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Determination of Some Atomic Parameters for Aktaş, Çıldır Lake, and Kura River Water with the Help of WinXCom

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Abstract
In this study, elemental analyses of water samples taken from Aktaş, Çıldır Lake, and Kura River basins in Ardahan province were carried out using Inductively Coupled Plasma Mass Spectrometry. The mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities were determined with the help of WinXCom for the main gamma-ray energies released when Ra-226, which is an important source of natural radiation, decays into Rn-222, Bi-214, and Po-214. As a result of the study, it was determined that Çıldır Lake would have more γ-ray interaction than Aktaş Lake and Kura River for the γ-ray energies taken into account. For γ-ray interaction degrees, the order can be made: Çıldır Lake > Kura River > Aktaş Lake.

1. Introduction

Information on the interaction of electromagnetic radiation with matter and energy loss is the basis for detecting radiation, determining protection principles, studying its biological effects, and using nuclear techniques in a wide variety of fields. The main agents in the interaction of electromagnetic radiation with matter are atomic electrons [1]. The interaction of electromagnetic radiation with matter reveals two main events, absorption and scattering. As a result of these events, atomic and molecular information about the matter can only be obtained by determining atomic parameters. Determination of atomic parameters: It is also very important in radiation applications such as space physics, astronomy, nuclear physics, nuclear weapon construction, solid state physics, cosmic ray studies, geology, plasma physics, satellite construction, determination of material thickness, dosimetry, radiology, and radiotherapy [2].

In many studies, atomic parameters at different energies for different substances are determined theoretically or experimentally. In our literature review, it has been seen that the subject has been popular in recent years, and sample studies are given. Akhdar et al. [3] investigated the mass attenuation coefficients, effective atomic numbers, and electron densities of the polyethylene glycol material for the energy range of 8.67-23.19 keV. The obtained results were compared with the XCom and Monte Carlo results. A good agreement was found between the measured experimental results and the theoretical values, and there was a 5% deviation in the XCom values. Tech et al. [4] calculated the mass attenuation coefficients, atomic and electronic cross sections, and effective atomic numbers of cambisol soils in Serra Dourada State Park in Brazil using XCom for 1-100 keV energy. In addition, oxide analysis in combisol soils was performed with EDXRF (Energy Dispersive X-ray Florescence) and WDXRF (Wavelength Dispersive X-ray Florescence). It was observed that the radiation

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interaction parameters depend on the chemical composition of the material. Seenappa et al. [5] calculated effective atomic numbers, electron densities, and CT (Computerized Tomography) numbers of newborn and adult tissue of organs such as the lungs, hearts, kidneys, and brain. Moreover, for the energy range of 1 keV-100 keV, the effective atomic numbers were calculated with the WinXCom program by calculating molecular, atomic, and electronic cross-sections. It was determined that atomic number, CT number, and electron density were different in newborn tissue and adult tissue, and other calculated atomic parameters were similar. It has been stated that these results will be useful in radiotherapy and radiology [5].

Akça [6] measured the γ-ray linear attenuation coefficients and transmission factors for Erzurum Ispir dry bean and Ankara Kızılcahamam dry bean. It has been observed that Ankara Kızılcahamam dry beans absorb more γ-ray than Erzurum Ispir dry beans. Saim et al. [7] examined the total mass attenuation coefficient of trichloride gadolinium using Geant4 compared with WinXCom theoretical data for 1–10 MeV energies. The theoretical results have been used to calculate the total cross-section, atomic, and electronic cross-sections. Akça and Erzeneoğlu [8] measured important atomic parameters for compounds of biomedically important elements at 59.54 keV gamma-ray energy. Böke [9] calculated the photon interaction cross sections of human cortical bone tissue at smaller angles.

As a result of the literature search, no studies on radiation and interaction with radiation related to Aktaş, Çıldır Lakes, and Kura River were found. When determining the atomic parameters, the mixing rule is used if the substance is complex. According to the mixing rule, the mass percent of the elements in the substance must be known, and these must be taken into account in the atomic parameters. releases.

2. Material and Method

2.1. Theoretical Basis

The overall total mass attenuation coefficient for the multi-element compound is the sum of the mass attenuation coefficients of each element according to the mixing rule.

$$\frac{\mu}{\rho} = \sum_i \omega_i \left(\frac{\mu}{\rho}\right)_i \tag{1}$$

ω_i term in Equation (1) weight fraction of the element, $(\mu/\rho)_i$ (cm^2/g) is the mass attenuation coefficient of the element. Also, here μ (cm^{-1}) is the linear attenuation coefficient and ρ (g/cm^3) is the density of the sample. For the material obtained from the mass attenuation coefficient mixing rule, the total photon interaction cross section (barn/atom) is expressed by the following equation.

$$\sigma_a = \frac{\mu/\rho}{N_A \sum_i w_i/A_i} \tag{2}$$

The mass attenuation coefficient μ/ρ in the formula, A_i, atomic weight of the element, and N_A is Avogadro's constant [10]. The effective atomic number of any compound using the mixing rule;

$$Z_{eff} = \frac{Z_1(\log\sigma_2 - \log_\sigma) + Z_2(\log_\sigma - \log_{\sigma_1})}{\log_{\sigma_2} - \log_{\sigma_1}} \tag{3}$$

It is calculated using the equation. Here, σ_1 and σ_2 are the basic sections in between, and Z_1 and Z_2 are the atomic numbers of the elements in which the atomic section of the material is found [11].

