L) as reported in Jooshan spa, Iran. All reported studies have maximum radon concentration value higher than the high value obtained in Sawa Lake (1.15 Bq/L) except that is reported in Dhi-Qar Province with the value of (0.681 Bq/L).

3.2.1. Annual Effective Dose of the Lake Water

The “effective dose” is a biological dose commonly used in radioprotection, as it determines how dangerous an individual’s exposure to radiations can be. It takes into consideration not only the nature at the incoming radiation but also the sensitivities at the body parts affected, and represents the stochastic health risk to the whole body. The annual effective dose (AED) due to radon concentration can be classified into two types, the dose from inhalation and the dose from ingestion, it depends on what someone inhales or ingests. The total annual effective dose and the relative proportions due to inhalation and ingestion will therefore be variable with location and the particular local

sources at radiation exposure. Because the salinity of the lake water exceeds high levels (about 27 ppt), so Sawa Lake water is not suitable for human consumption. Hence, in the present study, the annual effective dose received by a human being is estimated due to inhalation only (D_{inh}).

For the evaluation of AED due to inhalation in the studied area, the UNSCEAR model was adopted, as reported in the following equation [50]:

$$D_{inh}(mSv\ year^{-1}) = A_{RnW} \times C_{aW} \times F \times I \times DCF \dots (3.1)$$

where A_{RnW} the concentration of radon in the water (Bq/l), C_{aW} is the ratio of radon concentration in the air to radon concentration in the water ($=10^{-4}$), F is the equilibrium factor between radon and its products ($= 0.6$), I is the mean outdoor occupancy time per individual ($= 1760$ h/y), and DCF is the dose conversion factor for radon exposure [9 (nSv h^{-1}) / (Bq m^{-3})]. Annual inhalation doses associated with radon concentrations in water have been measured in winter and spring are shown in Table (3.5) and Table (3.6), respectively. From Table (3.5), it is observed that the maximum effective inhalation dose received in winter season was (0.917136 μ Sv/y) for sample (W46), while the minimum dose was for sample (W77) with value of (0.080784 μ Sv/y), with a mean value of (0.3025764 μ Sv/y). In the spring season, the higher and lower value of effective dose was (1.065 μ Sv/y) and (0.0883 μ Sv/y) for samples (W27) and (W77), respectively, and the mean value was (0.389 μ Sv/y), as shown in Table (3.6).

The values of annual effective dose received by the public due to inhalation of radon for both seasons are found to be very much less than permissible level of (1mSv/y) recommended by WHO [97], or far below the (20 mSv/y) proposed by ICRP [124].

Table (3.5): Annual effective dose of the lake water for the winter season.

No.	Sample	Mean (Bq/l)	Effective Dose (μSv/y)	No.	Sample	Mean (Bq/l)	Effective Dose (μSv/y)
1	W1	0.154	0.1463616	44	W44	0.511	0.4856544
2	W2	0.124	0.1178496	45	W45	0.431	0.4096224
3	W3	0.311	0.2955744	46	W46	0.965	0.917136
4	W4	0.124	0.1178496	47	W47	0.819	0.7783776
5	W5	0.154	0.1463616	48	W48	0.632	0.6006528
6	W6	0.363	0.3449952	49	W49	0.381	0.3621024
7	W7	0.356	0.3383424	50	W50	0.154	0.1463616
8	W8	0.216	0.2052864	51	W51	0.164	0.1558656
9	W9	0.154	0.1463616	52	W52	0.164	0.1558656
10	W10	0.351	0.3335904	53	W53	0.092	0.0874368
11	W11	0.384	0.3649536	54	W54	0.123	0.1168992
12	W12	0.532	0.5056128	55	W55	0.152	0.1444608
13	W13	0.278	0.2642112	56	W56	0.095	0.090288
14	W14	0.319	0.3031776	57	W57	0.123	0.1168992
15	W15	0.529	0.5027616	58	W58	0.121	0.1149984
16	W16	0.576	0.5474304	59	W59	0.249	0.2366496
17	W17	0.181	0.1720224	60	W60	0.128	0.1216512
18	W18	0.301	0.2860704	61	W61	0.177	0.1682208
19	W19	0.181	0.1720224	62	W62	0.184	0.1748736
20	W20	0.111	0.1054944	63	W63	0.195	0.185328
21	W21	0.368	0.3497472	64	W64	0.259	0.2461536
22	W22	0.264	0.2509056	65	W65	0.143	0.1359072
23	W23	0.255	0.242352	66	W66	0.329	0.3126816
24	W24	0.336	0.3193344	67	W67	0.292	0.2775168
25	W25	0.432	0.4105728	68	W68	0.259	0.2461536
26	W26	0.231	0.2195424	69	W69	0.369	0.3506976
27	W27	0.924	0.8781696	70	W70	0.56	0.532224
28	W28	0.552	0.5246208	71	W71	0.335	0.318384
29	W29	0.602	0.5721408	72	W72	0.161	0.1530144
30	W30	0.823	0.7821792	73	W73	0.288	0.2737152
31	W31	0.891	0.8468064	74	W74	0.129	0.1226016
32	W32	0.523	0.4970592	75	W75	0.403	0.3830112
33	W33	0.711	0.6757344	76	W76	0.258	0.2452032
34	W34	0.432	0.4105728	77	W77	0.085	0.080784
35	W35	0.113	0.1073952	78	W78	0.141	0.1340064
36	W36	0.181	0.1720224	79	W79	0.147	0.1397088
37	W37	0.341	0.3240864	80	W80	0.153	0.1454112
38	W38	0.511	0.4856544	81	W81	0.336	0.3193344
39	W39	0.223	0.2119392	82	W82	0.262	0.2490048
40	W40	0.231	0.2195424	83	W83	0.231	0.2195424
41	W41	0.637	0.6054048	84	W84	0.188	0.1786752
42	W42	0.288	0.2737152	85	W85	0.331	0.3145824
43	W43	0.363	0.3449952	Mean Value			0.306923294
Permissible Value [97]							1 mSv/y

Table (3.6): Annual effective dose of the lake water for the spring season

No.	Sample	Mean (Bq/l)	Effective Dose (μSv/y)	No.	Sample	Mean (Bq/l)	Effective Dose (μSv/y)
1	W1	0.155	0.147312	44	W44	0.648	0.6158592
2	W2	0.156	0.1482624	45	W45	0.684	0.6500736
3	W3	0.218	0.2071872	46	W46	1.15	1.09296
4	W4	0.156	0.1482624	47	W47	0.998	0.9484992
5	W5	0.217	0.2062368	48	W48	0.528	0.5018112
6	W6	0.373	0.3544992	49	W49	0.428	0.4067712
7	W7	0.342	0.3250368	50	W50	0.249	0.2366496
8	W8	0.373	0.3544992	51	W51	0.135	0.128304
9	W9	0.124	0.1178496	52	W52	0.151	0.1435104
10	W10	0.435	0.413424	53	W53	0.113	0.1073952
11	W11	0.714	0.6785856	54	W54	0.198	0.1881792
12	W12	0.621	0.5901984	55	W55	0.159	0.1511136
13	W13	0.528	0.5018112	56	W56	0.155	0.147312
14	W14	0.342	0.3250368	57	W57	0.103	0.0978912
15	W15	0.709	0.6738336	58	W58	0.275	0.26136
16	W16	0.559	0.5312736	59	W59	0.159	0.1511136
17	W17	0.218	0.2071872	60	W60	0.351	0.3335904
18	W18	0.342	0.3250368	61	W61	0.291	0.2765664
19	W19	0.187	0.1777248	62	W62	0.223	0.2119392
20	W20	0.093	0.0883872	63	W63	0.345	0.327888
21	W21	0.311	0.2955744	64	W64	0.391	0.3716064
22	W22	0.186	0.1767744	65	W65	0.194	0.1843776
23	W23	0.281	0.2670624	66	W66	0.422	0.4010688
24	W24	0.311	0.2955744	67	W67	0.161	0.1530144
25	W25	0.311	0.2955744	68	W68	0.251	0.2385504
26	W26	0.373	0.3544992	69	W69	0.498	0.4732992
27	W27	1.12	1.064448	70	W70	0.59	0.560736
28	W28	0.761	0.7232544	71	W71	0.295	0.280368
29	W29	0.669	0.6358176	72	W72	0.252	0.2395008
30	W30	1.06	1.007424	73	W73	0.356	0.3383424
31	W31	0.963	0.9152352	74	W74	0.162	0.1539648
32	W32	0.781	0.7422624	75	W75	0.513	0.4875552
33	W33	0.931	0.8848224	76	W76	0.193	0.1834272
34	W34	0.621	0.5901984	77	W77	0.093	0.0883872
35	W35	0.838	0.7964352	78	W78	0.253	0.2404512
36	W36	0.353	0.3354912	79	W79	0.254	0.2414016
37	W37	0.628	0.5968512	80	W80	0.223	0.2119392
38	W38	0.898	0.8534592	81	W81	0.274	0.2604096
39	W39	0.115	0.109296	82	W82	0.571	0.5426784
40	W40	0.301	0.2860704	83	W83	0.305	0.289872
41	W41	0.823	0.7821792	84	W84	0.318	0.3022272
42	W42	0.378	0.3592512	85	W85	0.45	0.42768
43	W43	0.574	0.5455296	Mean Value			0.389227934
Permissible Value [97]							1 mSv/y

3.3. Physiochemical Parameters

In order to establish a relationship between radon activity concentration and some physiochemical characteristics of the lake water, several parameters such as electric conductivity (EC), total dissolved solids (TDS), resistivity, turbidity, and pH, were measured for water samples during two seasons, winter and spring.

The correlation between radon concentration and physiochemical parameters has been estimated statistically, the Pearson Correlation Coefficient (r) was employed to establish such a relationship. Pearson Coefficient is a measure of linear correlation between two variables, it takes a value between (1) and (-1), where (1) represents a totally positive correlation, (0) indicates no correlation, and (-1) represents a totally negative correlation. The mathematical formula of the Pearson Coefficient is given as [125]:

$$r = \sqrt{\frac{\sum(x-\bar{x})(y-\bar{y})}{\sum(x-\bar{x})^2 \sum(y-\bar{y})^2}} \quad \dots\dots\dots (3.2)$$

where x = individual reading for the 1st parameter, $\bar{x}$ = the mean of $\sum x$
 y = individual reading for the 2nd parameter, $\bar{y}$ = the mean of $\sum y$.

For the winter season, The parameters values obtained for different samples from different locations are summarized in Table (3.7), which revealed diverse relationships between these parameters and radon concentrations. The electric conductivity (EC) of the collected water samples was found to be ranged from (20460 $\mu\text{s/cm}$) to (31900 $\mu\text{s/cm}$) with an average value of (26744.59 $\mu\text{s/cm}$), which is very much higher than the

maximum level (800 $\mu\text{S}/\text{cm}$) for drinking water as reported by WHO [97]. The high value of EC in the lake water is due to the presence of a high amount of dissolved salts since the EC is mostly influenced by dissolved salts such as sodium chloride and potassium chloride [126]. Fig. (3.4) represents the variation of radon concentration with (EC), it shows a weak positive correlation with radon concentration ($R^2 = 0.0872$). Total dissolved solids (TDS) values varied between (13708.2 mg/l) and (21373 mg/l) with an average value of (17918.87 mg/l). All water samples have TDS values very much higher than the WHO maximum permissible value of (500 mg/l) [127]. The high amount of dissolved solids of samples adversely affects the quality of water and it is unsuitable for any other purpose such as irrigation and drinking [126]. The TDS has a weak positive correlation with radon concentration ($R^2 = 0.0872$) as shown in Fig. (3.5). The resistivity values for collected water samples have been found to vary from ($3.13 \times 10^{-5} \Omega\cdot\text{m}$) to ($4.88 \times 10^{-5} \Omega\cdot\text{m}$) with an average value of ($3.7679 \times 10^{-5} \Omega\cdot\text{m}$). Fig. (3.6) represents the variation of radon concentration with resistivity, which indicates a negatively weak correlation ($R^2 = -0.866$). The turbidity values of collected water samples are carried out and it is found to be in the range of (1.42 – 8.86 NTU) with an average value of (4.701 NTU), which lies within the allowed levels of (0-10 NTU) recommended by WHO [97]. Fig. (3.7) shows no correlation ($R^2 = 0.0007$) between radon concentration and turbidity. The pH is a term used to express intensity of the acid or alkaline condition of solution, pH values of the collected water samples varied between (8.18) and (8.42) with an average value of (8.26), which is within the range (6.0-8.5) recommended by WHO for drinking water [127], and slightly higher than the range (7-8) of the ocean or sea water. The pH values of all samples show slightly alkaline trend and indicate a weak negative correlation with radon concentration ($R^2 = 0.0195$) (Fig. 3.8), this is mainly due to the

fact that radon is an inert gas [56]. The variation of the pH value of the water samples may be due to the contact with the carbonate rocks such as dolomite and limestone [128]. Additionally, the factors like air temperature bring about changes in the pH of water [129].

Table (3.7): Physiochemical Parameters of Different Water Samples for the winter season.

No.	Sample	EC ($\mu\text{S/cm}$)	TDS (mg/l)	Resistivity ($\Omega\cdot\text{m}$)	Turbidity (NTU)	pH
1	W1	25780	17272.6	3.87898×10^{-5}	5.23	8.22
2	W2	26390	17681.3	3.78931×10^{-5}	6.83	8.22
3	W3	26530	17775.1	3.76932×10^{-5}	5.19	8.23
4	W4	26480	17741.6	3.77644×10^{-5}	7.74	8.21
5	W5	26780	17942.6	3.73413×10^{-5}	7.13	8.22
6	W6	25890	17346.3	3.8625×10^{-5}	3.18	8.24
7	W7	25120	16830.4	3.98089×10^{-5}	5.92	8.19
8	W8	26360	17661.2	3.79363×10^{-5}	7.36	8.19
9	W9	27240	18250.8	3.67107×10^{-5}	8.17	8.2
10	W10	28980	19416.6	3.45066×10^{-5}	8.28	8.19
11	W11	28310	18967.7	3.53232×10^{-5}	7.69	8.2
12	W12	27980	18746.6	3.57398×10^{-5}	6.71	8.21
13	W13	27530	18445.1	3.6324×10^{-5}	4.37	8.21
14	W14	27520	18438.4	3.63372×10^{-5}	6.16	8.22
15	W15	26900	18023	3.71747×10^{-5}	7.73	8.19
16	W16	25560	17125.2	3.91236×10^{-5}	8.86	8.23
17	W17	26240	17580.8	3.81098×10^{-5}	8.3	8.23
18	W18	24920	16696.4	4.01284×10^{-5}	3.9	8.25
19	W19	28820	19309.4	3.46981×10^{-5}	7.15	8.24
20	W20	28780	19282.6	3.47464×10^{-5}	4.8	8.25
21	W21	31900	21373	3.1348×10^{-5}	4.79	8.25
22	W22	28700	19229	3.48432×10^{-5}	1.53	8.18
23	W23	27510	18431.7	3.63504×10^{-5}	4.95	8.2
24	W24	29480	19751.6	3.39213×10^{-5}	5.7	8.23
25	W25	30800	20636	3.24675×10^{-5}	8.09	8.25
26	W26	28710	19235.7	3.48311×10^{-5}	7.95	8.26
27	W27	26410	17694.7	3.78644×10^{-5}	3.93	8.31
28	W28	29250	19597.5	3.4188×10^{-5}	4.8	8.26
29	W29	29320	19644.4	3.41064×10^{-5}	7.13	8.28
30	W30	26830	17976.1	3.72717×10^{-5}	7.28	8.028
31	W31	28500	19095	3.50877×10^{-5}	8.16	8.27
32	W32	25880	17339.6	3.86399×10^{-5}	3.1	8.27
33	W33	28750	19262.5	3.47826×10^{-5}	3.45	8.29
34	W34	28510	19101.7	3.50754×10^{-5}	3.43	8.24
35	W35	28640	19188.8	3.49162×10^{-5}	4.4	8.25
36	W36	28950	19396.5	3.45423×10^{-5}	2.98	8.24
37	W37	28470	19074.9	3.51247×10^{-5}	2.31	8.26
38	W38	28490	19088.3	3.51×10^{-5}	2.37	8.27
39	W39	27890	18686.3	3.58551×10^{-5}	2.56	8.27

