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Environmental impact assessment of natural radioactivity and heavy metals in drinking water around Akkuyu Nuclear Power Plant in Mersin Province

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Abstract: The aim of this study was to determine natural radioactive and heavy element concentrations in Mersin drinking water samples before the commissioning of the Akkuyu nuclear power plant and to collect data for possible environmental contaminations in the future. Drinking water samples were taken from the provincial center, districts, and populated villages. The annual effective dose of natural radionuclides and cancer risks were calculated for each person living in the city. Hazard index and cancer risk were calculated, which were caused by heavy elements. Mean gross alpha and beta radioactivity concentrations in drinking water were 0.059 Bq/L and 0.120 Bq/L, respectively. The annual cumulative effective dose for people was 30.83 μSv. Average estimated excess cancer risk related to this exposure was 16.9×10^{-5}. Mean metal concentrations of Cr, Ni, Zn, Cu, Ba, and Cd in drinking water were 1.33, 4.65, 54.8, 11.1, 26.3, and 0.36 μg/L, respectively. Pb and As were lower than the detection limits. Mean calculated hazard index depending on heavy metal concentration was 6.8×10^{-1} for drinking water. Cancer risks of heavy metals decreased in the order of Cd $>$ Cr $>$ Ni for the region.

Key words: Mersin, drinking water, cancer risk, radioactivity, heavy metal, hazard index

1. Introduction

The environment is an essential element of human existence. Accumulation of some elements or compounds in the environment might cause very serious health problems for people. These health effects are mainly results of the biochemical interactions of heavy metals and radiologic interactions of energetic particles and photons with living cells. Therefore, it is important to determine background radiation levels and amounts of heavy metal accumulation in the environment to prevent possible health risks.

Water quality is an important parameter of environmental studies. The natural radionuclide and heavy element concentrations in drinking water are significant for human health. Radioactivity and heavy element rates should not exceed the permissible limits for drinking water. Otherwise, the probability of health risk will rise. For this reason, drinking waters should be examined radiologically and in terms of heavy elements and their concentrations should be determined.

Radionuclides are present in the form of dust or particles or molten minerals in drinking water. They are taken into the human body by digestion or inhalation. When they enter the body they cause internal irradiation. Natural waters contain both α (e.g., ^{238}U) and β (e.g., ^{40}K) emitters in widely varying concentrations, which are responsible for a generally small fraction of the total dose received from natural and artificial radioactivity.

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Alpha activity is mostly due to uranium isotopes (^{234}U, ^{235}U, and ^{238}U) and to ^{226}Ra. Beta activity is usually due to a large extent to ^{40}K and to short-lived daughters of ^{238}U, ^{234}Th, and ^{234m}Pa.[1]

Heavy metals reach water systems in natural and anthropogenic ways. Regardless of origin, many physicochemical and biochemical processes affect their distribution in the sediment–water system. Trace elements are essential for human life but they can be toxic depending on their concentration.[2–4] Lack of or elevated concentrations of elements and their tendency to bioaccumulate can have a negative impact on human health. Metals tend to bind with organic substances to form organometallic compounds with a high coefficient of lipid solubility and accumulation in sediment.[5,6]

The primary objective of the present study was to determine the natural radioactive and heavy element concentrations in city drinking water before the commissioning of the Akkuyu nuclear power plant and to follow up the potential level of environmental pollution that may occur after operation of the power plant. The second objective was to calculate the noncarcinogenic (acute health problems, allergic reactions, kidney and liver dysfunction, excessive fatigue, respiratory problems, etc.) and carcinogenic health risks emerge from the natural radioactivity and heavy metal accumulation in Mersin's drinking water. Therefore, all drinking water samples were taken to cover the whole city area as shown in Figure 1.