The electron density (electron/g);

$$N_e = N_A \frac{nZ_{eff}}{\sum_i n_i A_i} \tag{4}$$

is obtained by the equation. In the formula, n is the number of atoms in the mixture, and Z_{eff} is the effective atomic number [12].

2.2. Collection and Preparation of Water Samples

The theoretical calculations of the study started with taking water samples from Aktaş, Çıldır Lakes, and Kura River. To ensure the accuracy expected from water analysis, act within some principles while taking water samples, packaging them, and transporting them to the laboratory environment [13]. Water samples were collected considering these principles. Water samples were collected by immersing the sterilized bottle in water at least 25-30 cm downwards. The collected samples were filtered through a medical sterile cloth and cleaned of small residues in the water. All of these samples were collected in sterile and individually bagged conical bottom 15 ml falcon tubes. The lids of the falcon tubes were tightly closed and numbered with numbers according to the order of sampling.

The water samples taken from Aktaş Lake were taken from 10 different points, covering the entire water environment on the Turkish side of the lake, with a distance of 10 m in some places and 100-150 m in others. Çıldır Lake water samples were taken from 10 different points, starting from the opposite shore of Gölebakan Village of Çıldır District, at a distance of 10 m or 50 m, and at a distance of 100-150 m in some coastal areas. Water samples from the Kura River were taken from 3 different regions. Kura River water samples were taken from 3 different points from the entrance of the Kura River to Ardahan, from 4 different points from the city center of Ardahan, and 3 different points from the exit part of the river from the center of Ardahan. Water samples were taken from 10 different points for each of Aktaş, Çıldır Lake, and Kura River water, a total of 30 samples were obtained and numbered. While collecting all water samples, attention was paid to ensuring that the weather was not rainy and the lakes and rivers were not frozen to carry out the operations properly and to obtain healthy results. All water samples were taken on the same day in early October 2022. An earthquake with a magnitude of approximately 5 occurred in Ardahan province in September of the same year. Çıldır Lake is 1959 meters above sea level, and Aktaş Lake is 1798 meters above sea level. While the bottom altitude of the Kura River above the sea is 1800 m when entering the Ardahan plain, it drops to 1300 m when leaving the Turkish territory. Metsamor nuclear power plant is 197 km away from Çıldır Lake, 219 km away from Kura River, and 241 km away from Aktaş Lake.

2.3. Elemental Analysis with Inductively Coupled Plasma Mass Spectrometry

In the study, elemental analyses of lake and river waters were made with the ICP-MS (Inductively Coupled Plasma-Mass Spectrometer) device, with the support of the scientific research project titled "Determination of Atomic Parameters of Aktaş, Çıldır Lake and Kura River Water with the Help of WinXCom" and with the support of the "2022-2 ÖNP-Sağl-005" service to DAYTAM. “Inductively Coupled Plasma-Mass Spectrometer (ICP-MS-Agilent 7800 series, Agilent Technologies, Japan)” was used to determine the concentrations of the elements in the solution. In the process of preparing the water samples for the device, the water samples were first filtered with a syringe filter. Ultrapure water was used as a blank solution. Samples and blank samples were analyzed by giving them to the device. Each reading is the average of 3 parallel readings in itself. 0, 250, 500, 750, and 1000 ppb for Si; for Hg, 0, 2.5, 5, 7.5, and 10 ppb, and other studied elements, the reference range is 0, 10, 25, 50, 100, 250, and 500 ppb. While preparing the standards, for the 10 ppb standard solutions; separately from the 10 ppm stock standard solutions 30 µl, and 7.5 µl of Hg solution were taken with a micropipette and transferred to a 50 ml falcon tube, and the volume of the solution was completed to 30 ml with 2% HNO_3 solution using a micropipette.

2.4. WinXCom

The WinXCom program is used to theoretically calculate the mass attenuation coefficients, which are atomic parameters. WinXCom is a mixture rule-based program that is calculated considering the element's mass attenuation coefficients. According to this rule, the elements in the material are examined one by one, and the calculation is made by accepting them as independent from each other. However, this rule neglects the changes in the atomic wave function resulting from changes in the molecular and chemical environment of the atom [14]. [15] developed the XCom program to calculate each element's total mass attenuation coefficients, or photon-interacting cross sections. With the help of this program, calculations of elements and mixtures with large photon energies ranging from 1 keV to 100 GeV can be made. WinXCom: It is the version of XCom transferred to Windows in 2001 by [16]. The program allows total cross-section, attenuation coefficients, and particle cross-section calculations for various interaction processes (atomic photoelectric effect, incoherent, coherent scattering) [16]. This program can theoretically calculate the mass attenuation coefficients of an element, compound, or mixture. The WinXCom program was very useful and was developed for radiological physics and dosimetry [17]. The energy values to be calculated first while using the program (0.053, 0.186, 0.242, 0.295, 0.352, 0.609, 0.665, 0.768, 0.786, 0.806, 0.934, 1.120, 1.155, 1.238, 1.281, 1.378, 1.401, 1.408, 1.509, 1.661, 1.730), 1.764, 1.847, 2.119, 2.204, and 2.448 MeV) were entered into the program manually. Since WinXCom calculates using the mixing rule (according to equation (1)), the elemental contents analyzed using ICP-MS and mass percentages of the water samples are entered into the system one by one, and the water samples are introduced to the program. Then, the sum (cm^2/g) values against the energy entered from the program, the mass attenuation coefficient, were obtained. This process was repeated for all samples and mass attenuation coefficients were obtained with the help of the WinXCom program. Other atomic parameters (Total Photon Interaction Cross Section, Effective Atomic Number, and Electron Density) were calculated with the help of formulas ((2), (3), and (4) equations) using the mass attenuation coefficient values calculated with WinXCom.

