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Characterization of Environmental Radioactivity Level in Al-Basrah City (Iraq)

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Abstract Soils and earth-derived building materials contain radioactive materials provide external exposure to nearby individuals and result in detrimental health effects including cancer. The risk of cancer incidence (morbidity) and mortality to individuals in Al-Basrah's population (south of Iraq) related to external exposure to ambient gamma radiation is evaluated in this study. The risk estimations include delayed radiation effects (cancer morbidity, mortality and hereditary genetic damages). Radiation exposure rates were measured using BGS-4 gamma-ray scintillation (Scintrex, Canada) for the period 2012-2013. Absorbed dose rates in air and in human tissues are determined by applying typical conversion factors available in the literature. Age-dependent radiation dose is calculated for infants, children, and adults. Dose-to-risk conversion factors are applied to estimate potential risk to various body organs and tissues as a result of exposure to ambient gamma radiation. The findings of this study report that about 0.26% of Al-Basrah population are expected to be diagnosed with radiation-induced cancer over there lifetime. The lifetime fatal cancer probability (mortality) is found to be occurs at a rate of 0.19%. The risk of developing fatal stomach cancer is found to be occurs at a largest extent in comparison with other exposed body organs and tissues. Children and infants are found to be at a greater radiation risk than adults due to lower body weight. Other consequences of radiation injury such as genetic effects transmitted to succeeding generations are expected to occur at a rate of 0.03% in the offspring of Al-Basrah population as a result of changes transmitted via the genetic mechanisms due to irradiation of gonads.

Keywords: *environmental radioactivity level, Al-Basrah city*

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1. Introduction

Al-Basrah city, located to the south of Iraq, has been widely contaminated by depleted uranium (DU) particles during the 1991 and 2003 Gulf wars. Cancer, birth defects, hereditary genetic effects and other radiation-derived biological diseases have been widely observed among the population of Al-Basrah city.

Gamma energy is a high-energy electromagnetic radiation that can penetrate most substances. Because of its high energy, gamma radiation can penetrate the human body from the outside and damage cells, which would lead to cancer later in life [1]. Humans are exposed to many sources of radiation in the environment of which natural sources are the most important ones [2]. Natural sources deliver the highest radiation dose that people normally receive. The average annual dose from natural sources is 2.4 mS_v, which is a reference level representing the average 1-5 mS_v, and in extreme cases to 1 S_v or more [3].

The term natural radiation background is used to designate naturally occurring radioactive materials and high-energy radiations. The various members of the uranium and thorium families and a radioactive isotope of potassium are the most important naturally occurring radioactive materials. Naturally occurring radiations are due partly to these natural radioactive materials and partly to the cosmic radiation. The total background radiation levels to which people may be exposed are of considerable interest. Measurements are usually made with ionization chambers and the results expressed in milli-roentgens per year, i.e. in terms of the rate of energy absorption. The sea-level value is about 0.01 mR/h (88 mR/y) in regions of low background but will be considerably higher in many places [4].

The aims of this study are:-

(1) Make quantitative estimations of the biologically damaging effects associated with exposure of Al-Basrah inhabitants to natural background radiation by using a hypothetical linear no threshold (LNT) statistical model. The specific risks concerned in this study focus on the ionizing radiation as the cause, cancer morbidity, mortality (an abnormal process in which cells begin a phase of uncontrolled growth and spread) and genetic effects transmissible to progeny as the response. The assessed harmful consequences of ionizing radiation include somatic effects (risk of cancer, leukemia, sterility, cataracts, reduction in lifespan) and genetic damage (increasing the mutation rate in chromosomes and genes, affects future generations).

(2) Investigate the effect of the type of dwellings (single family house or flat) and materials of construction on the dose received by its occupants.

(3) To determine which population group (infants, children or adults) should be the primary target for radiation protection.

2. Materials and Methods

The exposure rates were measured 1m above the ground by using BGS-4 survey instrument. The measuring instrument utilized in this study is owned by Ministry of Science and Technology/ Hazardous Materials and Environmental Researches Directorate. The display in counts per second (c.p.s) was converted to exposure rates in μ R/hr using equation below [5]:

$$c.p.s \times \frac{1}{8.27} = \mu R / hr. \quad (1)$$

One roentgen (R) of exposure dose to a specific volume of air at standard conditions results in the absorbed dose of 0.87 rad. One rad (radiation absorbed dose) is equivalent to 0.01 Gray (Gy). A coefficient of 0.7 Sv/Gy is used to convert absorbed dose rate in air to effective dose equivalent. UNSCEAR 1993 report provides coefficients for exposure to terrestrial gamma rays for adults (0.72 Sv/Gy), children (0.80 Sv/Gy) and for infants (0.93 Sv/Gy) [6].