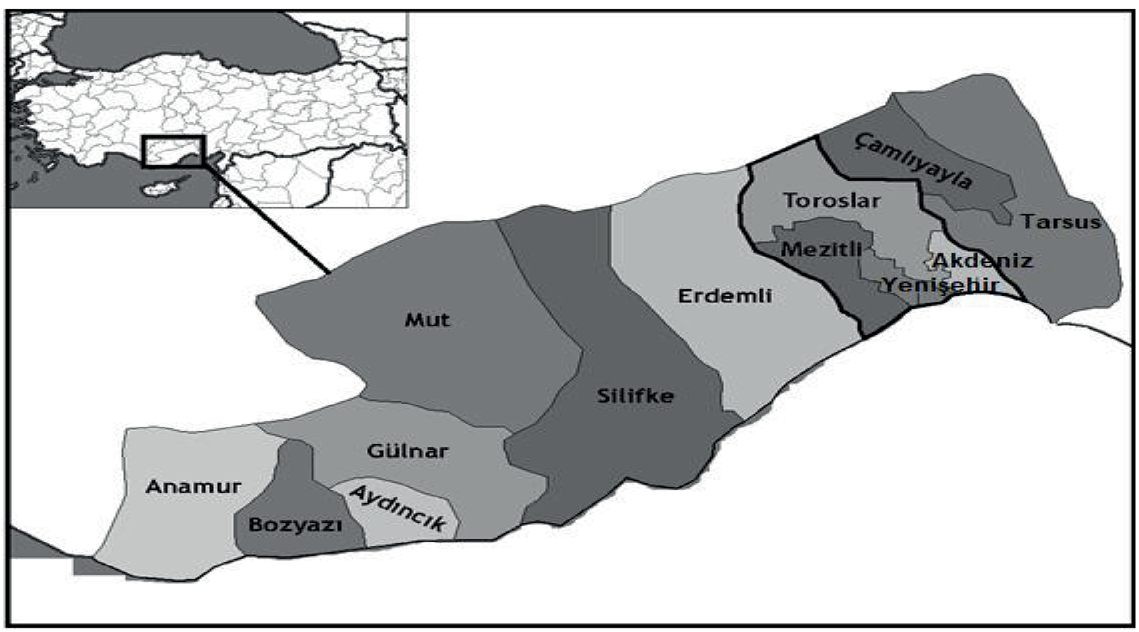

Figure 1. The research region of Mersin.

2. Results and discussion

2.1. Radioactivity and dose assessment in drinking waters

The source of radioactivity in water is natural radionuclides such as ^{238}U daughters, ^{232}Th daughters, and ^{40}K, which exist in dusts, particulates, and melted minerals. Water characterization, such as solubility, transport, and sedimentation, increases natural radioactivity concentration and heavy element rates in the water. In addition, dust and particles in water cause increase radioactivity and heavy elements when the water passes the surface of the ground. The gross alpha and gross beta radioactivity concentrations in drinking waters determined in this study are given in units of Bq/L in Table 1.

Table 1. Gross alpha and beta radioactivity concentrations in province water samples.

District	Location	Activity in water (Bq/L)	
		Gross α	Gross β
Anamur	Çamlıpınar	0.027 ± 0.008	0.060 ± 0.014
	Çataloluk	0.011 ± 0.006	0.066 ± 0.015
	Güngören	0.036 ± 0.008	0.151 ± 0.034
	Kaledran	0.039 ± 0.009	0.071 ± 0.029
	Lale	0.013 ± 0.007	0.036 ± 0.014
	Malaklar	0.019 ± 0.007	0.050 ± 0.013
Aydıncık	Center	0.075 ± 0.012	0.083 ± 0.016
Bozyazı	Dereköy	0.086 ± 0.014	0.023 ± 0.014
	Kömürlü	0.031 ± 0.008	0.055 ± 0.014
	Bozyazı	0.022 ± 0.007	0.016 ± 0.012
Çamlıyayla	Çamlıyayla	0.044 ± 0.009	0.158 ± 0.018
	Darıpınarı	0.076 ± 0.011	0.302 ± 0.023
	Kale	0.043 ± 0.009	0.257 ± 0.023
Erdemli	Center	0.051 ± 0.01	0.095 ± 0.029
	Kargıpınarı town	0.040 ± 0.009	0.094 ± 0.017
	Tömük town	0.039 ± 0.009	0.073 ± 0.033
Gülnar	Bardat	0.130 ± 0.014	0.100 ± 0.025
	Büyükeceli town	0.047 ± 0.009	0.082 ± 0.016
	Köseçobanı town	0.089 ± 0.012	0.129 ± 0.018
	Center	0.075 ± 0.012	0.038 ± 0.012
	Sipahili	0.057 ± 0.013	0.083 ± 0.017
	Zeynep	0.100 ± 0.013	0.126 ± 0.020
Mut	Burunköy	0.100 ± 0.013	0.390 ± 0.026
	Çömelek	0.043 ± 0.009	0.107 ± 0.024
	Diştaş	0.104 ± 0.013	0.231 ± 0.022
	Göksu town	0.085 ± 0.012	0.143 ± 0.017
	Hacıahmetli	0.025 ± 0.009	0.063 ± 0.016
	Kelceköy	0.075 ± 0.011	0.334 ± 0.024
Silifke	Kavak	0.025 ± 0.007	0.083 ± 0.016
	Keşlitürkmenli	0.034 ± 0.009	0.059 ± 0.013
	Narlıkuyu town	0.031 ± 0.008	0.093 ± 0.030
	Yeşilovacık town	0.029 ± 0.008	0.064 ± 0.014
Tarsus	Aladağlı	0.061 ± 0.01	0.064 ± 0.017
	Dedeler	0.303 ± 0.021	0.391 ± 0.030
	Karadiken	0.161 ± 0.015	0.120 ± 0.019
	Kisecik	0.032 ± 0.009	0.252 ± 0.022
	Yenice	0.031 ± 0.009	0.140 ± 0.011
City Center	Alanyalı	0.037 ± 0.009	0.081 ± 0.016
	Darısekisi	0.029 ± 0.008	0.052 ± 0.014
	Fatih town	0.025 ± 0.008	0.066 ± 0.016
	DSİ	0.028 ± 0.010	0.052 ± 0.015
	Karşıyaka	0.069 ± 0.011	0.090 ± 0.017