3. Results and Discussion

In this study, the extent to which Ra-226, which is known to be an important source of ionizing radiation, interacts with γ-rays in the radioactive decay chain was determined with the help of atomic parameters. In the study, the energies considered are the γ-energies in the products formed in the decay chain of Ra-226, which is seen as the most important cause of natural radiation. These γ-energies are the main γ-ray energy lines released as Ra-226 decays to Rn-222, Bi-214, and Po-214 (186.211 for Rn-222, 53.2275, 241.997, 295.224, 351.932, 785.96 for Bi-214, 609.312, 665.453, 768.356, 806.174, 934.061, 1120.287, 1155.19, 1238.111, 1280.96, 1377.669, 1401.50, 1407.98, 1509.228, 1661.28, 1729.595, 1764.494, 1847.420, 2118.55, 2204.21 and 2447.86 keV for Po-214) [18]. The reason for choosing Ra-226 in our study is the emergence of radon gas, which is known to be an important source of natural radiation and is the second most important cause of lung cancer after smoking, as a result of these radioactive decays. It is known that as a result of these radioactive decays, not only gamma rays ($^{0}_{0}\gamma$)but also alpha ($^{4}_{2}\alpha$) and beta particles ($^{0}_{-1}\beta$) which is in the ionizing radiation group. However, in our study, γ-rays were preferred because they are the most energetic and penetrating [19].

Today, the existence of Metsamor, which has all kinds of features that should not be in the standards related to nuclear power plants, poses a serious threat to Azerbaijan, Iran, and the whole region, especially Turkey, which is 16 kilometers away from the power plant [20]. Therefore, it is very important to study the radiation effect in Ardahan and its surroundings, which are close to Iğdır. The interaction of ionizing radiation with river and lake waters poses a threat to aquatic creatures, those who consume these creatures, and those who benefit from these waters at high interactions. The large interaction with radiation suggests that the dose taken by living things may also be large. It is very important to know the radiation that can cause fatal diseases such as cancer and the ways to protect yourself. In this study, the degree of interaction was determined by making calculations of the radiation interaction, especially in natural radiation energies. Since it is known that the naturally occurring radiation effect is constantly present, contributions from the environment will increase this amount.

Elemental content of Aktaş and Çıldır Lakes, Kura River waters obtained by ICP-MS (Li, Be, B, Na, Mg, Al, Si, P, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Sr, Zr, Mo, Ru, Rh, Pd, Ag, Cd, In, Sn, Sb, Te, Ba, La, Ce, Ta, W, Re, Os, Ir, Pt, Au, Hg, Tl, Pb, Bi) and their concentration (ppb) are given in Table 1. The mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities of Aktaş, Çıldır Lake, and Kura River water determined with the help of WinXCom are given in Table 2-4. The change of the mean values of the mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities of Aktaş, Çıldır Lake, and Kura River waters determined with the help of WinXCom with energy is given in Figure 1-12. Graphics are drawn using Origin Pro 8.

When Tables 2, 3, 4, and Figures 1, 5, and 9 are examined**,** it is seen that the mass attenuation coefficients of Aktaş and Çıldır Lakes, and Kura River water decrease as the energy increases. That is, as the energy increased, the mass attenuation coefficient decreased; in other words, the γ-ray interaction decreased. Increasing the γ-ray or γ-radiation energy caused the already highly penetrating beam to become more penetrating. If the beam is very fast when it hits the material, it will be more penetrating, pass faster, spend less time on the material, and create less interaction. Since this causes the duration of the interaction to be shorter, the mass attenuation coefficient value will be smaller. While the mass attenuation coefficient values of Çıldır Lake and Kura River are very close to each other, these values are larger than the Aktaş Lake mass attenuation coefficient values. Accordingly, the γ-ray interaction in Lake Çıldır and Kura River will be higher than in Lake Aktaş. When Tables 2, 3, 4, and Figures 2, 6, and 10 are examined, it is seen that the total photon interaction cross-section values of Aktaş, Çıldır Lake, and Kura River waters decrease with the increase in energy. When sorting is done for the total photon interaction cross-section values, it becomes Çıldır Lake> Kura River> Aktaş Lake. According to this result, Çıldır Lake will interact with γ-rays more than Aktaş Lake and Kura River. It can be said that Çıldır Lake is more dangerous, especially for the creatures living in it, due to its high γ-ray absorption potential. However, if its usability as a shielding material is evaluated, Çıldır Lake water is better. When Table 2 and Figure 3 are examined, the effective atomic number value for Aktaş Lake increased with energy but decreased at 1.847 MeV energy. The effective atomic number of Aktaş Lake is in the range of $50.299 \leq Z_{eff} \leq 52.438$. When we look at the periodic table, it is thought that the effective atomic number values of Aktaş Lake water are close to the atomic numbers of Sn-50, Sb-51, and Te-52 elements, so it may show similar properties with the aforementioned elements. Aktaş Lake may exhibit weak and semi-metallic behavior accordingly. While $Z_{eff} \leq 10$

indicates organic substances, a large Z_{eff} is generally an indicator of inorganic compounds and metals [21]. When this situation is evaluated, the effective atomic number values of Aktaş Lake show inorganic or metal properties because $Z_{eff} \geq 10$.