40	W40	28230	18914.1	3.54233×10^{-5}	2.73	8.26
41	W41	28640	19188.8	3.49162×10^{-5}	2.41	8.25
42	W42	27980	18746.6	3.57398×10^{-5}	3.11	8.25
43	W43	28870	19342.9	3.4638×10^{-5}	3.78	8.21
44	W44	29120	19510.4	3.43407×10^{-5}	3.57	8.21
45	W45	29140	19523.8	3.43171×10^{-5}	4.17	8.2
46	W46	29690	19892.3	3.36814×10^{-5}	2.13	8.23
47	W47	29300	19631	3.41297×10^{-5}	5.78	8.21
48	W48	28900	19363	3.46021×10^{-5}	4.91	8.26
49	W49	28460	19068.2	3.5137×10^{-5}	6.41	8.3
50	W50	28510	19101.7	3.50754×10^{-5}	5.28	8.27
51	W51	29100	19497	3.43643×10^{-5}	5.12	8.28
52	W52	30120	20180.4	3.32005×10^{-5}	4.63	8.23
53	W53	28910	19369.7	3.45901×10^{-5}	2.98	8.25
54	W54	28190	18887.3	3.54736×10^{-5}	3.81	8.19
55	W55	27860	18666.2	3.58938×10^{-5}	3.46	8.19
56	W56	27310	18297.7	3.66166×10^{-5}	4.71	8.21
57	W57	27900	18693	3.58423×10^{-5}	5.73	8.26
58	W58	28450	19061.5	3.51494×10^{-5}	5.24	8.27
59	W59	27100	18157	3.69004×10^{-5}	4.87	8.25
60	W60	27120	18170.4	3.68732×10^{-5}	4.16	8.28
61	W61	24240	16240.8	4.12541×10^{-5}	1.42	8.38
62	W62	24180	16200.6	4.13565×10^{-5}	5.16	8.41
63	W63	24180	16200.6	4.13565×10^{-5}	1.66	8.35
64	W64	23290	15604.3	4.29369×10^{-5}	1.53	8.39
65	W65	24390	16341.3	4.10004×10^{-5}	2.45	8.42
66	W66	24420	16361.4	4.095×10^{-5}	2.25	8.33
67	W67	23750	15912.5	4.21053×10^{-5}	3.61	8.31
68	W68	23240	15570.8	4.30293×10^{-5}	2.71	8.32
69	W69	24440	16374.8	4.09165×10^{-5}	6.14	8.38
70	W70	23380	15664.6	4.27716×10^{-5}	4.32	8.35
71	W71	24040	16106.8	4.15973×10^{-5}	3.05	8.31
72	W72	23350	15644.5	4.28266×10^{-5}	2.11	8.29
73	W73	24140	16173.8	4.1425×10^{-5}	2.23	8.31
74	W74	23840	15972.8	4.19463×10^{-5}	3.95	8.3
75	W75	22910	15349.7	4.36491×10^{-5}	3.99	8.32
76	W76	24170	16193.9	4.13736×10^{-5}	1.68	8.39
77	W77	23530	15765.1	4.24989×10^{-5}	2.12	8.29
78	W78	20460	13708.2	4.88759×10^{-5}	8.72	8.36
79	W79	24230	16234.1	4.12712×10^{-5}	4.48	8.36
80	W80	23560	15785.2	4.24448×10^{-5}	6.42	8.35
81	W81	24250	16247.5	4.12371×10^{-5}	1.69	8.29
82	W82	23710	15885.7	4.21763×10^{-5}	2.75	8.31
83	W83	23930	16033.1	4.17885×10^{-5}	5.41	8.31
84	W84	23520	15758.4	4.2517×10^{-5}	5.92	8.3
85	W85	24140	16173.8	4.1425×10^{-5}	5.93	8.29

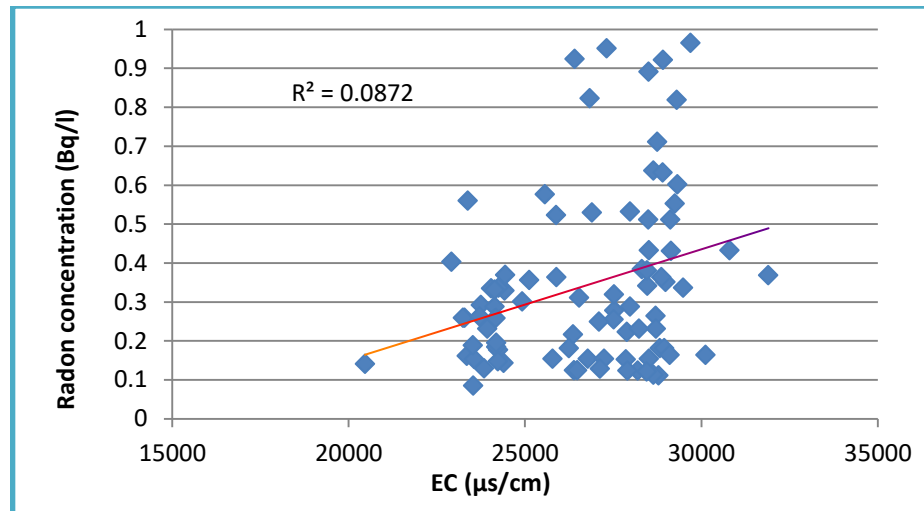


Figure (3.4): Correlation between radon concentration and EC.

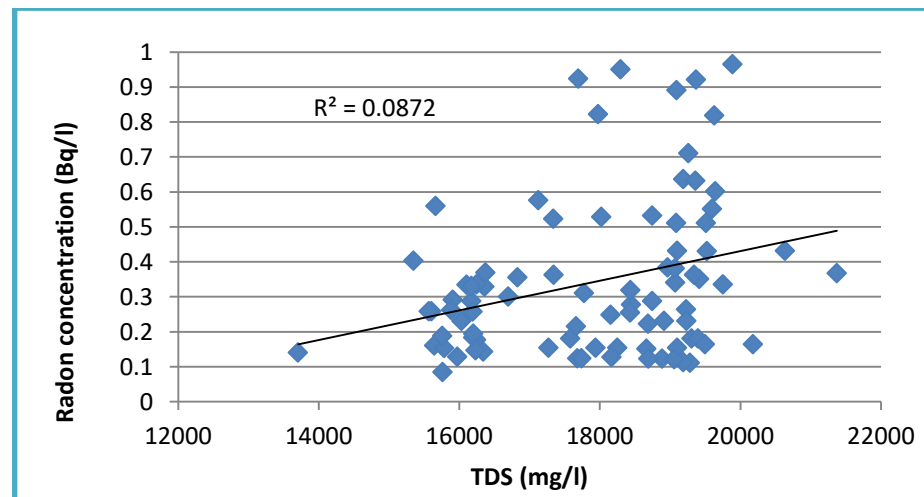


Figure (3.5): Correlation between radon concentration and TDS.

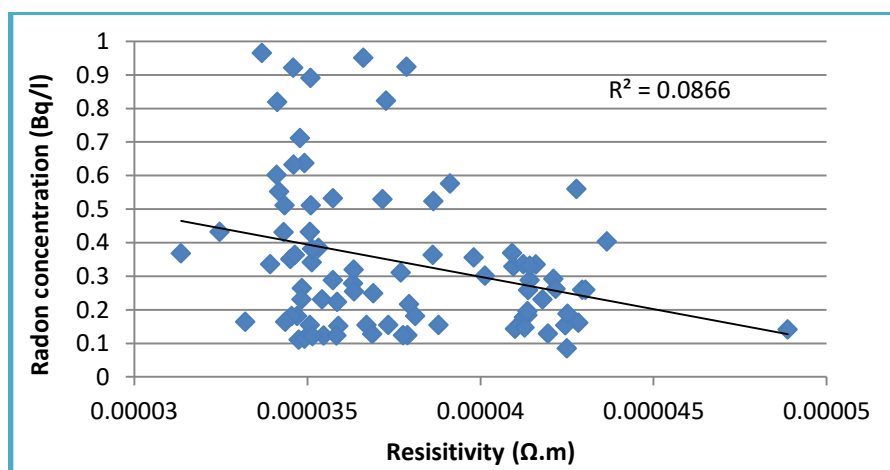


Figure (3.6): Correlation between radon concentration and resistivity.

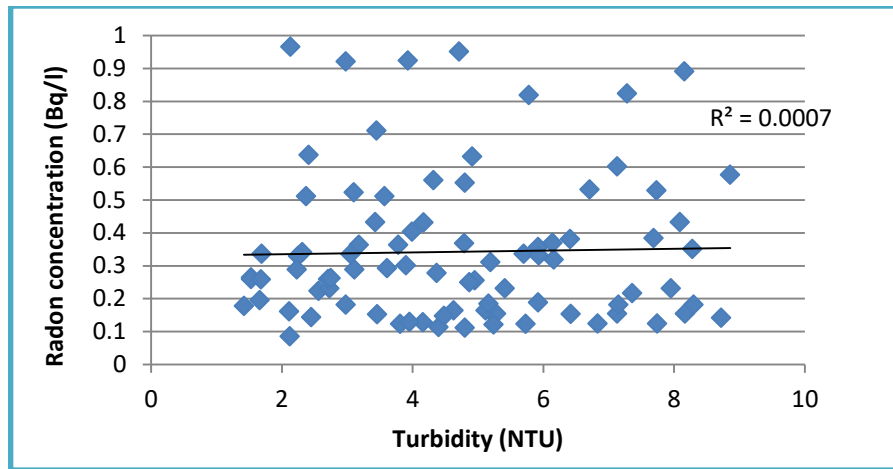


Figure (3.7): Correlation between radon concentration and turbidity.

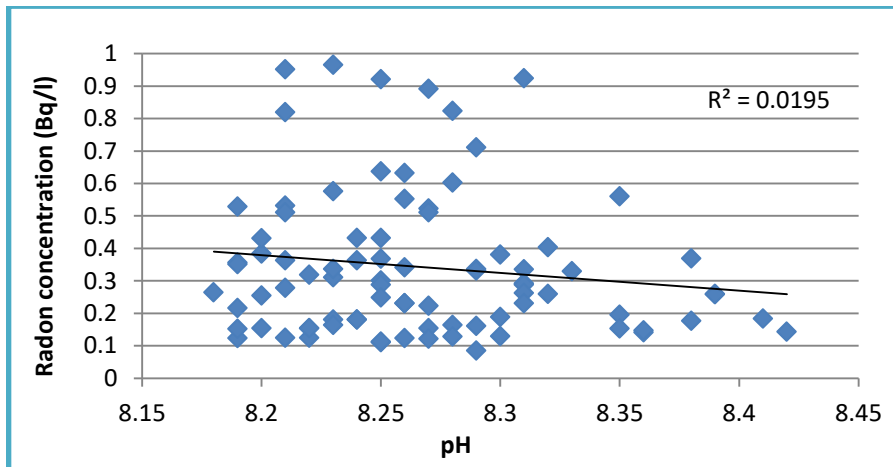


Figure (3.8): Correlation between radon concentration and pH.

Physiochemical parameters are obtained with the same method and instruments for the spring season and summarized in table (3.8). The EC was found to be in the range of (20820-32690 $\mu\text{S/cm}$), with an average value of (24586.35 $\mu\text{S/cm}$), which is slightly less than the EC value obtained in winter season, the correlation between EC and radon concentration was positive weak ($R^2 = 0.0749$) as shown in Fig. (3.9). TDS value also was lower than that obtained in the winter season where it is varied from (13949.4 mg/l) to (21902.3 mg/l) with a mean value of (16472.86 mg/l), Fig. (3.10) reveals a positive weak correlation between TDS and radon concentration. The little drop in values of EC

and TDS in spring relative to the winter season. It may be due to frequent rains in spring which in turn led to an increase in water level and hence decrease in the concentrations of salts in the lake water. However, the correlation between EC, TDS and radon activity level in spring followed a similar trend as that of the winter season. According to the decrease in EC, it is natural to observe a relative increase in resistivity value in the spring as compared with that of the winter. Resistivity values were found to be ranged between ($3.059 \times 10^{-5} \Omega.m$) and ($4.803 \times 10^{-5} \Omega.m$), with an average value of ($4.087 \times 10^{-5} \Omega.m$). The resistivity of analyzed water samples is correlated with radon concentration by a negative weak correlation (Fig. 3.11). Turbidity was higher during the spring which was because the rains bringing the sediments from the adjoining areas (the lake surrounding area is higher than the lake surface) and due to water flow which stirred up the nonliving matter like silt and sand at the bottom of the lake. Turbidity values varied between (1.89 NTU) and (11.23 NTU), with an average value of (5.056 NTU). There is no correlation observed between turbidity and radon activity in water as shown in Fig. (3.12). The maximum value of pH was (8.36) and the minimum value was (8.16), whereas the mean value was (8.27). The pH value for the spring is lower than that for the winter, the reason beyond that is, may be due to the accumulation of free CO_2 and higher respiration of organisms at a higher temperature. A high organic content will tend to decrease the pH because of the carbonate chemistry. As microorganisms break down organic materials, the by-product will be CO_2 that will dissolve and equilibrate with the water forming carbonic and (H_2CO_3) [126], which contributes to decrease in pH value, since there is an inverse relation between pH and carbon dioxide [130]. The relationship between pH and radon concentration is found to be negative weak (Fig. 3.13).

Table (3.8): Physiochemical Parameters of Different Water Samples for the spring season.

No.	Sample	EC ($\mu\text{S}/\text{cm}$)	TDS (mg/l)	Resistivity ($\Omega.\text{m}$)	Turbidity (NTU)	pH
1	W1	22150	14840.5	4.51467×10^{-5}	2.64	8.36
2	W2	22990	15403.3	4.34972×10^{-5}	7.71	8.32
3	W3	23480	15731.6	4.25894×10^{-5}	5.87	8.32
4	W4	21360	14311.2	4.68165×10^{-5}	6.23	8.32
5	W5	23090	15470.3	4.33088×10^{-5}	5.43	8.33
6	W6	24760	16589.2	4.03877×10^{-5}	6.53	8.31
7	W7	24510	16421.7	4.07997×10^{-5}	5.12	8.32
8	W8	24010	16086.7	4.16493×10^{-5}	11.23	8.3
9	W9	20930	14023.1	4.77783×10^{-5}	8.72	8.31
10	W10	24880	16669.6	4.01929×10^{-5}	8.11	8.25
11	W11	25940	17379.8	3.85505×10^{-5}	5.18	8.26
12	W12	24750	16582.5	4.0404×10^{-5}	7.41	8.3
13	W13	24250	16247.5	4.12371×10^{-5}	3.92	8.32
14	W14	22850	15309.5	4.37637×10^{-5}	8.03	8.35
15	W15	20820	13949.4	4.80307×10^{-5}	7.95	8.3
16	W16	24690	16542.3	4.05022×10^{-5}	6.02	8.33
17	W17	22870	15322.9	4.37254×10^{-5}	9.21	8.35
18	W18	24590	16475.3	4.06669×10^{-5}	9.15	8.34
19	W19	26610	17828.7	3.75799×10^{-5}	7.62	8.32
20	W20	25420	17031.4	3.93391×10^{-5}	5.48	8.28
21	W21	25320	16964.4	3.94945×10^{-5}	7.33	8.26
22	W22	25260	16924.2	3.95883×10^{-5}	3.02	8.26
23	W23	25480	17071.6	3.92465×10^{-5}	4.61	8.31
24	W24	25710	17225.7	3.88954×10^{-5}	7.26	8.28
25	W25	24790	16609.3	4.03388×10^{-5}	5.42	8.27
26	W26	25150	16850.5	3.97614×10^{-5}	6.87	8.27
27	W27	24920	16696.4	4.01284×10^{-5}	2.56	8.26
28	W28	26750	17922.5	3.73832×10^{-5}	5.05	8.26
29	W29	24840	16642.8	4.02576×10^{-5}	6.33	8.24
30	W30	25860	17326.2	3.86698×10^{-5}	5.14	8.23
31	W31	25580	17138.6	3.9093×10^{-5}	7.35	8.29
32	W32	24360	16321.2	4.10509×10^{-5}	4.98	8.29
33	W33	25180	16870.6	3.97141×10^{-5}	5.44	8.23
34	W34	24960	16723.2	4.00641×10^{-5}	5.01	8.22
35	W35	23720	15892.4	4.21585×10^{-5}	6.53	8.29
36	W36	23650	15845.5	4.22833×10^{-5}	4.98	8.3
37	W37	25800	17286	3.87597×10^{-5}	3.67	8.26
38	W38	27400	18358	3.64964×10^{-5}	2.13	8.27
39	W39	26610	17828.7	3.75799×10^{-5}	3.22	8.26
40	W40	27290	18284.3	3.66435×10^{-5}	2.36	8.29
41	W41	24270	16260.9	4.12031×10^{-5}	5.52	8.27
42	W42	26910	18029.7	3.71609×10^{-5}	4.11	8.26
43	W43	24080	16133.6	4.15282×10^{-5}	5.96	8.27
44	W44	25870	17332.9	3.86548×10^{-5}	6.87	8.24