The basic levels of gross alpha radioactivity in drinking water in the province range between 0.011 ± 0.006 Bq/L and 0.161 ± 0.015 Bq/L. The minimum gross alpha activity was determined in Çamlıpınar village in Anamur and the maximum gross alpha activity was determined in Karadiken village in Tarsus. The ranges of gross beta radioactivity in drinking waters in the province are between 0.016 ± 0.012 Bq/L and 0.391 ± 0.030 Bq/L. The minimum gross beta activity was determined in Bozyazı district. The maximum gross beta activity was determined in Dedeler village in Tarsus. The average gross alpha and gross beta activities are 0.059 ± 0.051 Bq/L and 0.120 ± 0.095 Bq/L, respectively, for the region. The main reason for the variation in activities observed between different locations of the region is the change in the radiologic characteristics of the underground origin of water resources and pathways. Moreover, the relative distribution maps plotted for gross alpha and gross beta radioactivity in drinking water for the region are demonstrated together with the location of sampling stations in Figure 2.

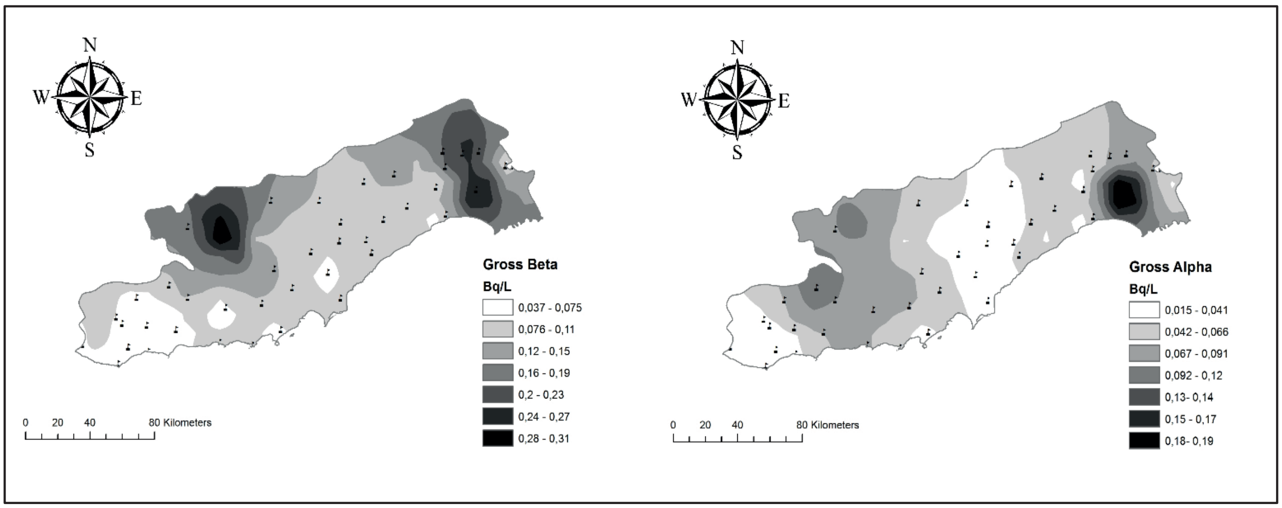

Figure 2. Relative distribution of water radioactivity in the region.

The health effects of ionizing background radiations in the research region were investigated by determining the biological effective radiation doses and the related cancer risks. Eq. (1) was used to calculate the effective dose (DR_W) due to drinking water radioactivity.

$$DR_W = A_W \times IR_W \times ID_F \times 2(forboth\alpha and\beta), \quad (1)$$

where DR_W is the dose equivalent effective (Sv/year). A_W is activity (Bq/L). IR_W is the intake of water for one person in a year. One person consumes an average of 2 L of water per day. ID_F is the ingestion effective dose equivalent factor for 3.58×10^{-7} Sv/Bq for alpha.[7] Annual effective dose results are given in Table 2 for all districts. The cumulative annual effective dose for people living in the region due to radioactivity in drinking water was determined as 30.83 μSv. Excess lifetime cancer risk value (ELCR) for 70 years of average life duration was calculated using Eq. (2).

$$ELRC = DR_W \times DL \times RF, \quad (2)$$

where DR_W is the annual effective dose equivalent (Sv/year). DL is the duration of life (70 years). RF is the risk factor (1/Sv). For risk assessment, the nominal probability coefficient of 7.3×10^{-2} (1/Sv) was recommended and adopted.[8,9] The calculated excess lifetime cancer risks rates from radioactivity materials in Mersin drinking water are also given in Table 2. The average estimated excess cancer risk value related to this exposure was calculated as 16.9×10^{-5}. As the activity increases, the risk of cancer will increase. The highest excess lifetime cancer risk was calculated as 33.7×10^{-5} for Tarsus district. Even the result of Tarsus district does not exceed the safety limits. The calculated annual biologic effective dose and the estimated excess cancer risk levels due to radiologic exposure in drinking water are also given for each district in Table 2.