The standard error of the arithmetic mean S.E$(\bar{x})$ for the exposure rate readings is estimated by using equation below [7]:

$$S.E(\bar{x}) = \frac{S_x}{\sqrt{n}} \quad (2)$$

where S_x is the standard deviation of the exposure rate readings of size (n).

Exposure is defined as contact of an organism, such as humans or endangered species with a contaminant. Exposure assessment is the estimation of the magnitude, frequency, duration, and route of exposure [8]. The purpose of exposure assessment is the estimation of the contaminant concentrations and dosages to the population at risk [9].

Observed radiation affects (or effects the other types of noxious agents) may be broadly classified into two categories, stochastic and non-stochastic effects. In the context of radiation protection, the main stochastic effects are cancer and genetic effects. The results of exposure to a carcinogen or to a mutagen are an increase in the probability of occurrence of the effect with the increase in probability being directly proportional to the size of the dose. Radiation doses to exposed individuals in Al-Basrah population are estimated by using equation below:

$$\bar{H}_i = \mathrm{ER} \times 10^{-3} \times 0.87 \times 0.01 \times 0.7 \times 24 \times 365 \quad (3)$$

Where $\bar{H}_i$ represent radiation dose rate in mSv/y, ER represent exposure rate in μR/h, 10^{-3}, 0.87 rad/R, 0.01 Gy/rad, 0.7 Sv/Gy, 24 hr/day, and 365 day/y are conversion factors.

The collective effective dose equivalents S_E (human-Sv/y) were assessed according to the following expression [10]:

$$S_E = \bar{H}_i . N(\bar{H})_i \quad (4)$$

where $\bar{H}_i$ is the effective dose equivalent and $N(\bar{H})_i$ is the number of individuals in population subgroup i receiving dose equivalent of $\bar{H}_i$.

3. Risk Characterization

Toxicity Assessment is the acquisition and evaluation of toxicity data for each contaminant, a procedure that is performed for both non-carcinogens and carcinogens. The final step in a risk assessment is to bring the various studies together into an overall risk characterization. Public health risk for individual members in Al-Basrah population is modeled in this study as a linear function of radiological dose:

$$\begin{aligned}\mathrm{Risk} &= \mathrm{Dose}\left(\frac{mSv}{y}\right) \times 10^{-3} \left(\frac{Sv}{mSv}\right) \\ &\times \mathrm{Lifetime}\,(\mathrm{y}) \times \mathrm{Risk\ Factor}\left(\frac{Risk}{Sv}\right)\end{aligned} \quad (5)$$

where Risk = the probability of carcinogenic risk (dimensionless), lifetime exposure is taken to be 70 y (standard exposure duration for an adult exposed to a carcinogen) [11].

Table 1. Risk factors to various body organs and tissues (1 Sv=100 rem) [14]

Cancer	Radiation mortality (risk per rem)	Radiation inecidence (risk per rem)	Lethality
Bladder	0.00003	0.00006	0.5
Bone surface	0.000005	0.00001	0.7
Breast	0.00002	0.00004	0.5
Colon	0.000085	0.00015	0.55
Leukemia (Bone marrow)	0.00005	0.00005	0.99
Liver	0.000015	0.00002	0.95
Lung and Bronchus	0.000085	0.00009	0.95
Oesophagus	0.00003	0.00003	0.95
Ovary	0.00001	0.00001	0.7
Skin	0.000002	0.001	0.002
Stomach	0.00011	0.00012	0.9
Thyroid	0.000008	0.00008	0.1
Remainder	0.00005	-	-

Estimation of the potential risk from low levels of ionizing radiation requires application of dose-to-risk conversion factors to the estimation of the dose. For external sources of linear energy transfer (LET) radiation that provide nearly uniform irradiation of the body, the risk of cancer incidence (morbidity) and mortality as a function of external dose can be closely approximated using the conversion factors of 8×10^{-2} and 6×10^{-2} risk per sievert (Sv), respectively [12]. Morbidity and mortality risks to specific body organs and tissues can be estimated by means of the risks factors listed in Table 1. The risk coefficient for genetic effects in all generations following the radiation exposure of adults is 0.01 Sv^{-1} [13].