45	W45	23560	15785.2	4.24448×10^{-5}	2.54	8.25
46	W46	26190	17547.3	3.81825×10^{-5}	3.68	8.29
47	W47	32690	21902.3	3.05904×10^{-5}	5.27	8.21
48	W48	25070	16796.9	3.98883×10^{-5}	6.35	8.29
49	W49	23680	15865.6	4.22297×10^{-5}	6.33	8.2
50	W50	23330	15631.1	4.28633×10^{-5}	3.21	8.23
51	W51	25360	16991.2	3.94322×10^{-5}	4.14	8.22
52	W52	27840	18652.8	3.59195×10^{-5}	4.02	8.22
53	W53	26510	17761.7	3.77216×10^{-5}	4.34	8.24
54	W54	26980	18076.6	3.70645×10^{-5}	4.78	8.27
55	W55	26490	17748.3	3.77501×10^{-5}	4.15	8.26
56	W56	25920	17366.4	3.85802×10^{-5}	4.31	8.23
57	W57	24870	16662.9	4.02091×10^{-5}	4.54	8.24
58	W58	25380	17004.6	3.94011×10^{-5}	5.67	8.18
59	W59	26270	17600.9	3.80662×10^{-5}	5.06	8.16
60	W60	26510	17761.7	3.77216×10^{-5}	4.11	8.18
61	W61	25370	16997.9	3.94166×10^{-5}	2.39	8.2
62	W62	25810	17292.7	3.87447×10^{-5}	4.87	8.21
63	W63	24090	16140.3	4.1511×10^{-5}	3.12	8.23
64	W64	22930	15363.1	4.3611×10^{-5}	4.23	8.25
65	W65	23740	15905.8	4.2123×10^{-5}	1.89	8.26
66	W66	23390	15671.3	4.27533×10^{-5}	3.94	8.26
67	W67	23610	15818.7	4.23549×10^{-5}	2.45	8.25
68	W68	22800	15276	4.38596×10^{-5}	2.38	8.26
69	W69	24060	16120.2	4.15628×10^{-5}	4.99	8.29
70	W70	24010	16086.7	4.16493×10^{-5}	4.21	8.25
71	W71	22570	15121.9	4.43066×10^{-5}	3.01	8.29
72	W72	22940	15369.8	4.3592×10^{-5}	2.76	8.31
73	W73	24120	16160.4	4.14594×10^{-5}	3.04	8.32
74	W74	23710	15885.7	4.21763×10^{-5}	3.87	8.31
75	W75	24340	16307.8	4.10846×10^{-5}	4.56	8.3
76	W76	23920	16026.4	4.1806×10^{-5}	3.1	8.29
77	W77	23170	15523.9	4.31593×10^{-5}	4.93	8.3
78	W78	21780	14592.6	4.59137×10^{-5}	5.83	8.32
79	W79	22340	14967.8	4.47628×10^{-5}	4.12	8.34
80	W80	22060	14780.2	4.53309×10^{-5}	5.72	8.32
81	W81	22730	15229.1	4.39947×10^{-5}	5.45	8.3
82	W82	24180	16200.6	4.13565×10^{-5}	2.96	8.27
83	W83	22780	15262.6	4.38982×10^{-5}	4.16	8.26
84	W84	23990	16073.3	4.1684×10^{-5}	4.69	8.27
85	W85	24040	16106.8	4.15973×10^{-5}	5.28	8.26

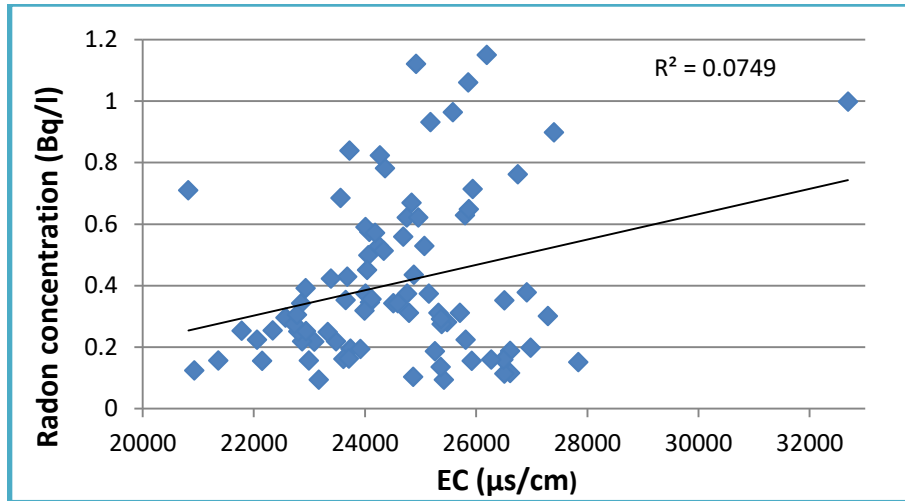


Figure (3.9): Correlation between Radon concentration and EC.

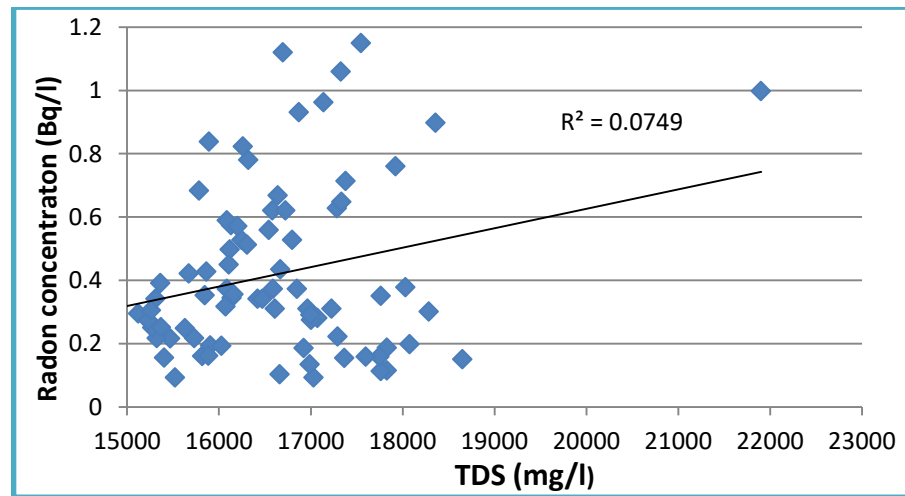


Figure (3.10): Correlation between radon concentration and TDS.

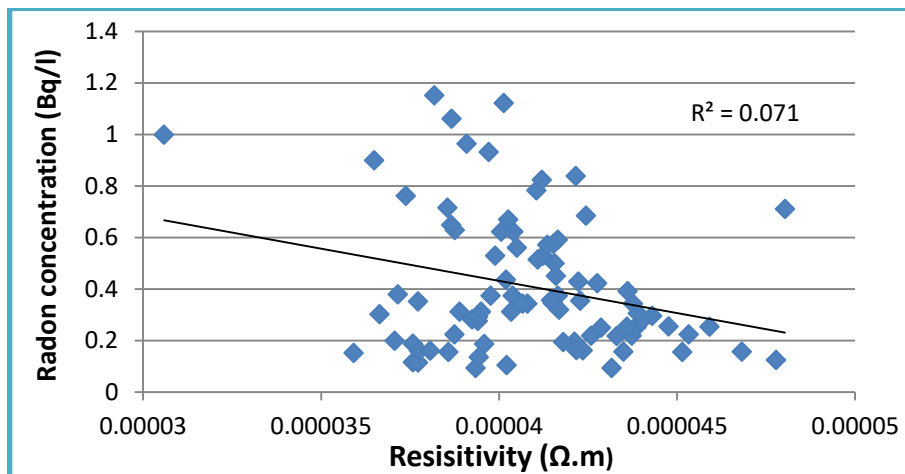


Figure (3.11): Correlation between radon concentration and resistivity.

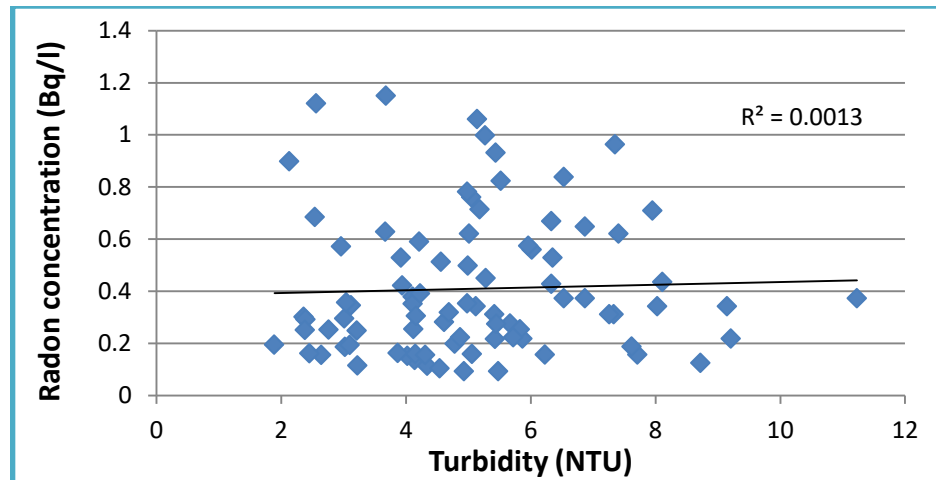


Figure (3.12): Correlation between radon concentration and turbidity.

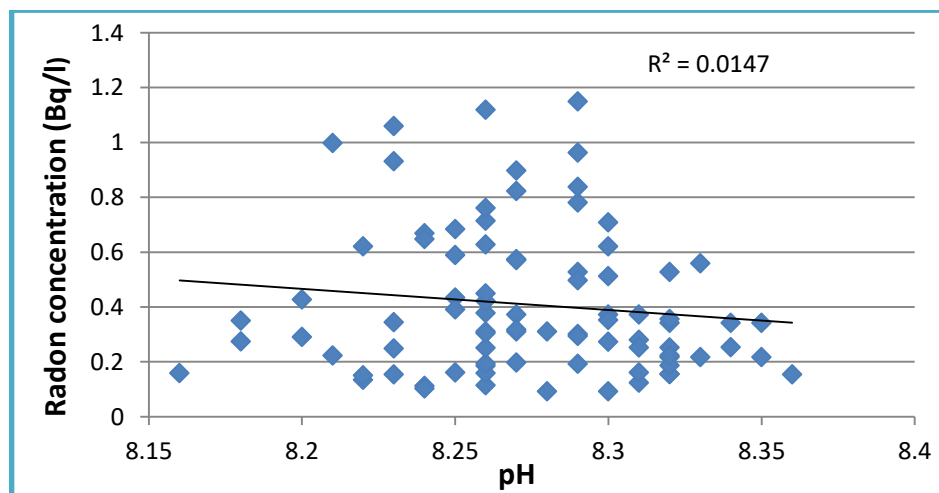


Figure (3.13): Correlation between radon concentration and pH.

3.4. Radon Activity Concentration in the Lake Soil

Radon measurements in the soil at the lake boundary were carried out. A total of (30) different locations around the lake were chosen in order to determine radon activity in the soil. A distance of (400 m) separates one location from another in an effort to cover the whole area surrounding the lake. The distances between sampling points and their locations were determined using GPS portable instrument and presented in Table

(3.9). Radon measurements were in situ conducted using RAD7 radon monitor provided with soil gas probe accessory which allows the determination of radon soil gas directly with proper care during the measurements to make sure that the radon will be measured with no contact with outside air as much as possible. Because of the rocky nature of the soil around the lake, a soil gas probe was not able to penetrate the soil deeply, so radon in soil activity is measured at a uniform depth of (30 cm) for all sampling points. Radon measurements were carried out during two seasons, winter and spring, in a period of one month for each season (January in the winter and March in the spring seasons).

Table (3.9): Locations of soil sampling points.

No.	Sample	Location		No.	Sample	Location	
		latitude	longitude			latitude	longitude
1	S1	N 31° 18.576'	E 45° 00.855'	16	S16	N 31° 18.165'	E 45° 00.746'
2	S2	N 31° 18.804'	E 45° 00.750'	17	S17	N 31° 18.075'	E 45° 01.024'
3	S3	N 31° 19.027'	E 45° 00.631'	18	S18	N 31° 17.863'	E 45° 01.170'
4	S4	N 31° 19.228'	E 45° 00.521'	19	S19	N 31° 17.736'	E 45° 01.378'
5	S5	N 31° 19.432'	E 45° 00.395'	20	S20	N 31° 17.769'	E 45° 01.623'
6	S6	N 31° 19.681'	E 45° 00.307'	21	S21	N 31° 17.958'	E 45° 01.745'
7	S7	N 31° 19.849'	E 44° 59.997'	22	S22	N 31° 18.121'	E 45° 01.587'
8	S8	N 31° 19.692'	E 44° 59.753'	23	S23	N 31° 18.243'	E 45° 01.383'
9	S9	N 31° 19.458'	E 44° 59.607'	24	S24	N 31° 18.334'	E 45° 01.196'
10	S10	N 31° 19.143'	E 44° 59.557'	25	S25	N 31° 18.403'	E 45° 00.982'
11	S11	N 31° 18.857'	E 44° 59.589'	26	S26	N 31° 19.087'	E 45° 00.606'
12	S12	N 31° 18.573'	E 44° 59.678'	27	S27	N 31° 19.155'	E 45° 00.569'
13	S13	N 31° 18.395'	E 44° 59.901'	28	S28	N 31° 19.288'	E 45° 00.461'
14	S14	N 31° 18.335'	E 45° 00.190'	29	S29	N 31° 19.355'	E 45° 00.426'
15	S15	N 31° 18.267'	E 45° 00.459'	30	S30	N 31° 19.503'	E 45° 00.377'

The experimental results obtained in this study for radon concentration levels in Sawa Lake soil for the winter season are presented in Table (3.10).

Table (3.10): Radon concentrations in the soil gas during the winter season.

No .	Sample	Radon concentration (Bq/m ³)					Mean concent. (Bq/m ³)
		1	2	3	4	5	
1	S1	0.00±140	91.3±200	183±230	45±180	194±230	102±60
2	S2	265±260	221±250	132±220	174±230	43±180	167±70
3	S3	5470±900	6260±900	5950±900	6640±1000	5670±900	6000±460
4	S4	5670±900	6010±900	6220±900	6120±900	5780±900	5960±460
5	S5	5910±900	6720±1000	6930±1020	7365±1080	5315±900	6448±480
6	S6	609±360	492±340	371±300	374±320	711±380	511±130
7	S7	1340±510	1080±480	1790±580	1010±460	1320±510	1310±200
8	S8	957±440	1620±550	1160±480	1290±500	984±440	1280±160
9	S9	1360±510	1210±490	1630±550	1560±540	998±450	1350±200
10	S10	313±290	394±310	592±360	357±300	358±300	403±110
11	S11	193±250	78±200	79±200	79±200	40±180	94±52
12	S12	172±230	132±220	134±220	90±200	90±200	124±60
13	S13	416±310	1020±440	723±380	1160±460	692±370	801±160
14	S14	549±350	715±390	636±370	601±360	882±420	677±150
15	S15	73.4±200	185±250	111±220	37.7±180	37.5±180	88.8±50
16	S16	364±320	441±350	478±340	295±290	518±350	419±110
17	S17	230±260	507±350	654±360	396±320	372±320	431±110
18	S18	181±249	72.6±198	72.6±198	72.6±198	36.3±175	86.9±54.7
19	S19	289±289	363±313	545±363	327±302	327±302	370±101
20	S20	506±352	654±389	581±372	545±363	799±421	617±116
21	S21	1310±514	1160±490	1560±554	1490±543	944±450	1292±160
22	S22	1310±514	1050±477	1740±581	980±457	1270±508	1270±155
23	S23	903±441	1530±549	1090±477	1200±496	908±443	1130±257
24	S24	423±310	313±290	584±360	342±295	527±350	437±110
25	S25	217±263	182±251	109±218	145±235	36±175	138±69
26	S26	3726±760	6478±1000	5361±900	7423±1080	4735±880	5544±420
27	S27	618±360	7956±1080	6298±1000	8507±1100	3501±740	5376±400
28	S28	4841±880	6078±1000	9248±1140	5178±900	6394±1000	6347±480
29	S29	1923±596	7390±1080	5271±900	7674±1080	7625±1080	5976±460
30	S30	2385±618	6901±1020	5372±900	4736±880	1376±518	4154±335
Mean Value							1963
Permissible Value [19]						0.4 – 40 KBq/m ³	

As is seen from the table, The samples indicate a high variation between location and another, where the radon concentration values ranged between (86.9 Bq/m^3) and (6448 Bq/m^3) with an average value of (1963 Bq/m^3). The samples S3, S4, and S5, recorded the highest values of radon concentration during the measurements, which required to take more samples between and close to these sampling points in order to confirm the validity of the measurements results. So, the radon concentration measurements of the samples S26, S27, S28, S29, and S30, were conducted and the results came to confirm the high radon concentration in this zone relative to other parts of the study area, which is located at the northeastern side of the lake. The reason behind this high concentration is, this area lies in the vicinity of the springs that provide the lake with water, and hence the radon activity is higher when compared to other locations of soil samples. The other possible reason it may be because of these locations lie in the direction of the wind that blows in the north-west direction most of the year which contributes to drift water continuously toward these locations. It is worthy to mention that this region lies in the vicinity of that of water which recorded the highest values of radon concentration in water as illustrated previously. The lower radon concentrations were observed in the samples S1, S2, S11, S12, and S25. The reason behind that, these sampling points may be located far from the springs, or it may be caused by the lack of uranium and radium content beneath it. Fig. (3.14) shows radon soil gas variation in the winter season.