Table 2. Health risk levels due to water radioactivity in the province.

District	Radioactivity in water	
	Annual effective dose (μSv)	Excess lifetime cancer risk
Anamur	12.6	6.9×10^{-5}
Aydıncık	39.20	21.5×10^{-5}
Bozyazı	24.22	13.3×10^{-5}
City Center	19.65	10.8×10^{-5}
Çamlıyayla	28.40	15.6×10^{-5}
Erdemli	22.65	12.4×10^{-5}
Gülnar	43.38	23.8×10^{-5}
Mut	37.64	20.6×10^{-5}
Silifke	15.55	8.5×10^{-5}
Tarsus	61.47	33.7×10^{-5}
Average	30.83	16.9×10^{-5}

2.2. Heavy metals concentrations and cancer risk assessment in drinking waters

Water samples collected from the province were also analyzed to determine the heavy metal accumulation in the research region. The basic levels of all heavy metal concentrations in drinking water in the province are given in Table 3. Pb and As in all water samples were lower than detection limits (LDL). Cu, Ni, and Ba were detected in all drinking waters. Zn was measured in all drinking waters except in Zeyne village. The highest concentrations of Cu, Ni, Zn, and Ba were determined in Laleli village of Anamur, Dedeler village of Tarsus, Darıpınar village of Çamlıyayla, and Karadiken village of Tarsus, respectively. However, concentrations of Cr, Cu, Ni, and Zn are quite below the limits of the WHO and EPA. Cd was detected in just 19 water samples. The highest concentration of Cd in the drinking water was found in Aladağlı village of Tarsus district. Cd concentration was slightly above the WHO limits, but below the EPA limits. The highest Cr value was detected in Burunköy drinking water in Mut district. Mean metal concentrations of Cr, Ni, Zn, Cu, Ba, and Cd in drinking water were 1.33, 4.65, 54.8, 11.1, 26.3, and 0.36 μg/L, respectively. The relative distribution maps are plotted for heavy metal concentration in drinking water in Figure 3.

The level of heavy metal concentration in water is the result of physical and chemical interactions of water sources and their pathways with geologic units around them. This is the main reason for variation in heavy metal concentration within the region.

In terms of health risk due to heavy metal accumulation in the region, noncarcinogenic and carcinogenic health effects were investigated. The potential exposure pathways for heavy metals in drinking water are calculated by Eq. (3).[10−12]

Table 3. Heavy metal concentrations in province drinking water samples.