When Table 3 and Figure 7 are examined, the effective atomic number for Çıldır Lake increases at an energy of 0.186 MeV and reaches its maximum. It then decreases at 0.352 MeV and becomes almost constant up to 2.448 MeV. The effective atomic number of Çıldır Lake is generally in the range of $68.930 \leq Z_{eff} \leq 69.971$. When we look at the periodic table, since these values are close to the atomic numbers of the elements Er-68 and Tm-69, it can be thought that they may show similar properties to the aforementioned elements. In this case, it can act as Lanthanide or Rare earth elements. When the effective atomic number values of Çıldır Lake are taken into account, $Z_{eff} \geq 10$ shows inorganic or metal properties.

When Table 4 and Figure 11 are examined, while the effective atomic number for the Kura River is at a minimum value of 0.053 MeV, it has a maximum value of 2.448 MeV. The effective atomic number first increased with energy increase, decreased after 0.609 MeV, remained almost constant up to 2.204 MeV, then increased again at 2.448 MeV. The effective atomic number of the Kura River is generally in the range of $63.228 \leq Z_{eff} \leq 64{,}439$. When we look at the periodic table, since these values are close to the atomic numbers of Eu-63 and Gd-64 elements, it is thought that they may show similar properties to the mentioned elements. In this case, it can act as Lanthanide or Rare earth elements. When the effective atomic number values of the Kura River are taken into account, $Z_{eff} \geq 10$ shows inorganic or metal properties.

When Figures 3, 7, and 11 are examined, it is seen that the effective atomic number changes depending on the energy. The partial effects of the Photoelectric Effect, Coherent Scattering, and Pair Production cause this change. Apart from this, the Photoelectric Effect is more dominant at energies below 100 KeV. In addition, it is seen that the effective atomic number and energy change graphs of river and lake waters are characteristic. It is thought that this situation is caused by the different interaction cross-sections and elemental contents. Aktaş and Çıldır Lakes, the effective atomic number order for the Kura River is Lake Çıldır>Kura River>Aktaş Lake. According to this order, Aktaş Lake has the smallest effective atomic number value. Çıldır Lake interacts more with γ-rays and exhibits more absorbing properties for γ-rays. When Tables 2, 3, 4 and Figures 4, 8, and 12 are examined, the changes in electron densities with energy are similar to the change in effective atomic number for Aktaş, Çıldır Lake, and Kura River. When we sort by considering the electron densities, it becomes Çıldır Lake>Kura River>Aktaş Lake. According to this order, as the electron density of Çıldır Lake is higher, its interaction with γ-rays will be greater. The high electron density indicates that the γ-ray will encounter more electrons in the medium it enters and will create a greater interaction. The most basic atomic parameters for calculating the average radiation absorption in a medium or material are the effective atomic number and electron density. It is seen that the electron density and energy exchange graphs of river and lake waters are characteristic, as are the effective atomic number and energy exchange graphs. In this case, the interaction cross-sections and elemental contents are thought to be different. Aktaş and Çıldır Lakes, the distance of Kura River to Metsamor Nuclear Power Plant is Çıldır Lake<Kura River<Aktaş Lake. This means that the degree of interaction of Çıldır Lake with radiation is quite large.

Table 1. Elemental analysis of Aktaş, Çıldır Lake, and Kura River water .