The genetic injury or damage to Al-Basrah population from radiation exposure is estimated in this study from the total number of human-sieverts delivered to the gonads. It is thought that in the majority of cases the inherited change will have a deleterious effect on the individual. This may be premature death, inability to produce offspring, susceptibility to disease, or any number of changes of lesser or greater importance [13]. The genetic risk coefficient for gonads is taken to be 4×10^{-3} Sv^{-1} for the first 2 generations (Cember, 1987) and 0.01 Sv^{-1} for all generations [14].

4. Results and Discussion

Multi-step risk assessment process is used in this study to predict the biologically damaging effect of public exposure to ambient background radiation. The 1st step is making quantitative measurements of the ability to produce ionization in air or the exposure dose to individuals in Al-Basrah population living in the area of the study by using BGS-4 Gamma-ray Scintillation Counter (SCINTREX, Canada) and the results are expressed in micro roentgen per hour $(\mu R / hr)$. Extensive measurements of the natural γ-radiation background in the outdoor air spaces are made. The 2nd step is estimation of the absorbed dose rate in air (in μrad/hr) and biological dose in human tissues and organs (in mSv/y) for local inhabitants by using a series of conversion factors available in the literature. The last step is making a correlation between the dose administered and the radiation injury produced by using a linear, no-threshold (LNT) dose-response statistical model.

Results of gamma exposure rates measurements are presented in Table 2. All field measurements were conducted in the period 2012–2013. The standard error of the exposure rate readings listed in Table 2 for outdoor exposure is estimated to be 0.33 μR/h. Step-by-step computation of the effective dose equivalent from the exposure rates is shown in Table 3. The natural background γ-radiation level in Al-Basrah City (8.87 μR/hr) is comparable to that in the USA (8 μR/hr) ersity, 2003]. The whole-body effective dose equivalent inferred from measurement (0.472 mSv/y) is found to be greater than the annual effective dose equivalent of 0.01 mSv, which corresponds to the National Council on Radiation Protection and Measurement (NCRP) concept of negligible individual risk level [15,16]. This result indicates that public exposure to natural background radiation causes considerable possible long term bioeffects include increased incidence of somatic and hereditary genetic effects (increased incidence of genetic abnormalities in humans) to a large number of individuals in Al-Basrah population.

Effective dose equivalent to infants, children, and adults arising from external exposure to indoor and outdoor gamma radiation are listed in Table 4. Infants are at greater risk than adults and children due to lower body weight.

The likelihood or probability of radiation risk to Al-Basrah population is evaluated in Table 5 by using a linear, no-threshold (LNT) dose-response model (Eq.(5)) and the risk factors listed in Table 1. The biological effects of natural background radiation are expressed in statistical terms due to biological variability accounts for a difference in sensitivity among individuals and a wide variation in susceptibility to radiation damage exists among different types of cells and tissues. The probabilities of cancer risks to various body organs and tissues are calculated and the results are listed in Table 5. The results of quantitative risk assessment are written in Table 5 in the following form (Risk = Number of injuries or deaths per number of people exposed to hazard). The risk of developing blood cancer (leukemia) as a result of the irradiation of the bone marrow is calculated to be 1 in 6060 exposed individuals, while the risk of developing bone cancer is evaluated to be 1 in 62500. The fatality rate in Al-Basrah population owing to natural γ-radiation exposure is evaluated at 28 extra fatal cancer case/million people/year. The gonad dose of 0.472 mSv/y is found to be less than the population dose limit for genetic effects of 1.7 mSv/y proposed by the National Council on Radiation Protection and Measurements (NCRP) [17] and less than the dose limits for gonads of 5 mSv/y recommended by the International Commission on Radiological Protection (ICRP) [18].

Table 2. Results of gamma exposure rates measurements

No.	Location/district	Mean exposure rate (μR/hr)
1	Al-Tameemiya (Al-Robat Youth Center)	9.12
2	Al-Jamhuriya (near football stadium)	10.48
3	Al-Barakhiya (near educational hospital)	8.2
4	Bab Al- Zubair (near economic and management college)	9.7
5	Al-Zubair (near Al-Zubair hospital)	11.2
6	Al-Zubair	12
7	Al-Basrah University (Karmat Ali)	7.8
8	Karmat Ali (center)	8
9	Al-Ma'aqal (near rain station)	8.0
10	Al-Tanoma	6.8
11	Al-Seba	7.6
12	Abi-Al-khasib	6.6
13	Hamdan	9.12
14	Safwan (center)	10.25
15	Safwan (farms)	10.95
16	Safwan (Salam mountain)	11.40
17	Al-Hartha (center)	7.5
18	Al-Deer (center)	9.4
19	Al-Kurna (center)	7.8
20	Al-Huwair (center)	7.2
21	Talha (near petroleum wells, west of Al-Kurna)	10.0
22	Ahmad Ebn-Ali (Talha center)	7.8
23	Al-Mdayna (center)	7.1
Mean ± standard deviation		8.87 ± 1.61
Range		6.6 - 12