District	Station	Concentration (μg/L)					
		Cd	Cr	Cu	Ni	Zn	Ba
Anamur	Çamlıpınar	LDL	LDL	1.66 ± 0.22	2.47 ± 0.20	18.57 ± 0.28	6.37 ± 0.10
	Çataloluk	LDL	0.78 ± 0.03	16.77 ± 0.04	1.66 ± 0.29	71.65 ± 0.58	33.85 ± 0.30
	Güngören	LDL	0.76 ± 0.07	2.77 ± 0.06	2.26 ± 0.22	27.65 ± 0.35	32.86 ± 0.17
	Kaledran	0.34 ± 0.03	LDL	4.46 ± 0.39	3.06 ± 0.12	26.62 ± 0.44	27.34 ± 0.15
	Laleli	LDL	LDL	35.55 ± 0.68	30.26 ± 0.44	31.59 ± 0.08	8.27 ± 0.02
	Malaklar	0.48 ± 0.08	LDL	11.48 ± 0.25	2.95 ± 0.25	26.56 ± 0.14	11.14 ± 0.08
Aydıncık	Center	0.42 ± 0.06	3.24 ± 0.04	24.85 ± 0.34	5.39 ± 0.09	121.40 ± 3.00	16.09 ± 0.12
Bozyazı	Bozyazı	0.46 ± 0.03	0.90 ± 0.12	3.41 ± 0.06	3.52 ± 0.22	62.88 ± 0.32	8.77 ± 0.11
	Kızılca	LDL	0.83 ± 0.22	21.40 ± 0.20	3.51 ± 0.25	29.66 ± 0.22	6.58 ± 0.03
	Kömürlü	0.49 ± 0.12	1.57 ± 0.06	33.36 ± 0.48	4.64 ± 0.23	53.02 ± 0.32	42.87 ± 0.17
City Center	Alanyalı	0.37 ± 0.04	5.81 ± 0.07	5.95 ± 0.20	6.83 ± 0.34	44.79 ± 0.34	13.84 ± 0.13
	Darısekisi	1.03 ± 0.09	2.01 ± 0.02	3.74 ± 0.32	4.67 ± 0.22	15.40 ± 0.04	6.66 ± 0.16
	DSİ	0.69 ± 0.07	0.83 ± 0.04	6.82 ± 1.16	3.89 ± 0.09	176.0 ± 1.02	9.68 ± 0.06
	Fatih Kasabası	LDL	6.56 ± 0.18	15.33 ± 0.23	4.06 ± 0.20	28.63 ± 0.15	93.4 ± 0.69
	Yenice	0.45 ± 0.04	LDL	9.34 ± 0.19	3.01 ± 0.18	1.50 ± 0.12	8.93 ± 0.11
Çamlıyayla	Kale	LDL	LDL	LDL	2.42 ± 0.18	96.71 ± 0.89	3.60 ± 0.06
	Center	LDL	0.76 ± 0.03	9.31 ± 0.20	2.47 ± 0.09	62.98 ± 0.68	6.10 ± 0.09
	Darıpınarı	LDL	0.78 ± 0.19	17.67 ± 0.37	3.31 ± 0.20	611.2 ± 11.2	7.18 ± 0.04
Erdemli	Kargıpınarı	LDL	2.23 ± 0.10	8.57 ± 0.07	4.29 ± 0.24	13.90 ± 0.04	18.63 ± 0.08
	Tömük	LDL	1.76 ± 0.12	7.84 ± 0.68	3.91 ± 0.09	50.51 ± 0.51	18.97 ± 0.09
	Center	LDL	1.39 ± 0.15	11.72 ± 0.08	4.44 ± 0.10	150.3 ± 0.2	20.84 ± 0.11
Gülnar	Bardat P. village	LDL	LDL	12.00 ± 0.27	3.67 ± 0.19	3.49 ± 0.12	58.47 ± 0.13
	Büyükeceli	0.41 ± 0.03	2.17 ± 0.05	16.90 ± 0.14	6.15 ± 0.22	69.79 ± 0.31	77.35 ± 0.96
	Gülnar	LDL	LDL	8.10 ± 0.18	3.29 ± 0.19	11.08 ± 0.07	15.79 ± 0.16
	Köseçobanı	LDL	1.31 ± 0.09	12.96 ± 0.29	4.44 ± 0.20	0.57 ± 0.00	50.92 ± 0.32
	Sipahili	0.54 ± 0.08	1.13 ± 0.12	35.32 ± 0.22	8.38 ± 0.22	7.19 ± 0.19	75.31 ± 1.17
	Zeyne	0.39 ± 0.12	0.65 ± 0.12	6.28 ± 0.25	3.50 ± 0.29	LDL	29.33 ± 0.38
Mut	Burunköy	0.48 ± 0.09	7.75 ± 0.24	3.89 ± 0.61	3.53 ± 0.36	23.01 ± 0.19	7.56 ± 0.03
	Çömelek	LDL	LDL	5.14 ± 0.68	2.84 ± 0.09	62.08 ± 0.11	8.73 ± 0.07
	Dıştaş	0.37 ± 0.06	2.04 ± 0.04	3.84 ± 0.08	4.01 ± 0.18	21.57 ± 0.16	24.43 ± 0.12
	Göksu	LDL	LDL	7.12 ± 0.10	3.39 ± 0.23	5.93 ± 0.15	7.52 ± 0.20
	Hacıahmetli	LDL	LDL	15.06 ± 0.42	2.59 ± 0.06	4.73 ± 0.11	7.74 ± 0.05
	Karşıyaka	0.51 ± 0.12	LDL	8.06 ± 0.22	2.93 ± 0.20	43.06 ± 0.86	8.42 ± 0.06
	Kelceköy	LDL	0.78 ± 0.30	26.28 ± 0.30	3.58 ± 0.06	2.92 ± 0.17	7.30 ± 0.17
Silifke	Kavak	0.36 ± 0.01	LDL	3.00 ± 0.64	2.65 ± 0.19	41.39 ± 0.91	4.49 ± 0.05
	Keşlitürkmenli	0.39 ± 0.04	LDL	4.67 ± 0.20	2.98 ± 0.16	17.28 ± 0.14	4.75 ± 0.04
	Narlıkuyu	LDL	0.76 ± 0.12	3.65 ± 0.13	3.47 ± 0.08	4.72 ± 0.11	5.73 ± 0.04
	Yeşilovacık	0.39 ± 0.11	0.64 ± 0.04	8.03 ± 0.64	3.08 ± 0.08	2.02 ± 0.14	49.36 ± 0.11
Tarsus	Aladağlı	3.07 ± 0.51	2.82 ± 1.21	8.88 ± 5.89	11.08 ± 1.64	16.08 ± 0.11	80.53 ± 0.53
	Dedeler	LDL	LDL	7.32 ± 0.42	12.24 ± 0.11	7.33 ± 0.27	58.22 ± 0.75
	Karadiken	LDL	LDL	7.13 ± 0.22	2.77 ± 0.30	7.35 ± 0.10	105.7 ± 0.40
	Kisecik	LDL	0.65 ± 0.26	7.53 ± 0.08	2.79 ± 0.14	176.0 ± 1.0	13.13 ± 0.14
EPA	Limit value	5	100	1300	-	5000	-
WHO	Limit value	3	50	2000	70	3000	-
LDL		0.3	0.6	2.3	0.9	0.5	1.7