	Li	Be	B	Na	Mg	Al	Si	P	K	Ca
Sample					**Concentration (ppb)**					
Aktaş Lake$_{Avg}$	24.45660	0.03460	857.19920	333258.39360	39826.01510	1157.78740	7291.50480	257.12700	26072.42110	3625.21540
Çıldır Lake$_{Avg}$	1.79200	0.00125	46.42370	6384.07420	4726.32320	27.12820	2968.46640	123.71470	3165.95220	1889.32080
Kura River$_{Avg}$	8.05170	<0.001	133.37030	13333.26130	11414.49890	17.43400	17536.90130	297.93380	5807.28310	5067.64390
	Ti	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**
Sample					**Concentration (ppb)**					
Aktaş Lake$_{Avg}$	53.62790	16.25290	1.92590	32.40900	606.61530	3.95160	9.50310	13.80410	87.63870	56.22140
Çıldır Lake$_{Avg}$	0.97430	2.63930	0.03940	0.62990	15.54210	0.03280	1.65920	0.93830	0.52870	2.12980
Kura River$_{Avg}$	0.72310	4.77380	0.17960	2.61110	25.01170	0.15130	1.93500	1.42840	1.06310	6.75640
	Se	**Sr**	**Zr**	**Mo**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**
Sample					**Concentration (ppb)**					
Aktaş Lake$_{Avg}$	0.32980	307.26640	3.17820	19.58660	0.00500	0.01400	0.02840	0.90460	0.05090	<0.001
Çıldır Lake$_{Avg}$	0.05870	66.32910	0.06590	0.72990	<0.000	0.03667	0.00744	0.00550	0.00170	<0.001
Kura River$_{Avg}$	0.09350	138.86900	0.08350	1.06720	<0.001	<0.001	0.00590	0.00100	0.00260	<0.001
	Sn	**Sb**	**Te**	**Ba**	**La**	**Ce**	**Ta**	**W**	**Re**	**Os**
Sample					**Concentration (ppb)**					
Aktaş Lake$_{Avg}$	0.68430	0.49590	0.02970	94.13060	0.66020	1.30100	0.04210	0.46470	0.01700	<0.001
Çıldır Lake$_{Avg}$	0.04860	0.07570	0.00356	21.92220	0.03240	0.04650	0.02100	0.54200	0.00500	<0.001
Kura River$_{Avg}$	0.10090	0.04830	0.00414	12.53580	0.01850	0.02630	0.00810	<0.001	0.00120	<0.001
	Ir	**Pt**	**Au**	**Hg**	**Tl**	Pb	Bi	-	-	-
Sample					**Concentration (ppb)**					
Aktaş Lake$_{Avg}$	0.08000	<0.001	0.04060	0.00540	0.01380	0.98150	<0.001	-	-	-
Çıldır Lake$_{Avg}$	0.18933	<0.001	0.10450	0.00267	0.01010	0.01920	0.04100	-	-	-
Kura River$_{Avg}$	<0.001	<0.001	<0.001	<0.001	0.00178	0.02760	<0.001	-	-	-

Table 2. Mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities for Aktaş Lake average value.

Sample	Daughter	Energy (MeV)	μ/ρ (cm^2/g)	σ_a ($x10^{-21}$) (cm^2/atom)	Z_{eff}	N_e ($x10^{24}$) (elektrons/kg)
Aktaş Lake$_{Avg}$	Rn-222	0.186	0.12506	12.22546	52.04028	3.15400
	Bi-214	0.053	0.31055	30.33736	50.29882	3.04800
		0.242	0.11291	11.03794	52.05297	3.15500
		0.295	0.10448	10.21385	52.11167	3.15800
		0.352	0.09742	9.52450	52.22950	3.16500
		0.786	0.06881	6.72747	52.28910	3.16900
	Po-214	0.609	0.07728	7.55481	52.36640	3.17400
		0.665	0.07428	7.26207	52.33417	3.17200
		0.768	0.06954	6.79863	52.28281	3.16900
		0.806	0.06800	6.64831	52.30423	3.17000
		0.934	0.06341	6.19903	52.43804	3.17800
		1.120	0.05794	5.66461	52.28843	3.16900
		1.155	0.05705	5.57778	52.29544	3.16900
		1.238	0.05509	5.38597	52.31114	3.17000
		1.281	0.05415	5.29347	52.30148	3.17000
		1.378	0.05217	5.09995	52.24508	3.16600
		1.401	0.05173	5.05691	52.23050	3.16500
		1.408	0.05159	5.04401	52.22626	3.16500
		1.509	0.04979	4.86793	52.18691	3.16300
		1.661	0.04740	4.63394	52.20970	3.16400
		1.730	0.04642	4.53809	52.22327	3.16500
		1.764	0.04596	4.49294	52.22585	3.16500
		1.847	0.04488	4.38801	52.21364	3.16400
		2.119	0.04182	4.08878	51.94764	3.14800
		2.204	0.04099	4.00762	51.86659	3.14300
		2.448	0.03888	3.80097	51.70584	3.13400

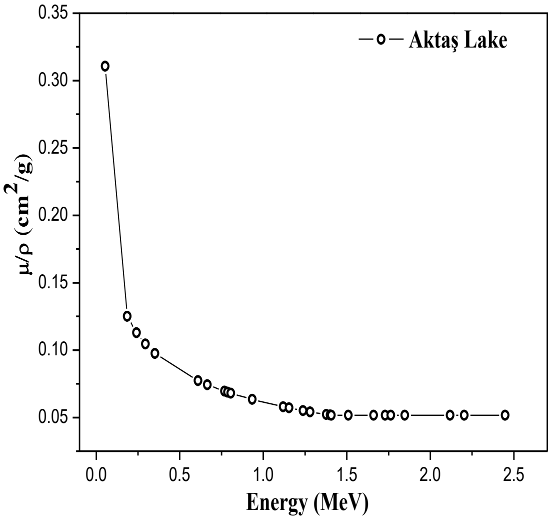

Figure 1. Variation of mass attenuation coefficients with energy for Aktaş Lake average value.