Table 3. Exposure rates, effective doses, morbidity and mortality risks from lifetime (70 year) external exposure to indoor and outdoor ambient γ-radiation level in Al-Basrah city

Parameters	Value
Ambient γ-radiation level, outdoor (μR/hr)	8.87 (6.6 – 12)
Absorbed dose rate in air (μrad/hr)	7.71
Absorbed dose rate in air (μGy/hr)	0.0771
Effective dose equivalent (mSv/y)	0.472
Lifetime morbidity health risk (extra cancer case per no. of exposed individuals)	1 per 377
Lifetime mortality health risk ((extra fatality case per no. of exposed individuals))	1 per 503

Table 4. Ranking of exposed groups in Al-Basrah population on the basis of the radiation dose administered (mSv/y) (age-dependent radiation dose)

Rank	Group	Radiation dose (mSv/y)
1	Infants (1<age(y)<2)	0.628
2	Children (2<age(y)<18)	0.540
3	Adults (age(y)>18)	0.472

Table 5. Lifetime (70 years) cancer mortality and morbidity risks to various body organs and tissues as a result of external exposure to indoor and outdoor gamma radiation

No.	Body organ or tissue	Mortality risk	Morbidity risk
1	Bladder	99 per million	198 per million
2	Bone surface	16 per million	33 per million
3	Breast	66 per million	132 per million
4	Colon	280 per million	495 per million
5	Leukemia (Bone marrow)	165 per million	165 per million
6	Liver	49 per million	66 per million
7	Lung and Bronchus	280 per million	297 per million
8	Esophagus	99 per million	99 per million
9	Ovary	33 per million	33 per million
10	Skin	6 per million	3304 per million
11	Stomach	363 per million	396 per million
12	Thyroid	26 per million	264 per million
13	Remainder	165 per million	–

5. Conclusions

(1) Al-Basrah City is situated in an area of low background radiation since the ambient γ-radiation level is found to be <10 μR/hr. The environmental γ-radiation background level in Al-Basrah City is classified as "unhealthy" since the mean γ-radiation exposure rate inferred from measurement (8.87 μR/hr) is found to be between 33 and 66% of the EPA's external gamma radiation criterion of 20 μR/hr for habitable structures [20,21].

(2) The effective dose equivalent is found to be less than the recommended dose limit to the public (1 mSv/yr) [22]. However, the results indicate that population exposure to natural background radiation causing considerable carcinogenic risks and genetic damage to a large number of people.

(3) Population exposure to natural background radiation is found to be causing considerable carcinogenic risks and genetic damage to a large number of people. The lifetime fatal cancer risk to a person receives 0.472 mSv/y is 0.19% (about 2 chances in a thousand exposed individuals, or there is one additional death in a group of 503 people if they would all receive 0. 472 mSv/y instantaneously).

(4) The chronic excess cancer risk estimates attributed to external exposure to natural background γ-radiation level is found to be exceed the EPA's 1×10^{-5} risk level of concern [21] for all receptors evaluated.

(5) The various body organs and tissues differ in their sensitivity to the ionizing radiation emitted from natural sources.

(6) Possible long-term bioeffects related to exposure of Al-Basrah population to natural background radiation include increased incidence of hereditary genetic abnormalities in humans at a rate of 0.03% due to irradiation of gonads.

(7) Children and infants are at greatest risk than adults ($Risk_{infant}$>$Risk_{child}$>$Risk_{adult}$) (Table 4) due to lower body weight.

(8) The appearance of cases such as cancer, inability to produce offspring, premature death, susceptibility to disease, and abnormal offspring among residents of Al-Basrah City is an evidence of the harmful consequences and biologically damaging effects associated with chronic doses of natural background ionizing radiation and public exposure to other carcinogens.

6. Recommendation

(1) The radioactivity of local and imported building materials needs to be monitored in Iraq to prevent dwellings from becoming a major source of radiation hazard.

(2) National radiation protection guides or criteria system for radioactive materials content in local and imported building materials are need to be established in Iraq in order to protect the public health from harmful consequences associated with exposure to natural background radiation and to maintain the radiological exposure of the public at the lowest practicable value (as low as reasonably achievable).

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