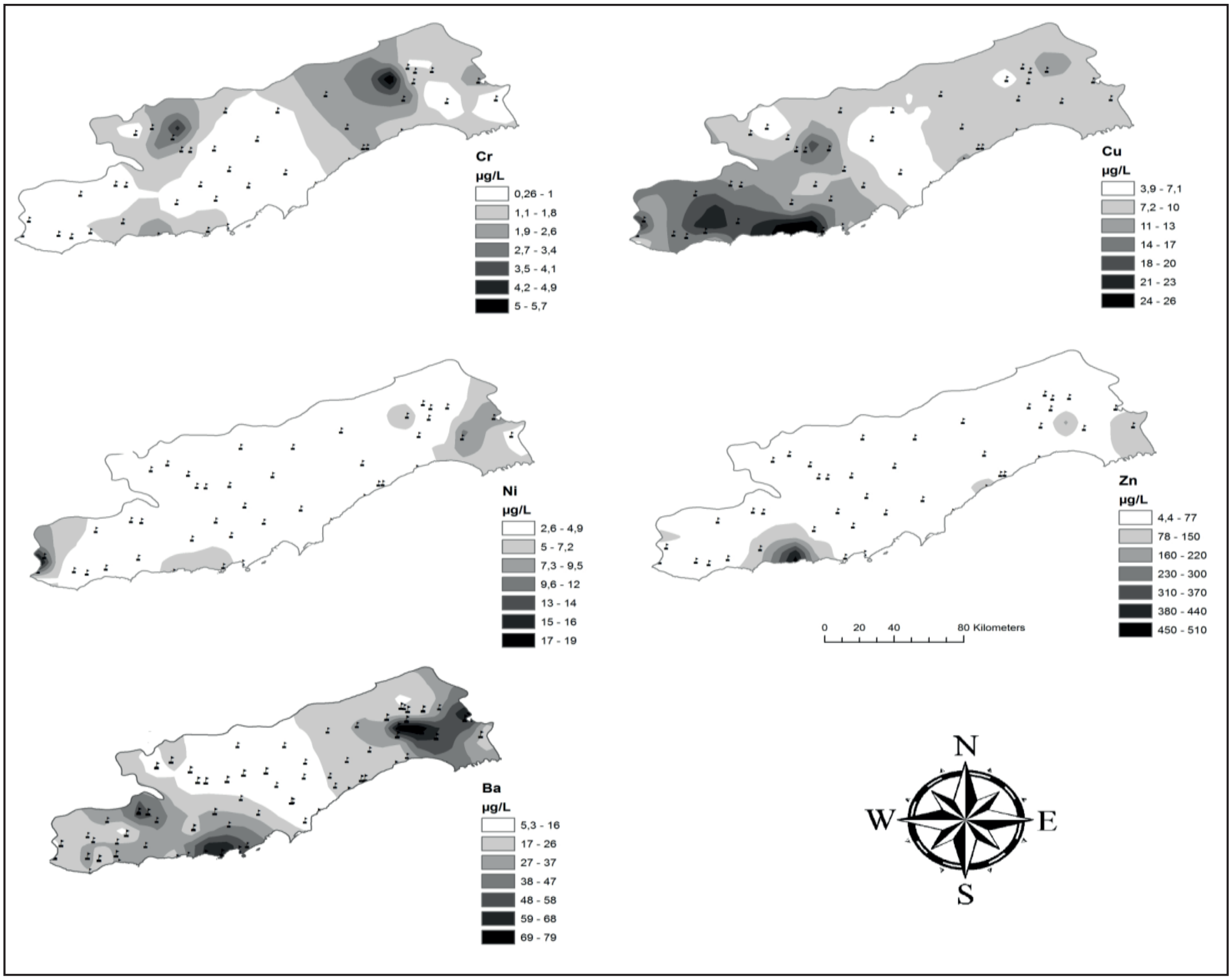

Figure 3. Relative distribution of heavy metals in drinking water of the region.

$$ADIWing = \frac{C \times IR \times EF \times ED}{BW \times AT}, \tag{3}$$

where $ADIWing$ is the average daily intake of heavy metals ingested from water (mg/kg-day). C is the heavy metal concentration in water (μg/L). IR is the daily intake of water, 2.2 L/day.[10] ED is the exposure duration, 70 years.[13] EF is the exposure frequency, 365 days/year.[14] AT is the time period over which the dose is averaged, 365 $\times$ 70 = 25,550 days for both carcinogens and noncarcinogens.[13] BW is the body weight of the exposed individual (70 kg).