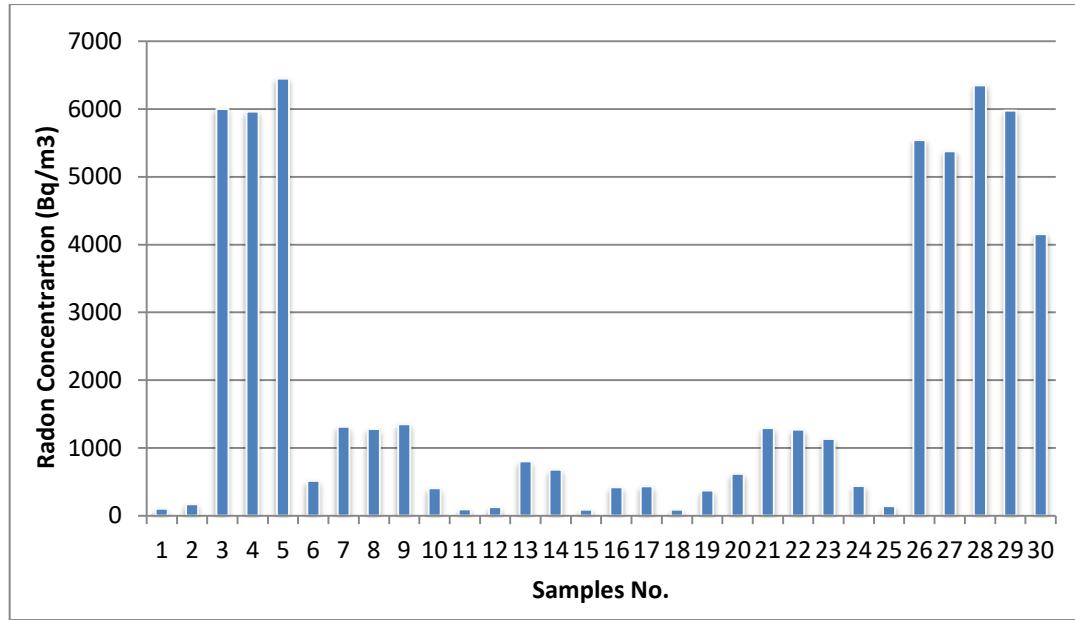


Figure (3.14): Radon soil gas variation during the winter season.

Radon soil gas measured during spring showed the same pattern of variation that observed in winter, as shown in Table (3.11) and Fig. (3.15), where the concentration of radon in soil varied between (40 Bq/m^3) and (4970 Bq/m^3), with a mean value of (1434.17 Bq/m^3). Highest concentrations are observed in the same locations that achieved high soil gas levels in winter (S3, S4, S5, S26, S27, S28, S29, and S30), while the lowest radon activity is found in samples S1, S2, S11, S12, S15, and S18

Table (3.11): Radon soil gas concentrations during the spring season.

No.	Sample	Radon concentration (Bq/m ³)					Mean concent. (Bq/m ³)
		1	2	3	4	5	
1	S1	0.00±145	0.00±145	157±220	145±220	0.00±145	60±52
2	S2	124±210	0.00±145	196±230	232±250	36.6±175	117±60
3	S3	1560±554	2000±616	2630±697	2450±675	2000±616	2128±190
4	S4	2530±620	4110±870	3980±760	5230±900	4260±860	4022±330
5	S5	3846±760	5870±900	2050±616	5870±900	3625±740	4252±335
6	S6	817±438	609±361	217±250	542±350	822±438	601±116
7	S7	976±450	1170±480	2524±650	818±438	769±380	1251±155
8	S8	528±350	2435±620	1578±550	723±390	553±350	1163±145
9	S9	2643±620	1167±480	1530±540	814±438	1273±480	1485±215
10	S10	514±350	418±340	518±350	622±370	378±320	490±120
11	S11	0.00±145	67±190	134±220	0.00±145	0.00±145	40±50
12	S12	0.00±145	154±230	311±310	195±240	0.00±145	132±65
13	S13	347±320	951±440	812±438	1010±460	731±390	770±160
14	S14	453±340	288±280	358±320	428±340	541±360	413±110
15	S15	98±200	0.00±145	218±250	281±280	55±180	130±65
16	S16	492±350	554±360	614±390	463±340	324±320	489±120
17	S17	234±260	489±350	351±320	351±320	218±250	328±105
18	S18	0.00±145	172±240	287±280	172±240	0.00±145	126±60
19	S19	234±260	351±320	351±320	211±250	237±260	276±80
20	S20	725±380	513±350	488±350	518±352	491±350	547±135
21	S21	818±438	1245±500	1398±520	845±440	634±390	996±180
22	S22	1060±470	1264±500	1361±500	829±440	678±380	1038±240
23	S23	1115±490	1010±460	843±440	917±450	843±440	945±170
24	S24	212±250	367±320	298±280	296±280	578±350	350±105
25	S25	0.00±145	345±320	417±350	332±320	0.00±145	218±70
26	S26	2785±630	1010±460	4278±870	1278±490	4615±880	2793±200
27	S27	1296±500	3927±760	5718±900	6176±900	2387±620	3900±305
28	S28	3789±760	4632±880	6131±1000	2965±680	4712±880	4445±345
29	S29	3471±740	5112±900	6245±1000	4742±880	5281±900	4970±360
30	S30	3871±760	5510±900	4970±880	6386±1000	2017±616	4550±345
Mean Value							1434.17
Permissible Value [19]						0.4 – 40 KBq/m ³	

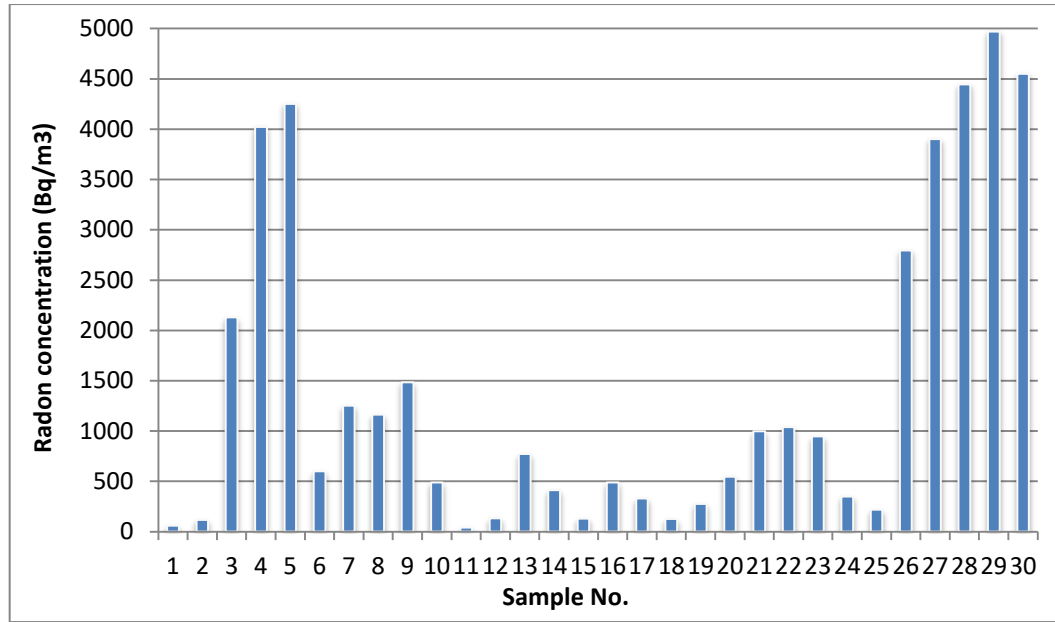


Figure (3.15): Radon soil gas variation during the spring season.

From obtained radon soil gas concentrations in both seasons, all analyzed locations contain radon concentrations less than or lie within the permissible range of (0.4 – 40 kBq/m³) that proposed by World Health Organization [19].

Radon soil gas exhibited an obvious spatial distribution in radon activity concentration in the soil of the studied area, the reason of that is, perhaps, due to the difference in the underlying bedrocks, or in the other words due to the geological condition of locations and geochemical process in soil. The big difference in the radon concentration may be due to holes falling exactly on covered fault lines in the earth crust since Radon gas concentration in soil is taken as proportional to fracture opening [27]. Also, it may be attributed to the variation of depth and concentrations of uranium and radium, since their presence in the bedrock and soil materials controls the amount of radon produced in the soil. In addition to the local variation in the source elements, there are many factors that affect the spatial variation of radon. For example, soil

permeability, porosity, CO₂, moisture content, temperature, and atmospheric pressure [131].

In addition to spatial variation, seasonal fluctuation has been observed in radon activity in soil estimated in both seasons, where it is found that the most of locations analyzed during the spring pose radon soil gas concentration lower than that measured during the winter. Seasonal variation of radon soil gas is due to the combined effect of the metrological variation. Such variation cannot be explained by climatic factors only such as temperature and barometric-pressure variation in a simple way, because all the different sites were interspersed and under similar climatic conditions. However, this fluctuation may be explained by invoking differences in soil response to rainfall [132]. Because of the soil permeability represents the most important physical characteristic which highly influences radon soil gas emanation and transporting within the soil. On the other hand, the water content has a large impact on the emanation coefficient and on the soil transport parameters for radon gas, and therefore, affect the radon concentration in the soil [133]. Due to heavy rainfall this year (in late winter and early spring), and increasing of lake water level, soil pores become saturated with water which inhibits radon soil gas migration to the upper layers especially the depth depended in this investigation is a little and very close to the surface. Another reason, it may be considerable and stand beyond this variation, which is caused by atmospheric pressure since a barometric pressure affects radon migration and emanation from the soil. During the spring, when the temperature increases relative to winter and hence pressure decrease, radon-rich soil gas is sucked from the soil. Similarly, during periods of pressure increase, transport of soil gas and concomitantly radon, within the soil is

hindered [134]. Fig. (3.16) shows a seasonal comparison of radon soil gas activity between spring and winter season.

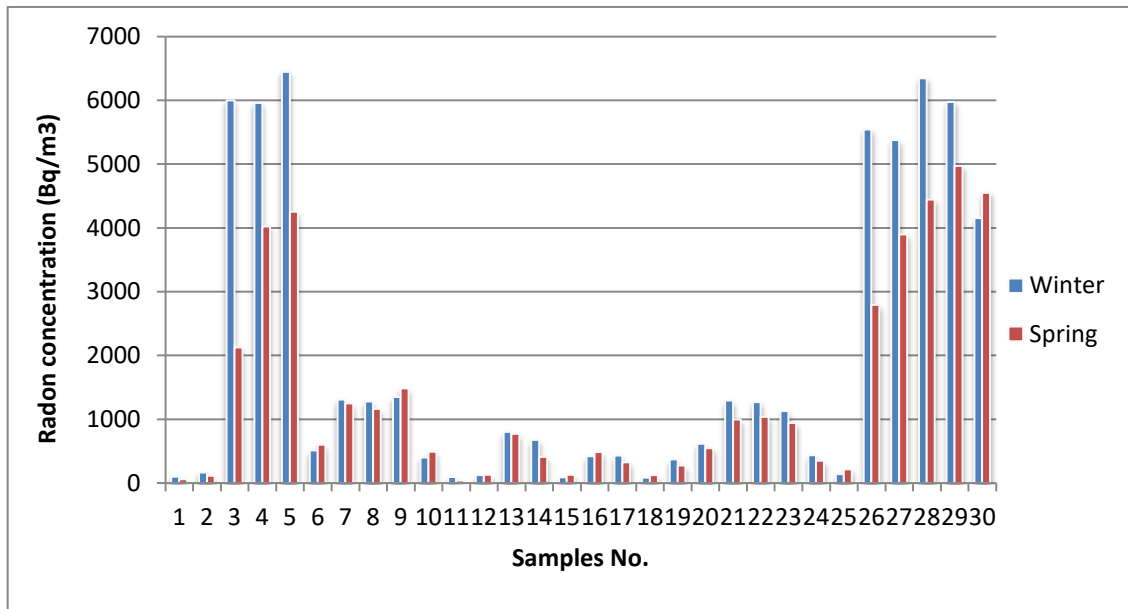


Figure (3.16): Comparison of radon soil gas concentration of two seasons.

The values of radon concentrations obtained in soil gas compared to those reported by the other investigators in different parts of the world are summarized in Table (3.12). According to the table, the minimum concentration level of Sawa Lake soil (40 Bq/m^3) exceeds some reported minimum values (Najaf Prov., Karbala, Amara, Kufa, Salahaddin, Hilla, and Al Qassim), and lower than some minimum values that obtained in sites (Basra, Jazan, Irbid, Dikili, Southwestern Sinai). On the other hand, the maximum value of radon soil gas concentration obtained in this investigation is found to be higher than maximum radon values reported by other investigators in some areas such as Basra, Amara, Najaf City, Salahaddin, Qassim, Jazan, Irbid, and Gaza, but at the same time it is less than those reported in areas such as Karbala, Kufa, Basra Sport City, Hilla, Dikili, and Southwestern Sinai. The radon concentration values that are conducted

in the soil of Karbala City, as observed in the table, were the closer values to these obtained in the soil of Sawa Lake, this may indicates similarities in the characteristics of these soils, or may be because the geological conditions are the same between them.

Table (3.12): Local and regional studies on the radon measurements in soil.

No.	Country	Location	Radon (Bq/m ³)		Mean (Bq/m ³)	Reference
			Low	High		
1	Iraq	Al Najaf City	9	9290	4649.5	[66]
2	Iraq	Karbala City	50	7800	3925	[135]
3	Iraq	Basra Province	61.18	2237.77	1149.47	[136]
4	Iraq	Amara City	53.18	2047.51	1050.34	[137]
5	Iraq	Al Kufa City	41.45	12775	6408.22	[67]
6	Iraq	Al Najaf Province	38.5	100	69.25	[138]
7	Iraq	Salahaddin Province	45.25	100.75	73	[139]
8	Iraq	Basra Sport City	1439	38765	20102	[140]
9	Iraq	Hilla City	25	12700	6362	[33]
10	Saudi Arabia	Al Qassim Area	26	340	183	[141]
11	Saudi Arabia	Jazan Region	896.81	302.91	599.86	[142]
12	Jordan	Irbid Province	697	6335	3516	[143]
13	Turkey	Dikili Geothermal Area	98	8594	4346	[144]
14	palastine	Gaza	23.48	584.15	308.315	[1]
15	Egypt	Southwestern Sinai	648	21361	11004.5	[145]
16	Iraq	Sawa Lake	40	6448	3244	Present study

3.4.1. Annual Effective Dose of The Lake Soil

The annual effective dose received by the public due to inhalation is assessed regarding radon soil gas concentration at the surface of the soil. Because of a particular amount of radon content penetrates the soil up to the surface which contributes later to inhalation effective dose. Therefore, the accumulated quantity of radon at the soil

surface is adopted in this investigation in order to estimate the annual effective dose received by individuals in the study area due to inhalation.

The annual effective dose (AED, mSv/y) has been calculated using the formula proposed by UNSCEAR 2000 which is [19]:

$$D_{inh} = C_{Rn} \times F \times I \times (DCF) \text{ ----- (3.3)}$$

Where D_{inh} is the annual effective dose received by the public, C_{Rn} is the radon concentration in the air near the soil surface, F is the equilibrium factor between radon and its products (= 0.6), I is the mean outdoor occupancy time per individual (= 1760 h/y), and DCF is the dose conversion factor for radon exposure [9 nSv (Bq h m⁻³)⁻¹]. Radon concentration at the surface of the soil (C_{Rn}) is given by the relation [146,147]:

$$C_{Rn} = C_{SG} \sqrt{\frac{d}{D}} \text{ ----- (3.4)}$$

Where C_{SG} is the radon activity in the soil, d is the exhalation diffusion constant (= 0.05 cm²/s), and D is the Eddy diffusion coefficient (=5×10⁴ cm²/s).