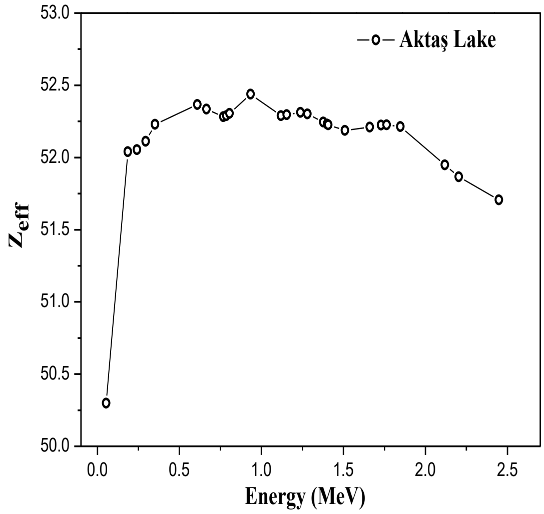

Figure 3. Variation of effective atomic numbers with energy for Aktaş Lake average value.

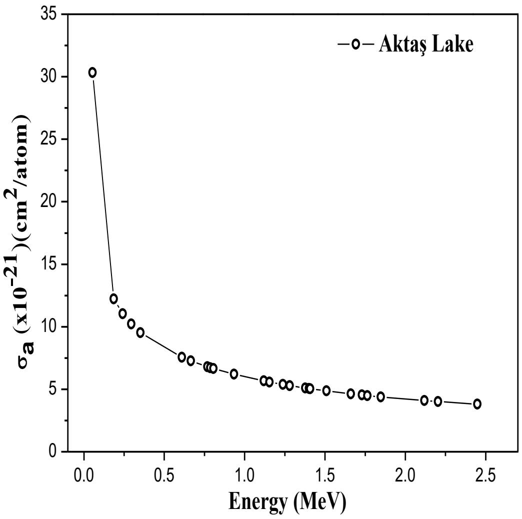

Figure 2. Variation of total photon interaction cross sections with energy for Aktaş Lake average value.

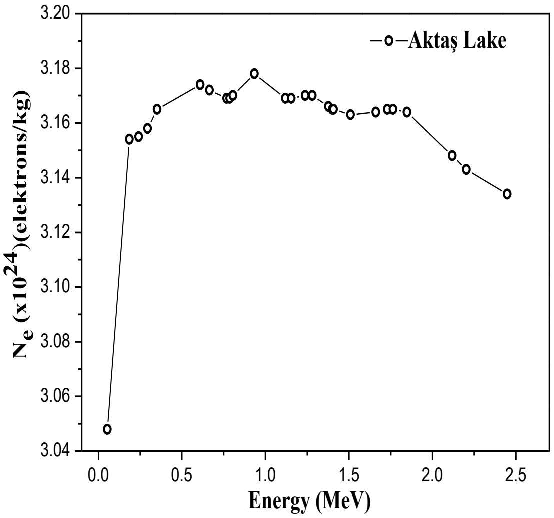

Figure 4. Variation of electron densities with energy for Aktaş Lake average value.

Table 3. Mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities for Çıldır Lake average value.

Sample	Daughter	Energy (MeV)	μ/ρ (cm^2/g)	σ_a ($x10^{-19}$) ($cm^2/atom$)	Z_{eff}	N_e ($x10^{25}$) (elektrons/kg)
Çıldır Lake$_{Avg}$	Rn-222	0.186	0.13073	3.03054	154.78946	16.65000
	Bi-214	0.053	0.45865	10.63216	68.92968	7.41300
		0.242	0.11648	2.70014	150.29052	16.16000
		0.295	0.10717	2.48438	153.50814	16.51000
		0.352	0.09961	2.30924	69.70509	7.49700
		0.786	0.06998	1.62231	69.77047	7.50400
	Po-214	0.609	0.07865	1.82335	69.87957	7.51600
		0.665	0.07558	1.75219	69.83466	7.51100
		0.768	0.07073	1.63961	69.76232	7.50300
		0.806	0.06915	1.60306	69.79060	7.50600
		0.934	0.06444	1.49394	69.97148	7.52500
		1.120	0.05890	1.36535	69.77079	7.50400
		1.155	0.05799	1.34435	69.77978	7.50500
		1.238	0.05599	1.29797	69.79949	7.50700
		1.281	0.05503	1.27565	69.78563	7.50500
		1.378	0.05302	1.22912	69.70785	7.49700
		1.401	0.05258	1.21879	69.68786	7.49500
		1.408	0.05244	1.21570	69.68204	7.49400
		1.509	0.05062	1.17351	69.62812	7.48800
		1.661	0.04821	1.11758	69.65893	7.49200
		1.730	0.04722	1.09473	69.67729	7.49400
		1.764	0.04676	1.08399	69.68071	7.49400
		1.847	0.04569	1.05907	69.66380	7.49200
		2.119	0.04264	0.98846	69.29943	7.45300
		2.204	0.04181	0.96934	69.18806	7.44100
		2.448	0.03972	0.92069	68.96592	7.41700

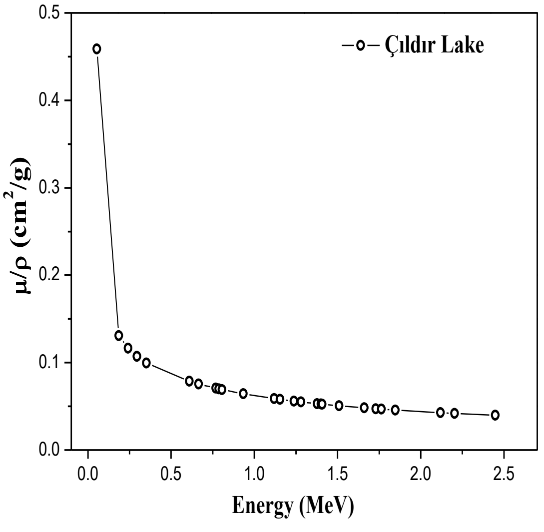

Figure 5. Variation of mass attenuation coefficients with energy for Çıldır Lake average value