Noncarcinogenic hazards are characterized by a term called hazard quotient (HQ) and this quotient is obtained using Eq. (4), which consists of two variables: average daily intake values (ADI) of heavy metals and the chronic reference dose values (R_{fD}) given in Table 4 for each heavy metal.[10,15] HQ is a unitless number that is expressed as the probability of an individual suffering an adverse effect.

$$HQ = \frac{ADI}{RfD} \tag{4}$$

Table 4. Reference dose values and cancer slope factors for heavy metals.

Heavy metal	Reference dose values (R_{fd}) (mg/kg per day)			Cancer slope factors (SF) 1/(mg/kg per day)		
	Oral	Inhalation	Dermal	Oral	Inhalation	Dermal
Cr	3.0×10^{-3}	2.9×10^{-5}	6.0×10^{-5}	5.0×10^{-1}	42	20
Ni	2.0×10^{-2}	2.1×10^{-2}	5.4×10^{-3}	1.7	8.4×10^{-1}	42.5
As	3.0×10^{-4}	3.0×10^{-4}	1.2×10^{-4}	1.5	15	1.5
Pb	3.5×10^{-3}	3.5×10^{-3}	5.3×10^{-4}	8.5×10^{-1}	NA	NA
Cd	5.0×10^{-4}	1.0×10^{-3}	1.0×10^{-5}	15	NA	NA
Ba	2.0×10^{-1}	NA	NA	NA		NA
Zn	3.0×10^{-1}	3.0×10^{-1}	6.0×10^{-2}	NA	NA	NA
Mn	1.4×10^{-1}	1.4×10^{-5}	2.3×10^{-2}	NA	NA	NA
Hg	1.0×10^{-4}	8.6×10^{-5}	2.1×10^{-2}	NA	NA	NA
Cu	4.0×10^{-2}	4.2×10^{-2}	1.2×10^{-2}	NA	NA	NA

NA: Not available

For n number of heavy metals, the noncarcinogenic effect on the population is as a result of the summation of all the HQs due to individual heavy metals. This is considered to be another term called the hazard index (HI) as described by a USEPA document.[10] Eq. (5) shows the mathematical representation of this parameter for heavy metals in drinking water.

$$HI = \sum_{k=1}^{n} HQk = \sum_{k=1}^{n} \frac{ADIk}{RfDk}, \tag{5}$$

where HQ_k, ADI_k, and R_{fDk} are values of heavy metal k. For carcinogens, the risks are estimated as the incremental probability of an individual developing cancer over his/her lifetime as a result of exposure to the potential carcinogen. Eq. (6) is used for calculating the excess lifetime cancer risk (ELCR) due to heavy metals in drinking water.

$$ELCR = \sum_{k=1}^{n} ADIk \times SFk, \tag{6}$$

where ELCR is a unitless probability of an individual developing cancer over a lifetime. ADI_k (mg/kg per day) and SF_k (1/(mg/kg per day)) are the average daily intake and the cancer slope factor, respectively, for the k_{th} heavy metal, for n number of heavy metals. The slope factors are given in Table 4. The slope factor converts the estimated daily intake of the heavy metal averaged over a lifetime of exposure directly to the incremental risk of an individual developing cancer.[10]

The calculated mean HI and HQ values for HM in drinking water are presented for each district in Table 5. It was seen that the HQ values of heavy metals decreased Cd > Cr > Cu > Ni > Zn > Ba in water. If HI value is less than one, the exposed population is unlikely to experience adverse health effects. However, if the HI value exceeds one, then there may be concern for potential noncarcinogenic effects.[10] Moreover, it is seen that the mean HI values for drinking water are higher than the reference value of one in the districts of Aydıncık and Tarsus. Moreover, ELCR values of heavy metals in drinking water are given in Table 5. It is seen that the cancer risk values of heavy metals investigated in the drinking water decreased in the order of Cd > Cr > Ni for the region. Similar studies on the determination of radioactivity in drinking water in this country

Table 5. Health risk levels due to heavy metals in province drinking water samples.