From the Table (3.13), it is observed that the annual effective dose received by individuals during winter season ranged between (0.000826 mSv/y) and (0.061282 mSv/y), with an average value of (0.01866 mSv/y). On the other hand, the annual inhalation dose due to radon concentration in soil gas received by the public in the spring season is found to be in the range of (0.000380-0.061282 mSv/y), with an average value of (0.01363 mSv/y) as presented in Table (3.14). The obtained values of annual effective dose in both seasons were found to be well within the safe limit of 0.1 mSv.y⁻¹

as recommended by World Health Organisation (WHO, 2004) and European Council (EU, 1998) [148], and far below from the reference levels proposed by ICRP of 1 mSv.y⁻¹ [124].

Table (3.13): Radon activity at the soil surface and associated effective dose for the winter season.

No.	Sample	C _{SG} (Bq/m ³)	C _{Rn} (Bq/m ³)	Effective Dose (mSv/y)
1	S1	102 ± 60	0.102	0.000969408
2	S2	167 ± 70	0.167	0.001587168
3	S3	6000 ± 460	6	0.057024
4	S4	5960 ± 460	5.96	0.05664384
5	S5	6448 ± 480	6.448	0.061281792
6	S6	511 ± 130	0.511	0.004856544
7	S7	1310 ± 200	1.31	0.01245024
8	S8	1280 ± 160	1.28	0.01216512
9	S9	1350 ± 200	1.35	0.0128304
10	S10	403 ± 110	0.403	0.003830112
11	S11	94 ± 52	0.094	0.000893376
12	S12	124 ± 60	0.124	0.001178496
13	S13	801 ± 160	0.801	0.007612704
14	S14	677 ± 150	0.677	0.006434208
15	S15	88.8 ± 50	0.0888	0.000843955
16	S16	419 ± 110	0.419	0.003982176
17	S17	431 ± 110	0.431	0.004096224
18	S18	86.9 ± 54.7	0.0869	0.000825898
19	S19	370 ± 101	0.37	0.00351648
20	S20	617 ± 116	0.617	0.005863968
21	S21	1292 ± 160	1.292	0.012279168
22	S22	1270 ± 155	1.27	0.01207008
23	S23	1130 ± 257	1.13	0.01073952
24	S24	437 ± 110	0.437	0.004153248
25	S25	138 ± 69	0.138	0.001311552
26	S26	5544 ± 420	5.544	0.052690176
27	S27	5376 ± 400	5.376	0.051093504
28	S28	6347 ± 480	6.347	0.060321888
29	S29	5976 ± 460	5.976	0.056795904
30	S30	4154 ± 335	4.154	0.039479616
Mean value		1963.456 ± 204	1.963456667	0.018660692
Permissible Value [19]				1 mSv/y

Table (3.14): Radon Activity at the soil surface and associated effective dose for the spring season.

No.	Sample	C _{SG} (Bq/m ³)	C _{Rn} (Bq/m ³)	Effective Dose (mSv/y)
1	S1	60 ± 52	0.06	0.00057024
2	S2	117 ± 60	0.117	0.001111968
3	S3	2128 ± 190	2.128	0.020224512
4	S4	4022 ± 330	4.022	0.038225088
5	S5	4252 ± 335	4.252	0.040411008
6	S6	601 ± 116	0.601	0.005711904
7	S7	1251 ± 155	1.251	0.011889504
8	S8	1163 ± 145	1.163	0.011053152
9	S9	1485 ± 215	1.485	0.01411344
10	S10	490 ± 110	0.49	0.00465696
11	S11	40 ± 50	0.04	0.00038016
12	S12	132 ± 65	0.132	0.001254528
13	S13	770 ± 160	0.77	0.00731808
14	S14	413 ± 110	0.413	0.003925152
15	S15	130 ± 65	0.13	0.00123552
16	S16	489 ± 120	0.489	0.004647456
17	S17	328 ± 105	0.328	0.003117312
18	S18	126 ± 60	0.126	0.001197504
19	S19	276 ± 80	0.276	0.002623104
20	S20	547 ± 135	0.547	0.005198688
21	S21	996 ± 180	0.996	0.009465984
22	S22	1038 ± 240	1.038	0.009865152
23	S23	945 ± 170	0.945	0.00898128
24	S24	350 ± 105	0.35	0.0033264
25	S25	218 ± 70	0.218	0.002071872
26	S26	2793 ± 200	2.793	0.026544672
27	S27	3900 ± 305	3.9	0.0370656
28	S28	4445 ± 345	4.445	0.04224528
29	S29	4970 ± 360	4.97	0.04723488
30	S30	4550 ± 345	4.55	0.0432432
Mean value		1434.166 ± 165	1.434166667	0.01363032
Permissible Value [19]				1 mSv/y

Chapter Four

CONCLUSIONS AND RECOMMENDATIONS

4.1. Conclusions

4.1.1. Radon Concentration in the Lake Water

1. Radon activity concentration in water obtained in both seasons were much lower than the permissible level reported by some international organizations which are (11.1 Bq/l) that proposed by the United States Environmental Protection Agency (EPA), or (20 Bq/l) reported by World Health Organization (WHO).
2. Spatial variation of radon content in water is noticed. An obvious difference in radon distribution between part and another in the study area has been conducted, since the higher radon concentrations observed at the northeastern side of the lake, while the lower concentration was in the southwestern side.
3. Radon concentrations measured during the spring season were higher than those measured during the winter season for the most samples, which indicates a clear seasonal variation.
4. The values of the annual effective dose received by the public due to inhalation of radon for both seasons are found to be very much less than the permissible level of (1mSv/y) recommended by WHO, or far below the (20 mSv/y) proposed by ICRP.
5. Several relationships have been established between radon concentration in water and five physiochemical parameters of the lake water. Generally, all correlations were found to be weak correlations except that with turbidity, since there is no correlation observed between turbidity and radon in water. These correlations can be described as follow:

weak positive with electric conductivity (EC) and total dissolved solids (TDS), and weak negative with pH and resistivity.

4.1.2. Radon Concentration in the Lake Soil

1. Radon concentrations measured during both seasons were found to be within the allowed range of (0.4-40 kBq/m³) that proposed by UNSCEAR 2000.
2. Radon concentrations in soil gas fluctuated from location and another clearly, which indicates a local variation of radon distribution between different locations. As same as radon in water, the highest radon in soil concentrations were observed in the northeastern side of the lake, while the lowest concentrations were observed in the southwestern side of the lake.
3. Obvious seasonal variation of radon in soil was observed between two seasons. Radon in soil gas recorded high concentration values during the winter season as compared to radon activity levels obtained in the spring.
4. Annual inhalation dose received by individuals due to radon concentrations at soil surface has been estimated in both seasons and is found to be far below the allowed limit of (1 mSv/y) reported by WHO.

It is worthy to mention that, in contrast of the radon concentration in water, radon concentration in soil gas recorded a higher values in the winter season, while in water it was higher in the spring season.

Finally, according to the obtained radon concentrations in the lake water and soil for both seasons. It is possible to say that the present study has revealed that radon

concentration in water and in soil gas and associated annual effective dose is within referenced levels and the study area does not pose any kind of health hazard for the tourist and population.

4.2. Recommendations and Future Work

The radon gases are dangerous to human health when their concentrations are increasing higher than the permitted levels which cause lung cancer. Therefore, it is necessary to measure radon concentrations continuously, during year seasons, as done in advance countries such as Britain. For the present study, it is found that the northeastern side of the lake contains high radon concentrations relative to other parts of the study area. Because it is well known that the exposure to radon and its products for a long time even though with allowed concentrations would lead to health problems, so we recommend taking this into consideration when establishing any economic projects or building tourist facilities.

There are several studies we plan to do it in the future as follow:

- (1) Using RAD7 radon detector to measure radon and thoron concentration in the soil and clay at the lake bottom.
- (2) Studying radon concentrations in the water of some wells around the lake that used for irrigation using RAD7 radon detector, and trying to find the relationship between their water and the lake water.
- (3) Studying the lake water and soil using gamma spectroscopy in order to determine the concentrations of a set of radionuclide such as (^{238}U , ^{232}Th , ^{40}K).

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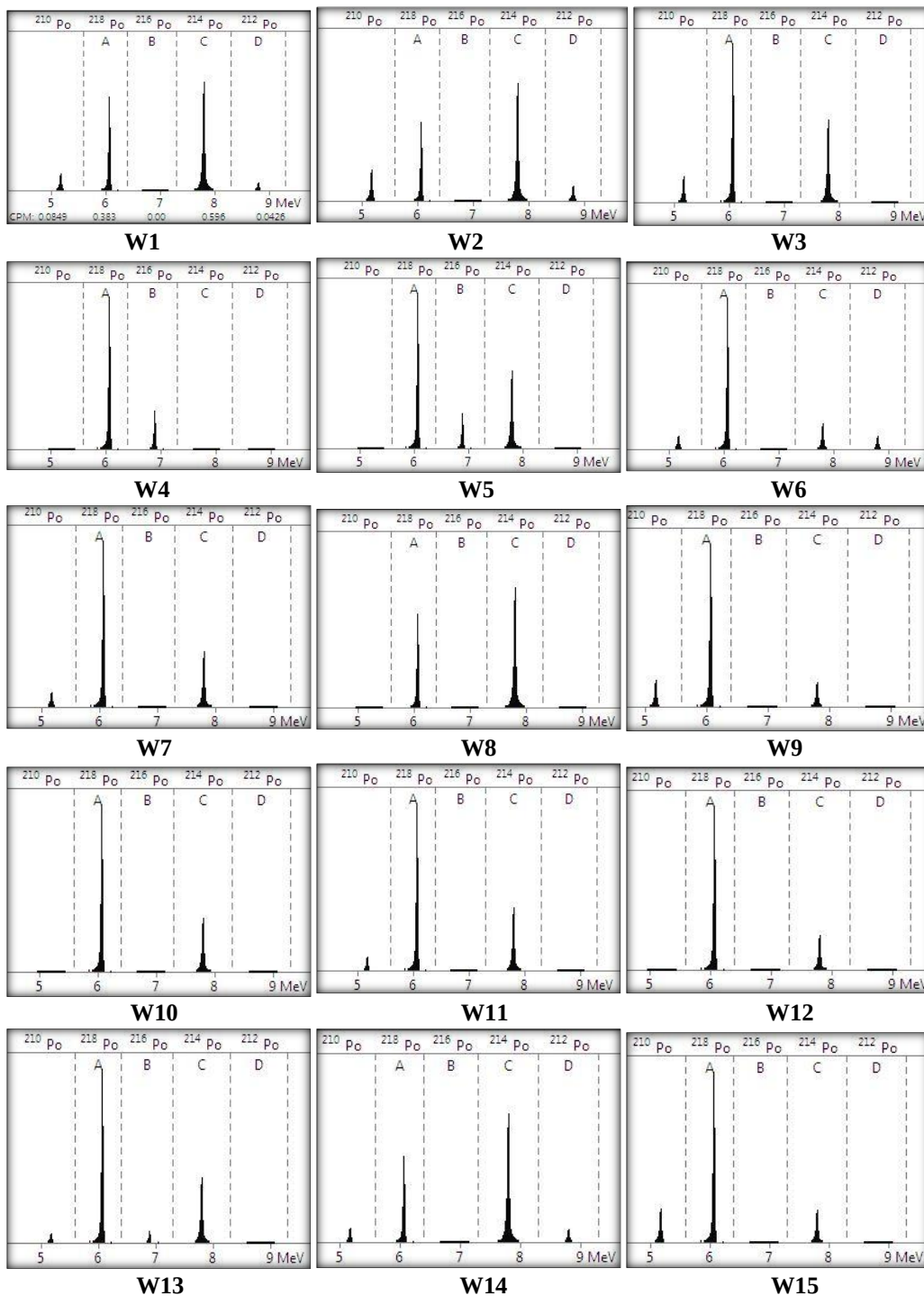
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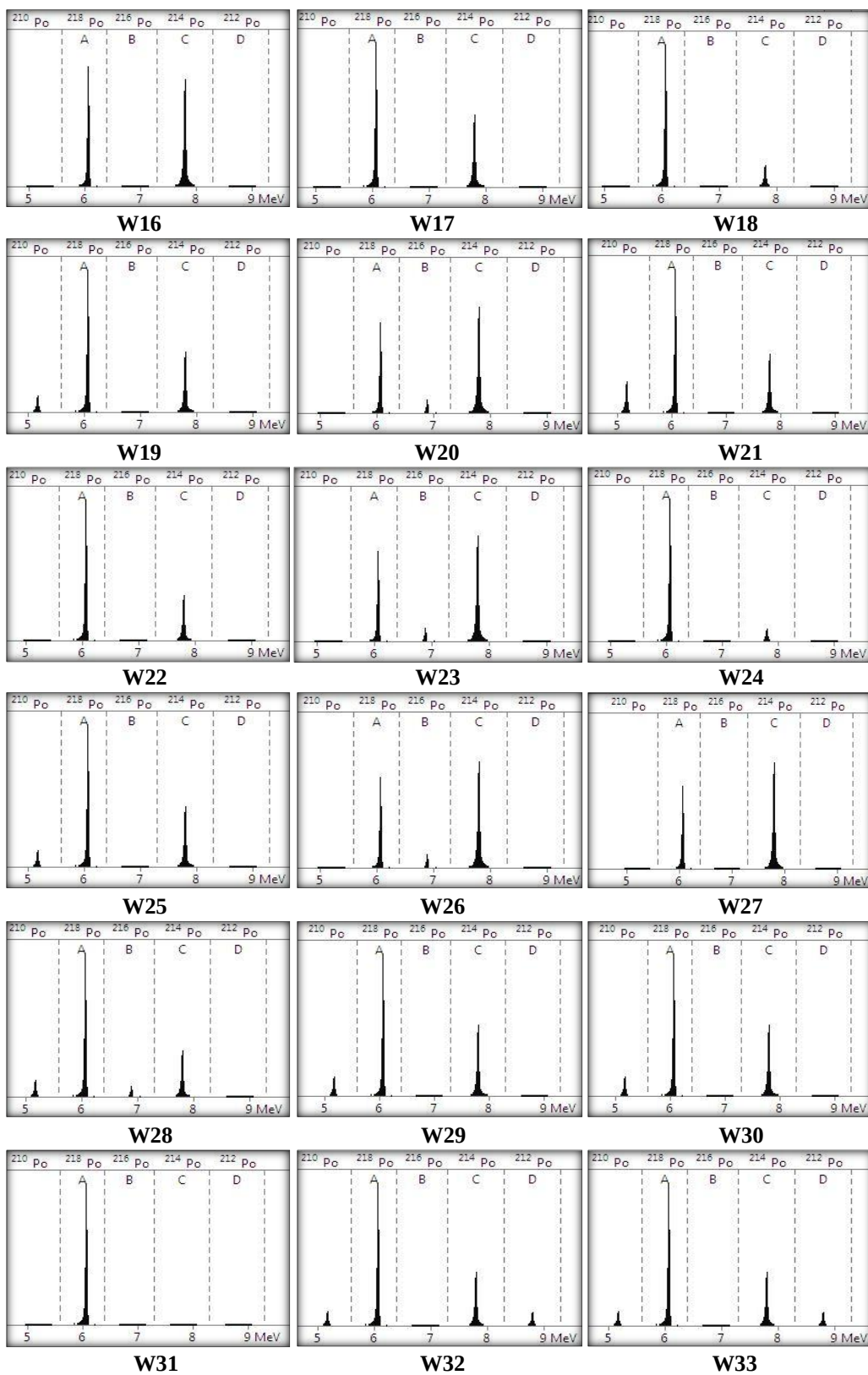
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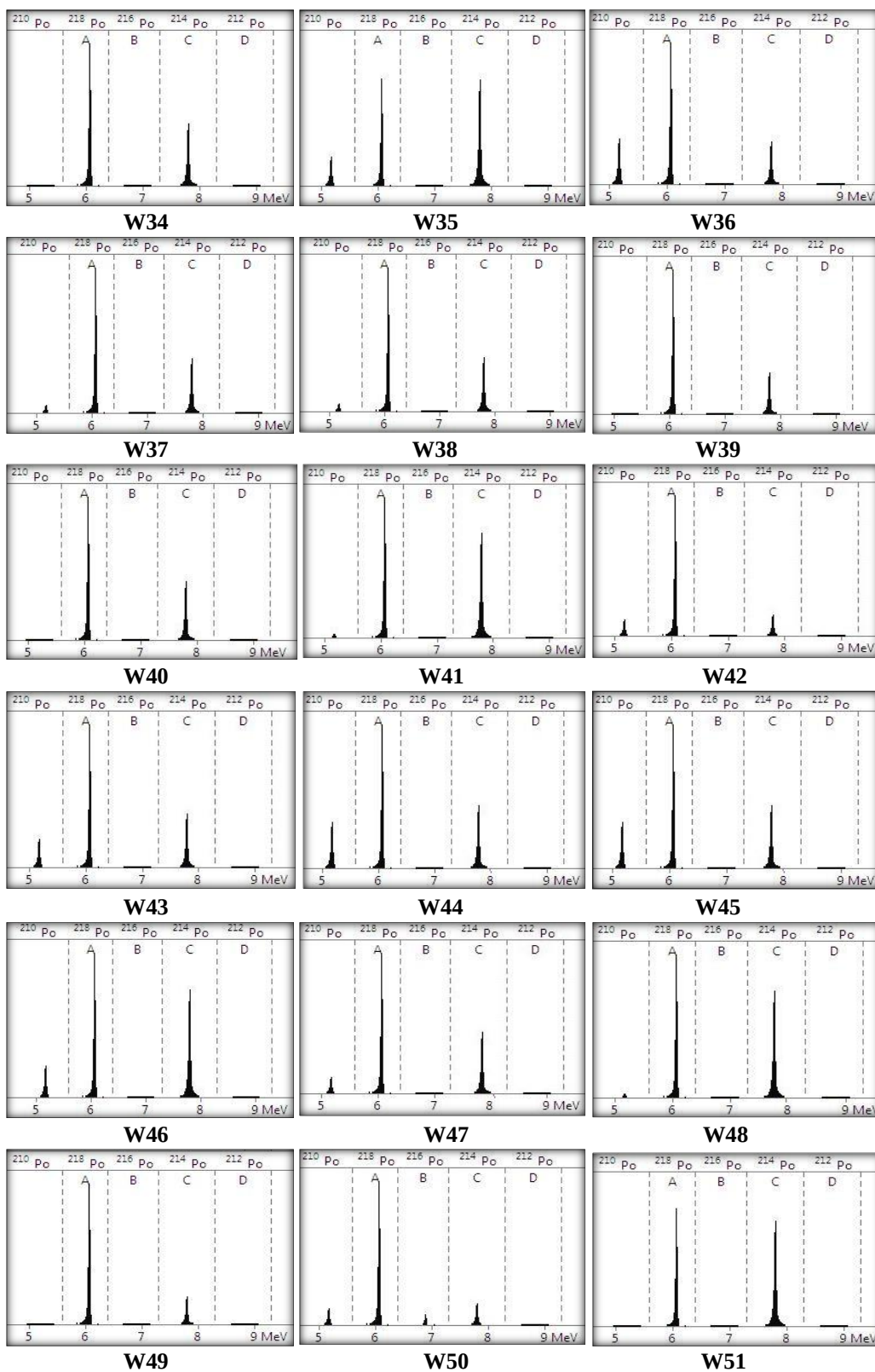
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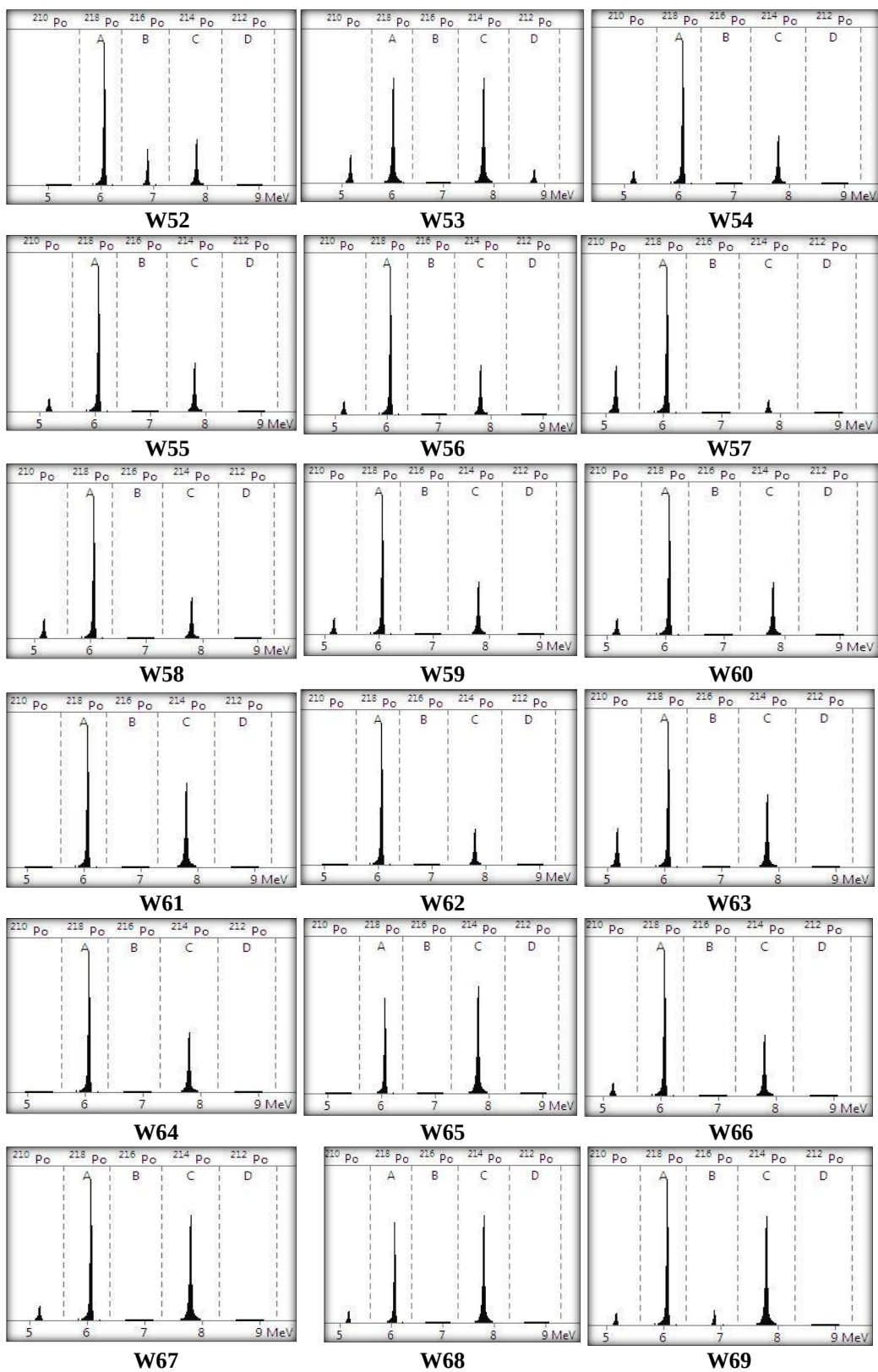
Appendix (1): RAD7 Spectrums