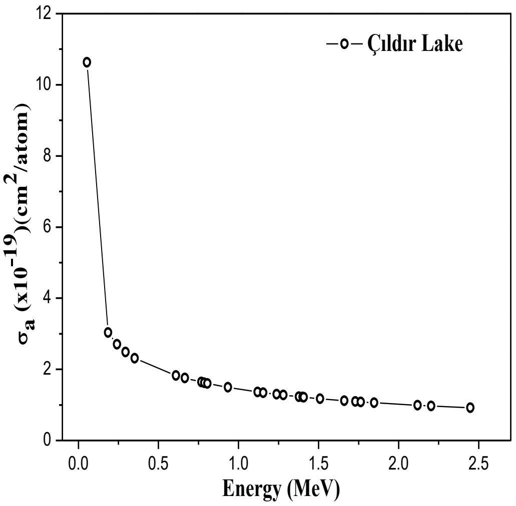

Figure 6. Energy variation of total photon interaction cross sections for Çıldır Lake average value

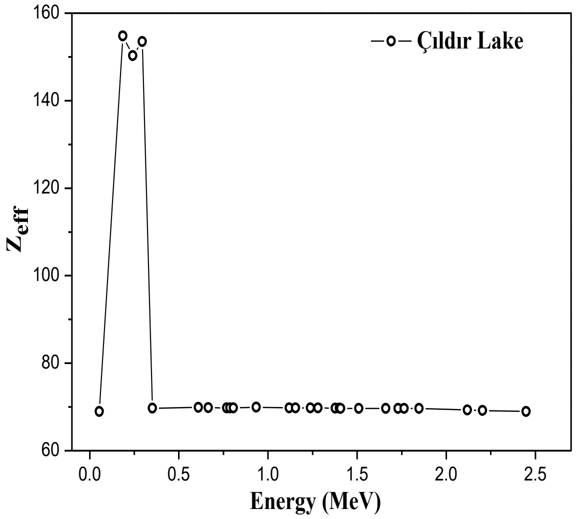

Figure 7. Variation of effective atomic numbers with energy for Çıldır Lake average value

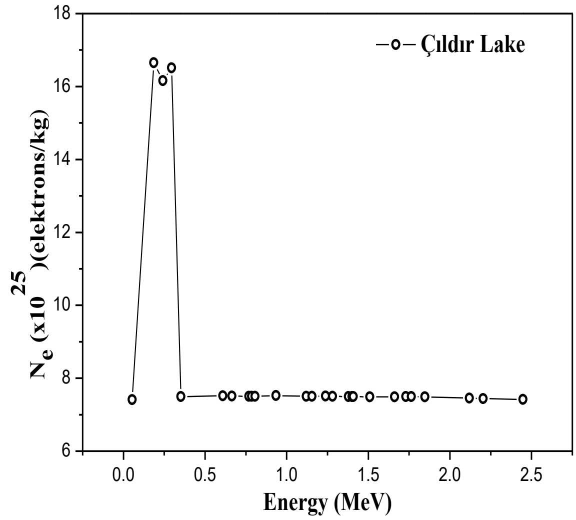

Figure 8. Variation of electron densities with energy for Çıldır Lake average value

Table 4. Mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers, and electron densities for Kura River average value

Sample	Daughter	Energy (MeV)	μ/ρ (cm^2/g)	$\sigma_a (x10^{-20})$ ($cm^2/atom$)	Z_{eff}	$N_e (x10^{25})$ (elektrons/kg)
Kura River$_{Avg}$	Rn-222	0.186	0.13074	11.03131	141.60246	5.57200
	Bi-214	0.053	0.43698	36.88448	63.22771	2.48800
		0.242	0.11677	9.85250	137.58028	5.41400
		0.295	0.10755	9.07470	140.50841	5.52900
		0.352	0.10003	8.43970	142.30428	5.60000
		0.786	0.07034	5.93493	64.25522	2.52800
	Po-214	0.609	0.07905	6.66935	64.35485	2.53200
		0.665	0.07597	6.40954	64.31386	2.53100
		0.768	0.07109	5.99820	64.24779	2.52800
		0.806	0.06951	5.86451	64.27360	2.52900
		0.934	0.06478	5.46533	64.43871	2.53600
		1.120	0.05921	4.99567	64.25526	2.52800
		1.155	0.05830	4.91883	64.26353	2.52900
		1.238	0.05629	4.74904	64.28168	2.52900
		1.281	0.05532	4.66737	64.26908	2.52900
		1.378	0.05330	4.49707	64.19814	2.52600
		1.401	0.05285	4.45928	64.17990	2.52500
		1.408	0.05272	4.44796	64.17460	2.52500
		1.509	0.05089	4.29355	64.12557	2.52300
		1.661	0.04846	4.08875	64.15437	2.52400
		1.730	0.04747	4.00510	64.17157	2.52500
		1.764	0.04700	3.96579	64.17495	2.52500
		1.847	0.04592	3.87464	64.16018	2.52500
		2.119	0.04286	3.61667	63.83018	2.51200
		2.204	0.04204	3.54675	63.72929	2.50800
		2.448	0.03992	3.36850	142.33755	5.60100