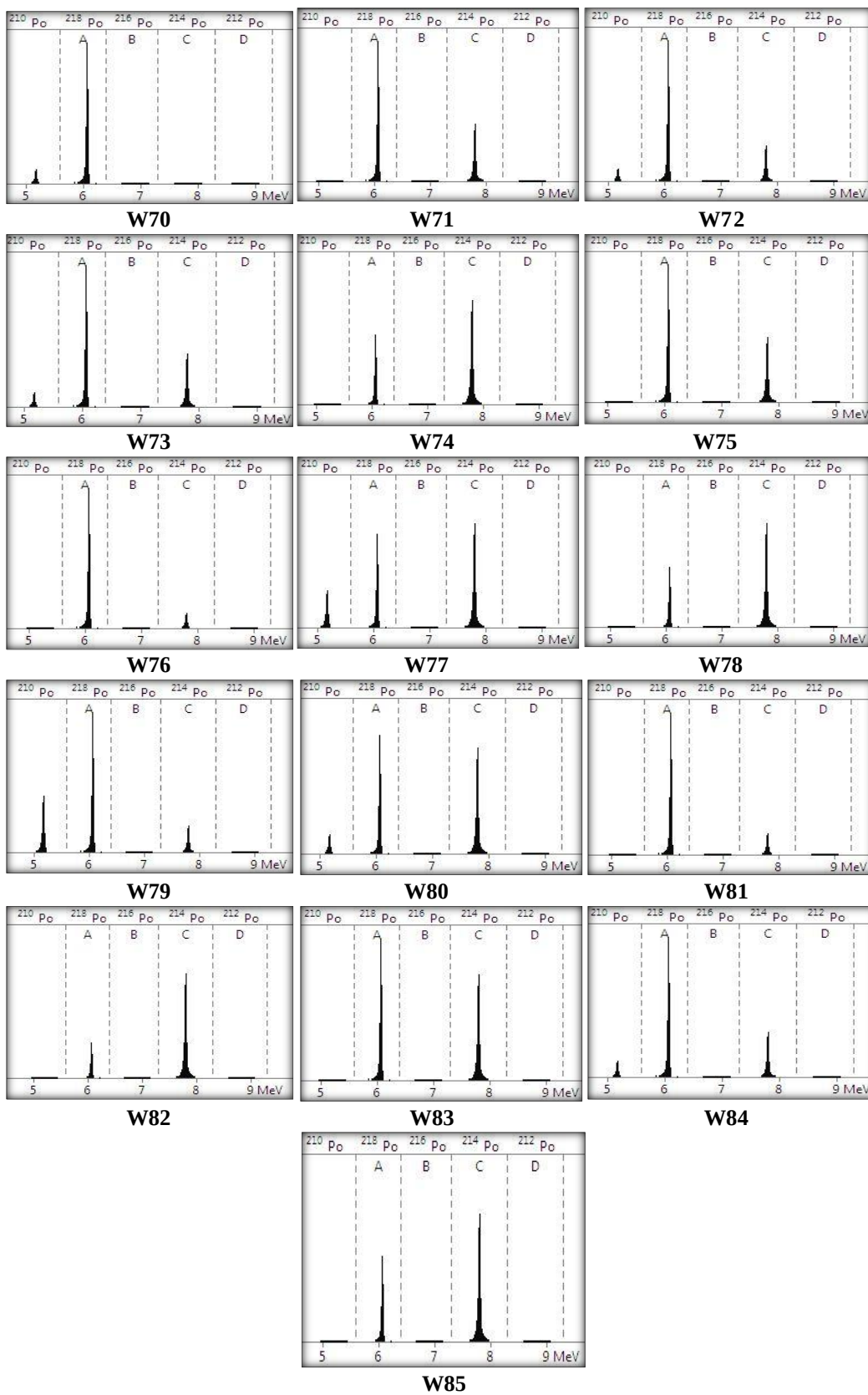
(1) Spectrums Obtained from Water Samples During the Winter Season.



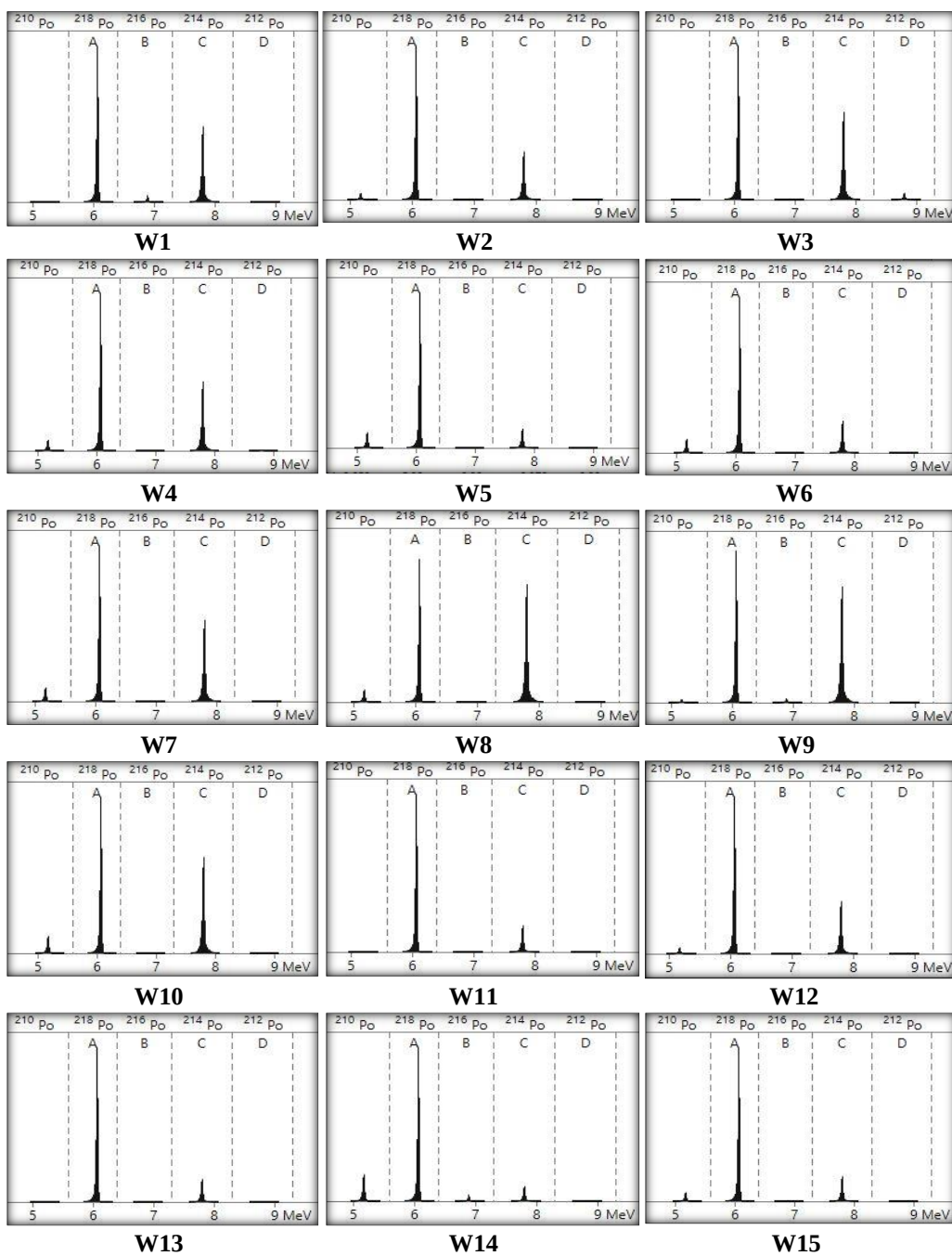


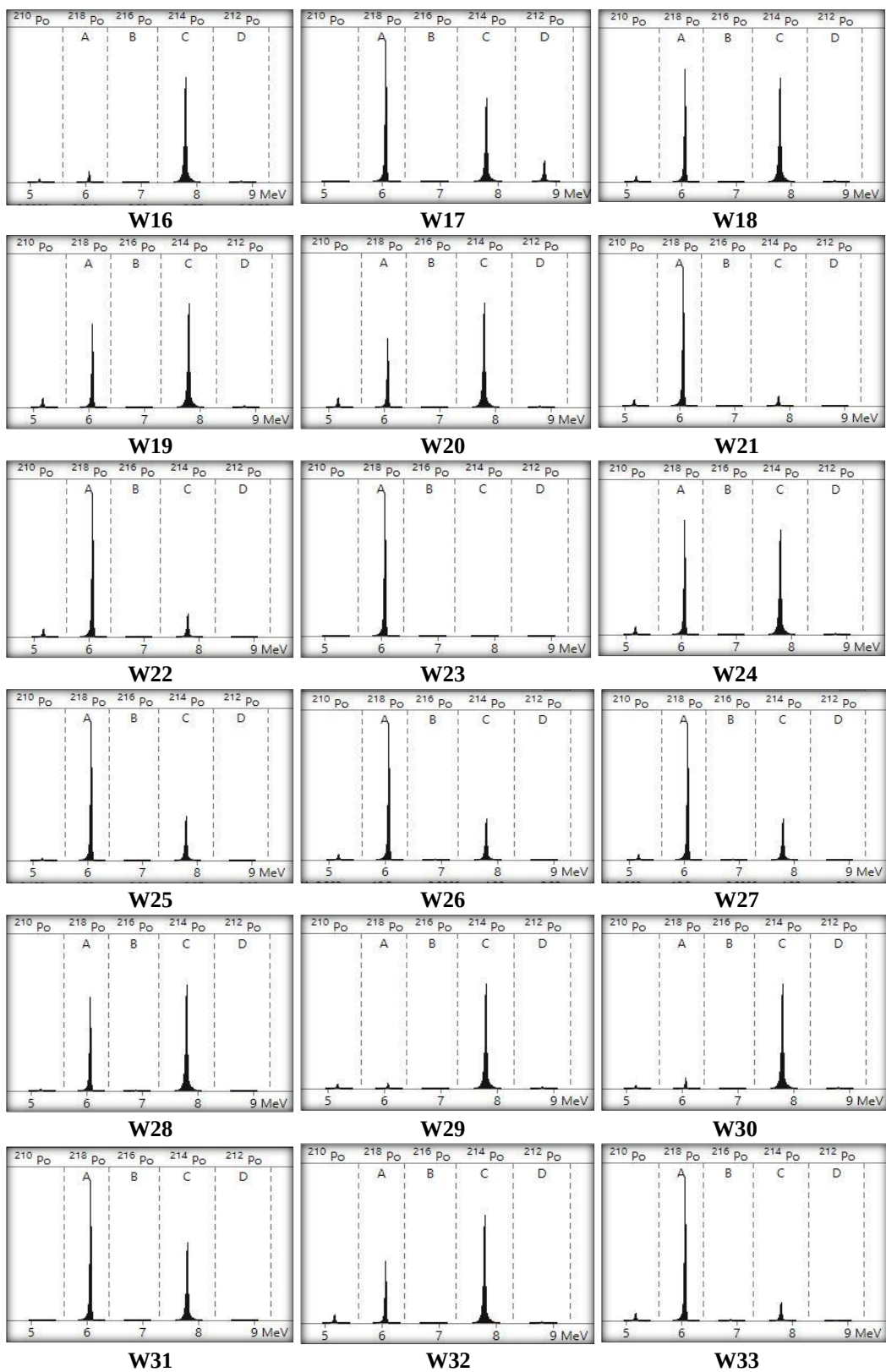


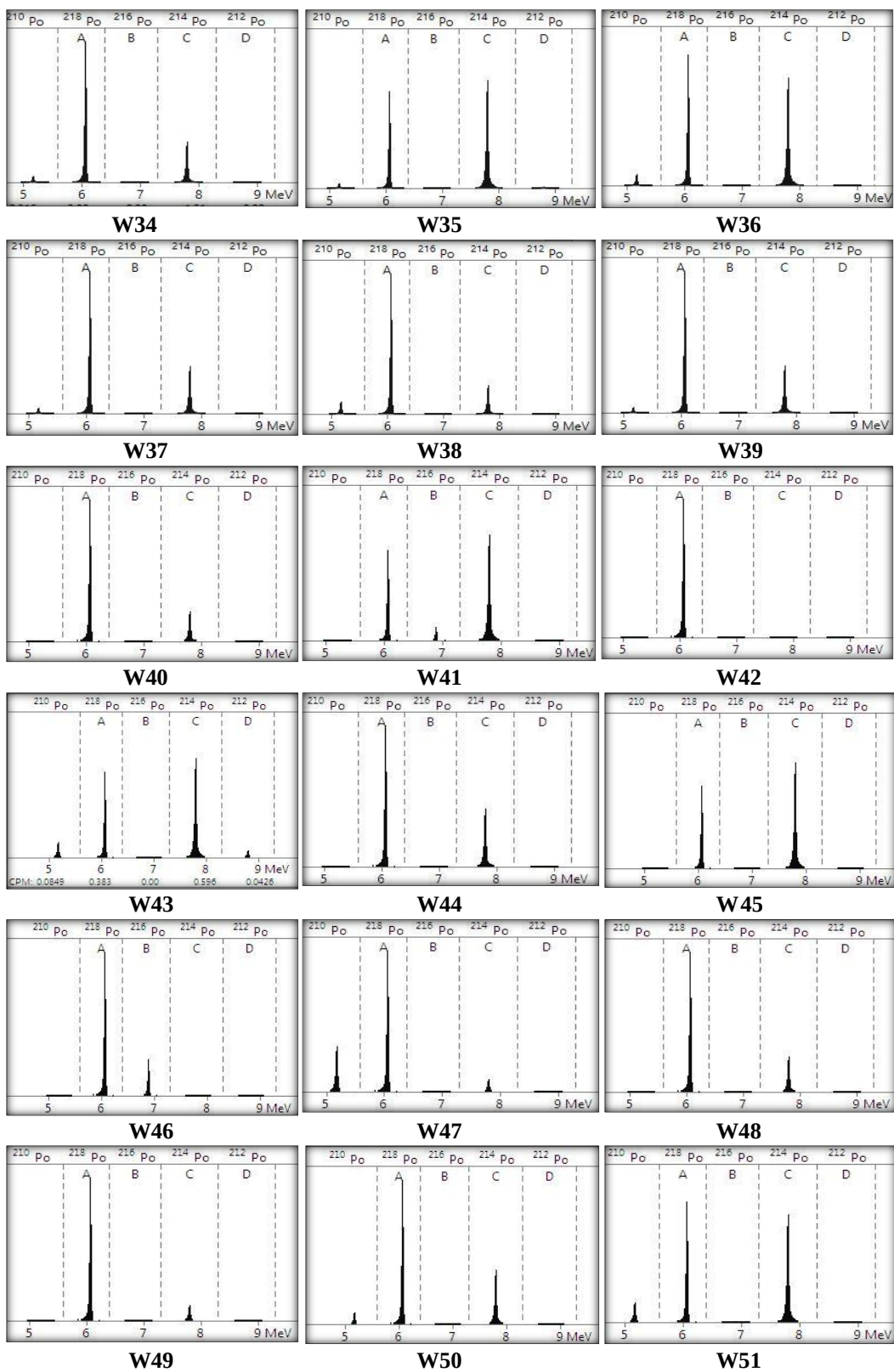


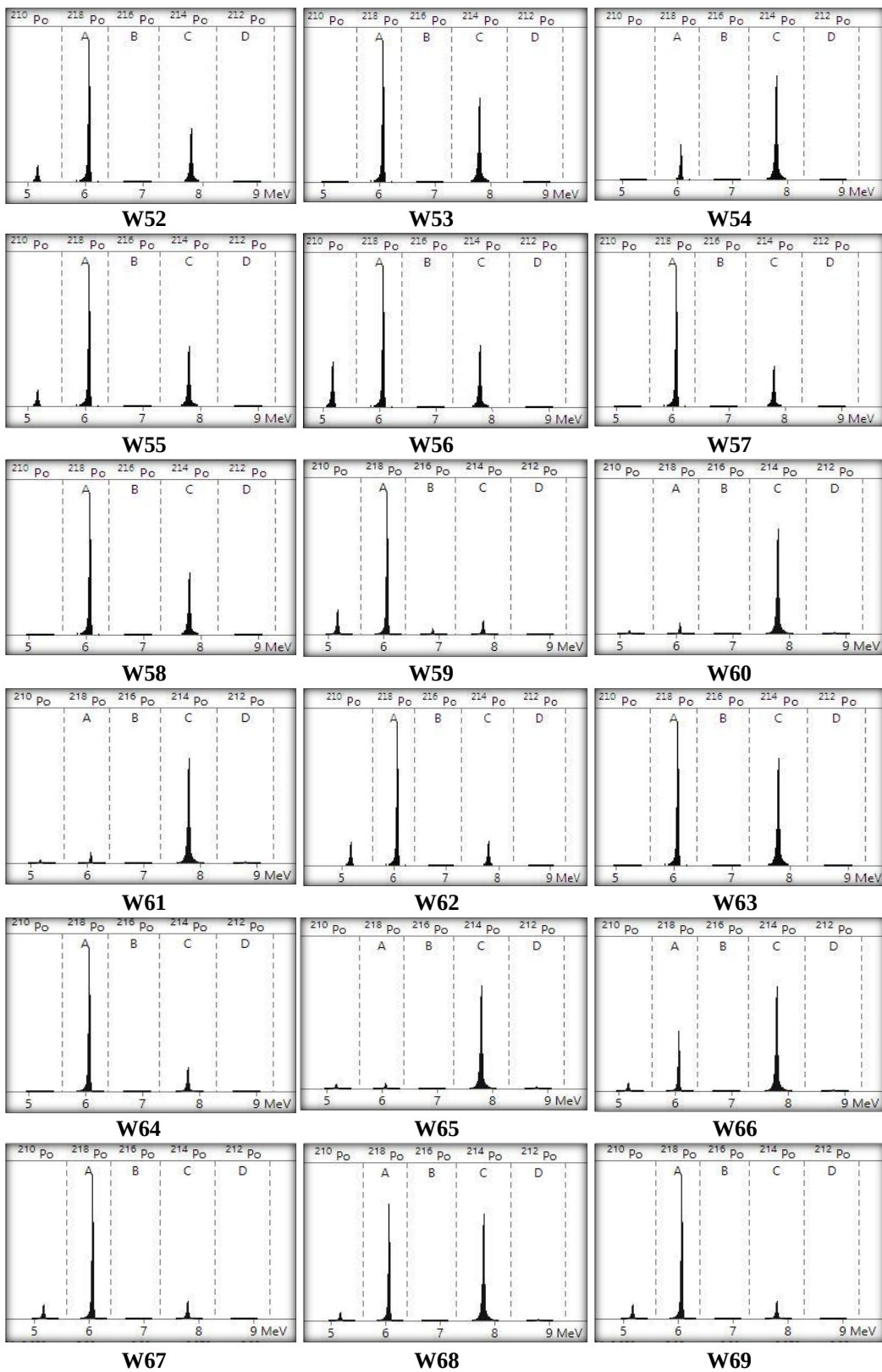


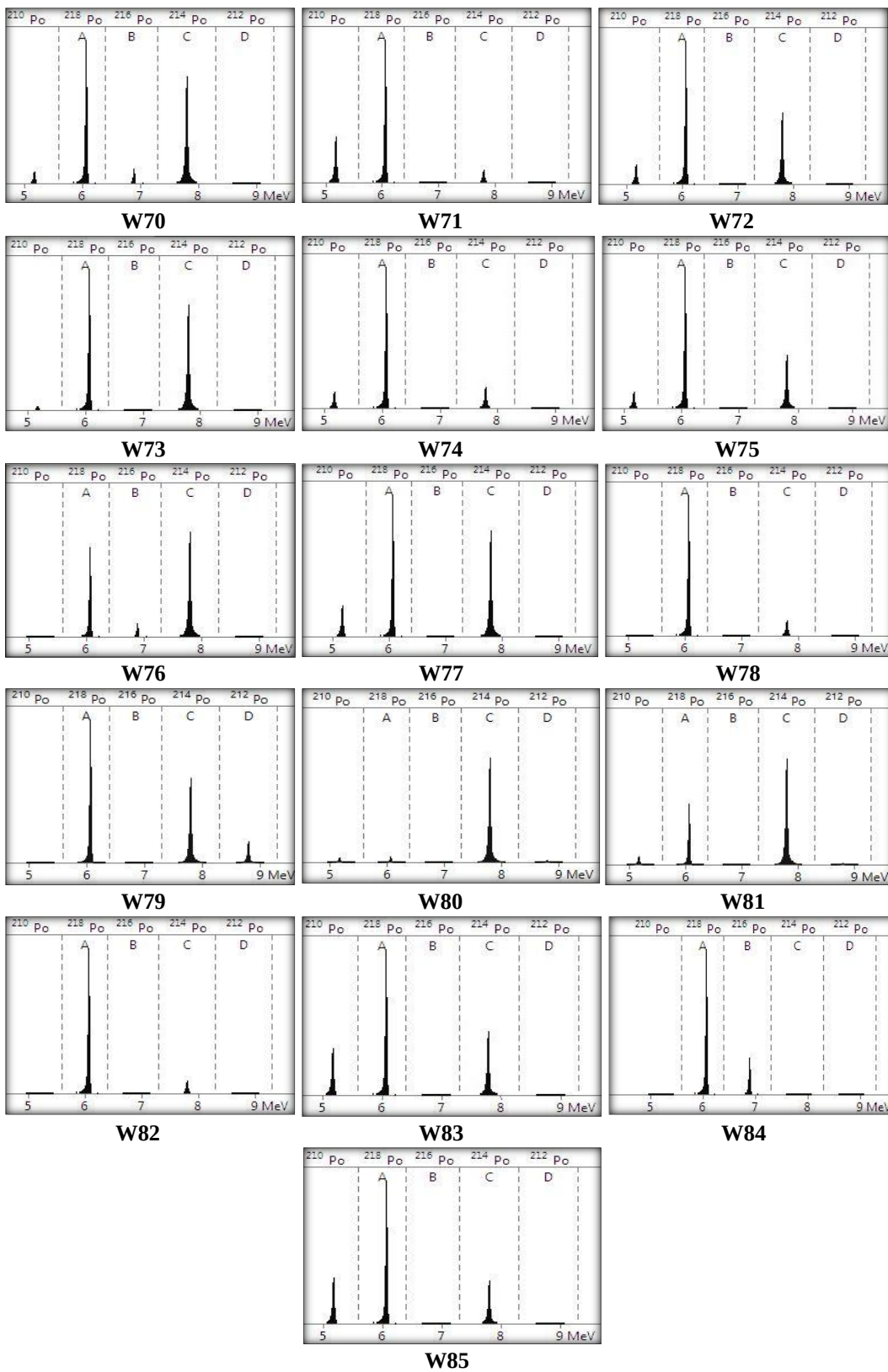
(2) Spectrums Obtained from Water Samples During the Spring Season.