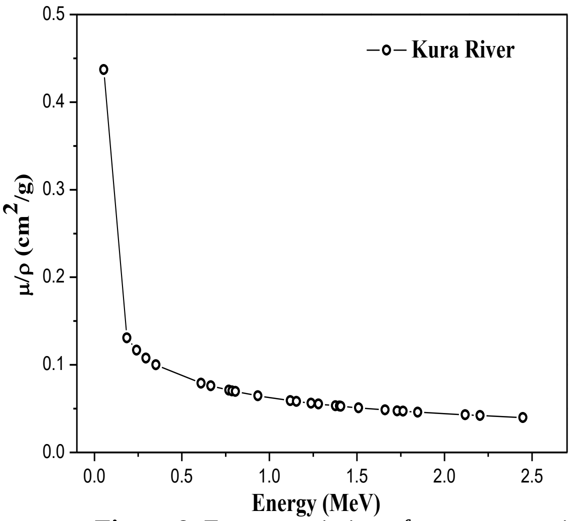

Figure 9. Energy variation of mass attenuation coefficients for Kura River average value

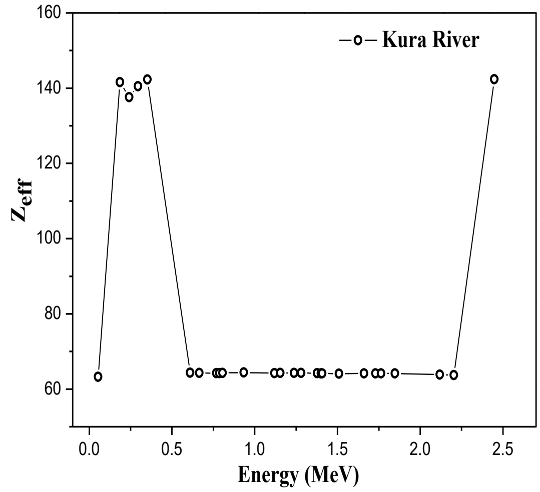

Figure 11. Energy variation of effective atomic numbers for Kura River average value

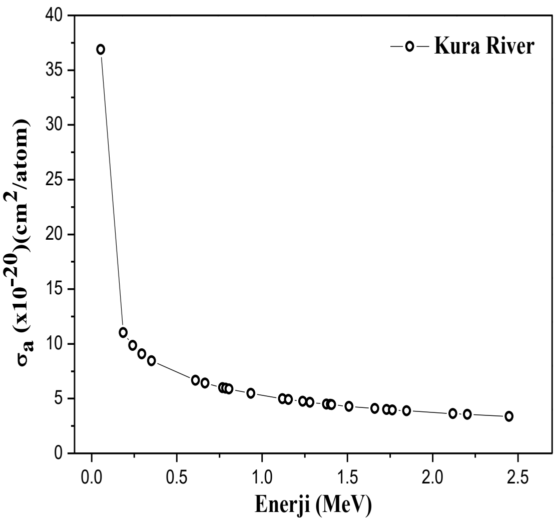

Figure 10. Energy variation of total photon interaction cross sections for Kura River average value

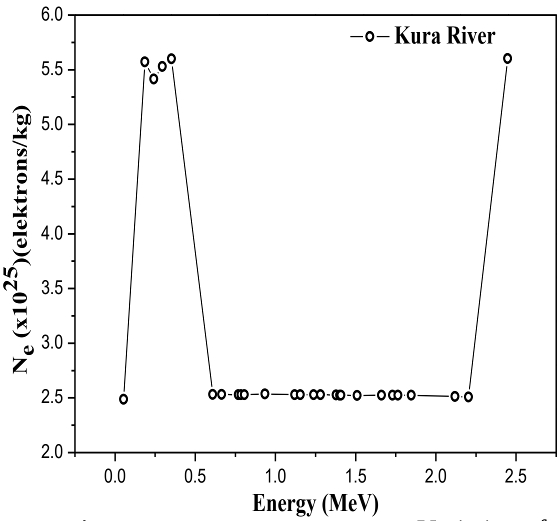

Figure 12. Variation of electron densities with energy for Kura River average value

4. Conclusion and Suggestions

As a result, when the atomic parameters for Aktaş, Çıldır Lake, and Kura River waters are examined, the interaction of γ-ray and the degree of interaction are Çıldır Lake>Kura River>Aktaş Lake. In other words, since Çıldır Lake interacts more with γ-rays than others, it tends to absorb the rays more. Aktaş Lake, on the other hand, has the smallest degree of interaction, meaning it interacts less with the γ-ray.
In the future, this work should be done experimentally or with different theoretical programs for different energies.

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Contributions of the authors

B. Akça: Writing, review, editing, investigation, supervision, project, original draft administration, conceptualization, methodology, **R. G. Ağaoğlu:** Review, editing, investigation, data curation, original draft, conceptualization, methodology.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study has complied with research and publication ethics.

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