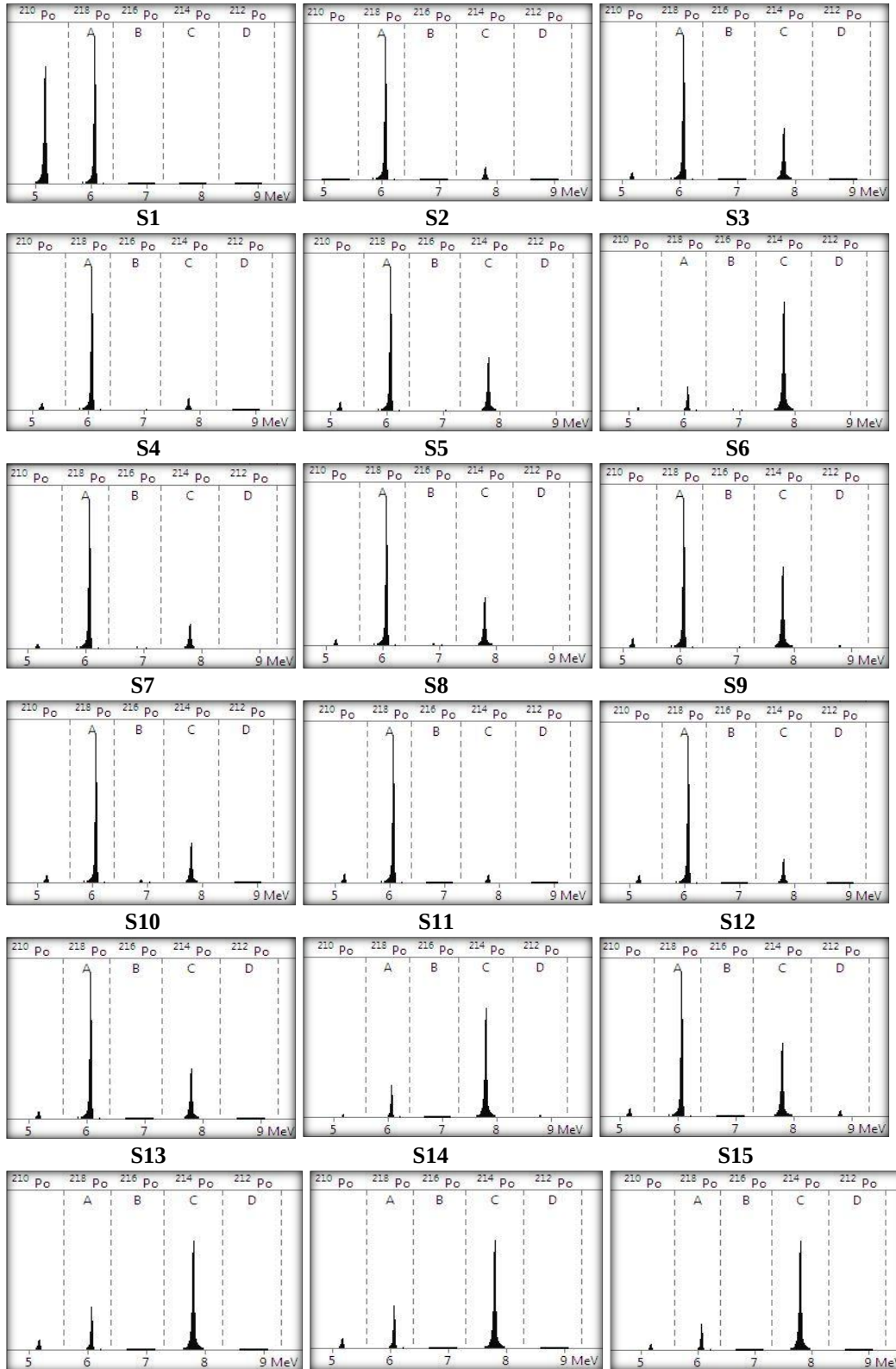


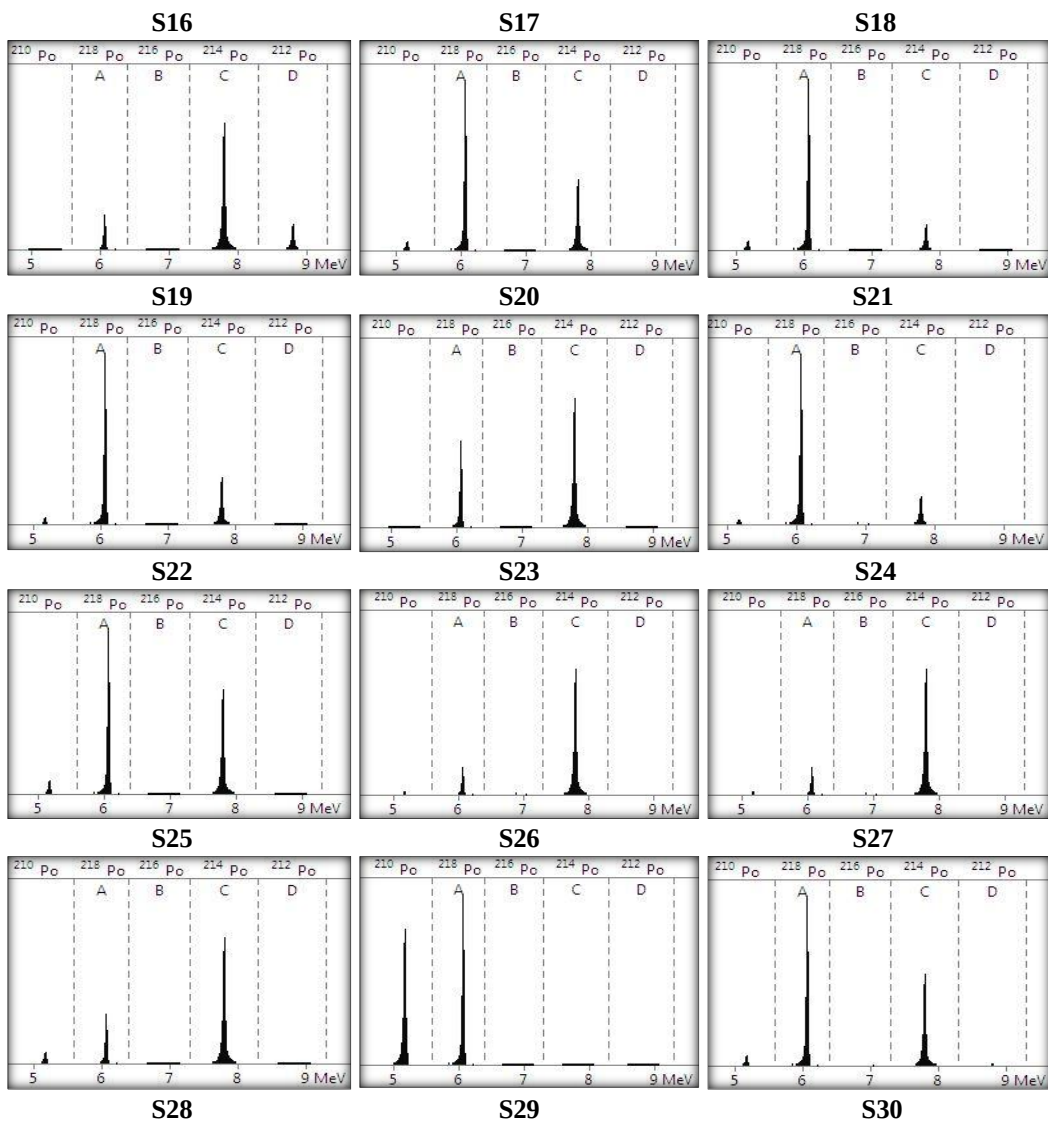




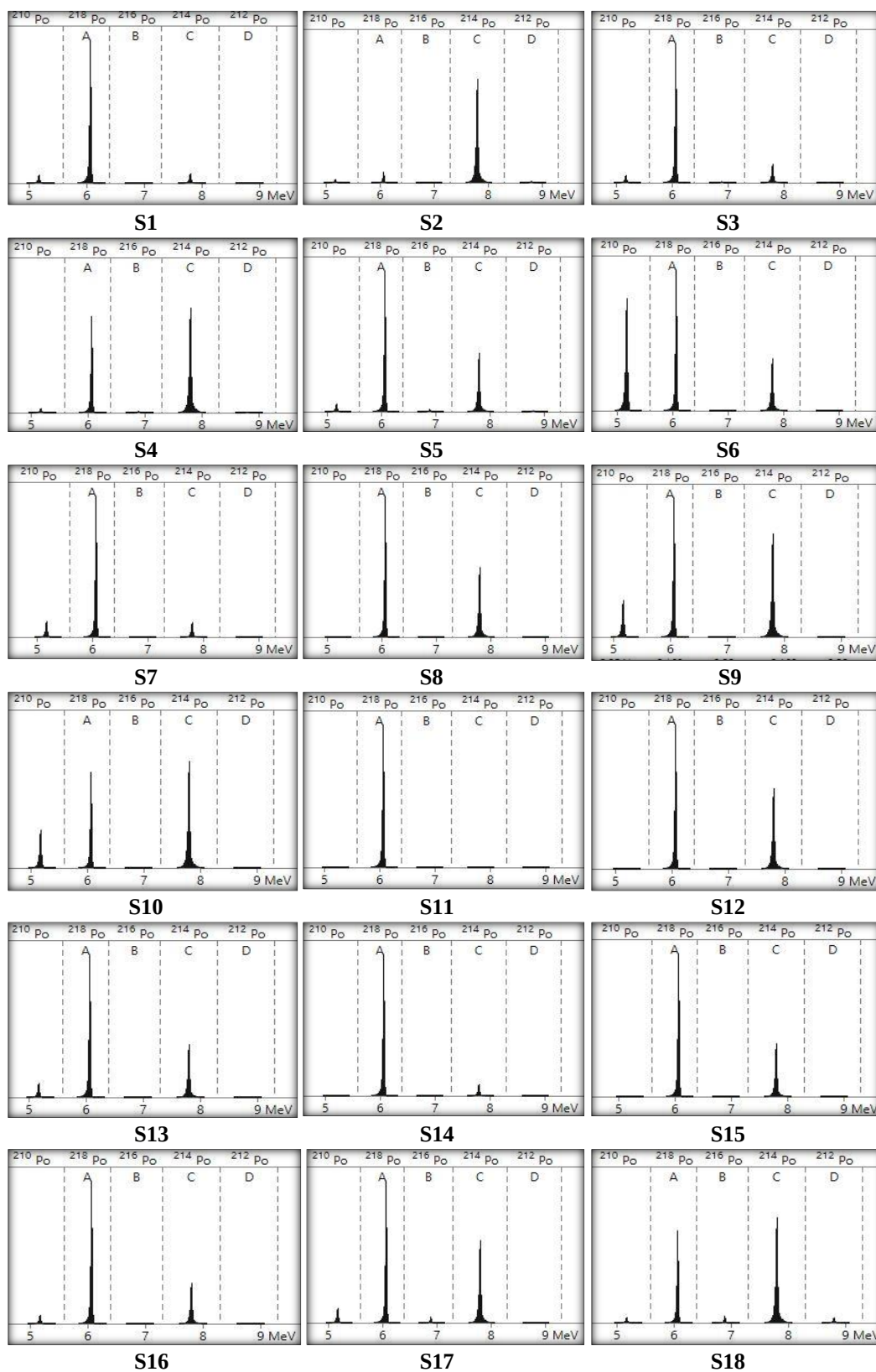


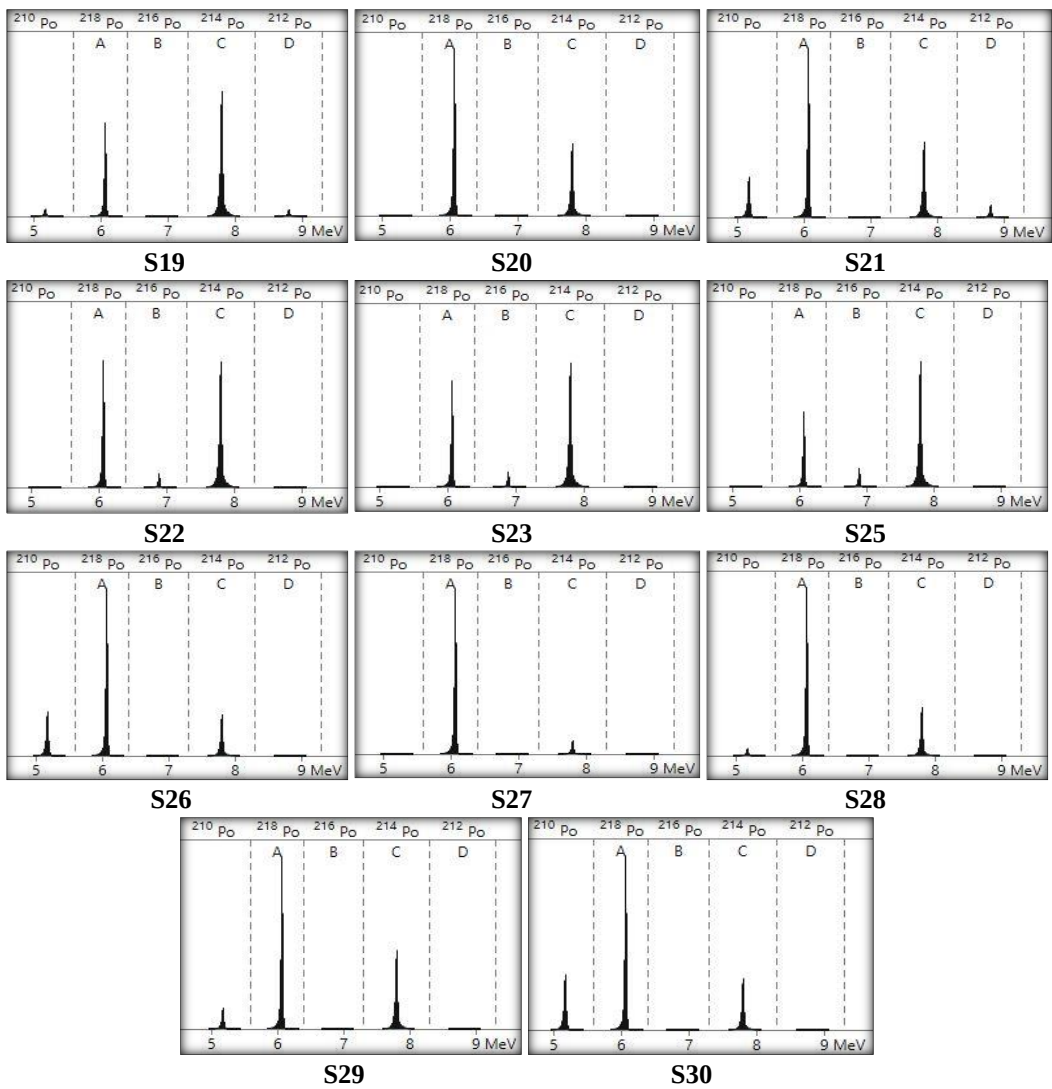
(3) Spectrums Obtained from Soil Samples During the Winter Season.





(4) Spectrums Obtained from Soil Samples During the Spring Season.





List of Publications

- (1) Ahmed A. Sharrad, Abdulameer K. Farhood, “Radon Concentration Measurements and Physiochemical parameters of Sawa Lake Water – Samawa City, South of Iraq”. Journal of Global Pharma Technology, Vol. 11, No. Supl.10-11, 2019.
- (2) Ahmed A. Sharrad, Abdulameer K. Farhood. “Radon Concentration Measurement in Soil Gas of Sawa Lake, Samawa City – South of Iraq”. Int. J. Adv. Res. Vol. 7, No. 6, pp. 170-177, 2019.

الخلاصة

في هذه الدراسة تم تحديد وقياس مستويات غاز الرادون موسمياً في مياه وتربة بحيرة ساوة الواقعة في مدينة السماوة- جنوب العراق باستخدام كاشف الرادون في الهواء RAD7، المصنوع من قبل شركة (DURRIDGE COMPANY Inc.)، القياسات تمت خلال موسمي الشتاء والربيع.

تم قياس تراكيز غاز الرادون في فصل الشتاء لـ (85) عينة تم جمعها من مواقع مختلفة في البحيرة لذلك الغرض، فترة القياس خلال الشتاء استمرت لمدة شهرين (من الاول من كانون الاول لعام 2018 ولغاية الاول من شباط لعام 2019). تراكيز غاز الرادون المقاسة في مياه البحيرة لهذه الفترة تراوحت ما بين (0.085 Bq/l) و (0.965 Bq/l) ، مع متوسط قيمة مساوٍ لـ (0.322 Bq/l) ، كما تم حساب الجرعة السنوية المكافئة ووجد انها تتغير بين $(0.080784 \mu\text{Sv.y}^{-1})$ و $(0.917136 \mu\text{Sv.y}^{-1})$ مع معدل قيمة يساوي $(0.325764 \mu\text{Sv.y}^{-1})$. تم قياس غاز الرادون لنفس العدد من العينات التي جمعت من نفس المواقع في البحيرة في فصل الربيع ولفترة شهرين ايضاً (ابتداءً من الثالث والعشرين من آذار ولغاية الثالث والعشرين من أيار). كان اعلى تركيز للرادون في هذه الفترة هو $(1.15 \pm 0.35 \text{ Bq/l})$ ، بينما كان اقل تركيز مساوٍ لـ $(0.093 \pm 0.085 \text{ Bq/l})$ مع معدل قيمة يساوي $(0.409 \pm 0.24 \text{ Bq/l})$. الجرعة السنوية المكافئة المقاسة تراوحت ما بين $(0.0883 \mu\text{Sv/y})$ و $(1.065 \mu\text{Sv/y})$ ، بينما كان متوسط القيمة يساوي $(0.389 \mu\text{Sv/y})$. بالإضافة الى قياس تراكيز الرادون لمياه البحيرة، بعض القياسات الفيزيوكيميائية ك- التوصيلية الكهربائية (EC)، الاملاح الكلية المذابة (TDS)، المقاومة الكهربائية، العكورة، بالإضافة الى الاس الهيدروجيني (pH)، تم قياسها لجميع عينات الماء وخلال كلا الفصلين لغرض ايجاد الترابط بينها وبين تراكيز غاز الرادون في تلك العينات احصائياً

كما تم ايضاً قياس تراكيز غاز الرادون في التربة المحيطة بمياه البحيرة ولـ (30) عينة متوزعة على طول محيط البحيرة ولكلا الفصلين، تراكيز غاز الرادون في تربة البحيرة خلال فصل الشتاء تراوحت ما بين (86.9 Bq/m^3) و (6448 Bq/m^3) مع متوسط قيمة مساوٍ لـ (1963 Bq/m^3) ، كما وجد ان الجرعة السنوية المكافئة تتغير بين $(0.000826 \text{ mSv.y}^{-1})$ و (0.061282 mSv/y) بمعدل قيمة $(0.01866 \text{ mSv.y}^{-1})$ ، في فصل الربيع، اعلى تركيز لغاز الرادون كان (40 Bq/m^3) بينما كان اقل تركيز مساوٍ لـ (4970 Bq/m^3) بمتوسط قيمة يساوي (1434.17 Bq/m^3) ، الجرعة السنوية المكافئة في هذا الفصل كانت تتراوح بين $(0.000380 \text{ mSv.y}^{-1})$ و $(0.061282 \text{ mSv.y}^{-1})$ بينما كان متوسط القيمة مساوٍ لـ (0.01363 mSv/y) ،

من النتائج اعلاه فانه من الممكن القول ان منطقة البحيرة لا تمتلك اي مخاطر اشعاعية فيما يخص الرادون بالنسبة للسواح وسكان المنطقة المجاورة لان تراكيز الرادون المقاسة تقع ضمن النسب المسموحة والمقرة من قبل المنظمات الدولية المختصة.



وزارة التعليم العالي والبحث العلمي

جامعة المثنى

كلية العلوم

قسم الفيزياء

قياسات فصلية لتراكيز غاز الرادون في بحيرة ساوة، مدينة السماوة- جنوب العراق

رسالة مقدمة الى كلية العلوم/ قسم الفيزياء كجزء من متطلبات نيل شهادة
الماجستير في الفيزياء

من قبل

احمد عكاب شراد

باشراف

أ.د. عبد الامير كاظم فرهود الخفاجي