District	Hazard quotient (HQ)						HI	Excess lifetime cancer risk		
	Cd	Cr	Cu	Ni	Zn	Ba		Cd	Cr	Ni
Anamur	1.49×10^{-1}	4.8×10^{-2}	9.5×10^{-2}	1.1×10^{-1}	3.6×10^{-2}	3.2×10^{-2}	4.7×10^{-1}	1.1×10^{-3}	7.2×10^{-5}	1.6×10^{-4}
Aydıncık	2.65×10^{-1}	3.4×10^{-1}	2.0×10^{-1}	8.5×10^{-2}	1.3×10^{-1}	3.4×10^{-2}	11×10^{-1}	2.0×10^{-3}	5.1×10^{-4}	1.2×10^{-4}
Bozyazı	2.31×10^{-1}	1.2×10^{-1}	1.5×10^{-1}	6.1×10^{-2}	5.1×10^{-2}	3.1×10^{-2}	6.4×10^{-1}	1.7×10^{-3}	1.7×10^{-4}	8.9×10^{-5}
Center	2.98×10^{-1}	2.8×10^{-1}	6.3×10^{-2}	6.6×10^{-2}	4.8×10^{-2}	4.2×10^{-2}	7.9×10^{-1}	2.2×10^{-3}	4.2×10^{-4}	9.6×10^{-5}
Çamlıyayla	9.45×10^{-2}	6.4×10^{-2}	7.5×10^{-2}	4.3×10^{-2}	2.7×10^{-1}	8.9×10^{-3}	5.6×10^{-1}	7.1×10^{-4}	9.7×10^{-5}	6.3×10^{-5}
Erdemli	9.45×10^{-2}	1.9×10^{-1}	7.4×10^{-2}	6.6×10^{-2}	7.5×10^{-2}	3.1×10^{-2}	5.3×10^{-1}	7.1×10^{-4}	2.8×10^{-4}	9.7×10^{-5}
Gülnar	1.88×10^{-1}	1.1×10^{-1}	1.2×10^{-1}	7.7×10^{-2}	1.9×10^{-2}	8.1×10^{-2}	5.9×10^{-1}	1.4×10^{-3}	1.5×10^{-4}	1.1×10^{-4}
Mut	1.76×10^{-1}	1.8×10^{-1}	7.8×10^{-2}	5.2×10^{-2}	2.5×10^{-2}	1.6×10^{-2}	5.2×10^{-1}	1.3×10^{-3}	2.7×10^{-4}	7.5×10^{-5}
Silifke	2.03×10^{-1}	5.3×10^{-2}	3.8×10^{-2}	4.8×10^{-2}	1.7×10^{-2}	2.5×10^{-2}	3.8×10^{-1}	1.5×10^{-3}	7.9×10^{-5}	8.0×10^{-5}
Tarsus	7.07×10^{-1}	1.3×10^{-1}	6.2×10^{-2}	1.4×10^{-1}	7.0×10^{-2}	1.0×10^{-1}	12×10^{-1}	5.3×10^{-3}	2.0×10^{-4}	2.0×10^{-4}
Mersin	2.26×10^{-1}	1.4×10^{-1}	8.7×10^{-2}	7.3×10^{-2}	5.8×10^{-2}	4.1×10^{-2}	6.8×10^{-1}	1.7×10^{-3}	2.1×10^{-4}	1.1×10^{-4}

are given in Table 6. The studies on heavy elements in different cities around the world are given in Table 7. The values determined for the region are quite compatible with the values of other cities investigated. Finally, the mean gross alpha and gross beta radioactivity concentration of the city's waters are at the same level as other cities results. City drinking waters are below the WHO's limit and at the drinkable level. Radioactivity and heavy element concentrations were at a slightly higher level than others in some districts and villages. We think the main reason for it is the geologic formation.

Table 6. Water radioactivity studies in different cities in Turkey.

Location	Activity in water (Bq/L)	
	Gross-α	Gross-β
İstanbul[17]	0.023	0.070
Kırklareli[20]	0.069	0.067
Çankırı[21]	0.250	0.260
Adana[1]	0.010	0.086
Artvin[7]	0.046	0.091
Mersin	0.059	0.120
WHO[22]	0.500	1

Table 7. Heavy metal investigations in different cities around the world.

Concentration in drinking water (μg/L)							
Location	Cu	Zn	Ba	Cd	Ni	Cr	Pb
Karachi[23]	0.121	-	-		0.037	0.012	0.006
Dawanqi[24]	-	4.46	-	0.031	0.86	3.79	0.04
Keyiri[24]	-	1.78	-	0.0078	1.22	2.52	0.045
SW-Punjab[25]	145	833	-	-	34.6	28.3	46.2
Delhi [26]	-	-	-	3.5	-	268	485
Bannu[27]	9.65	235	10,046	-	1.73	-	-
Bangkok[28]		250	43	-	0.3	-	-
Mersin	11.06	54.86	26.26	0.36	4.65	1.33	LDL
WHO[29]	2000	3000	700	3	70	50	10

3. Experimental

3.1. Survey area

Mersin, one of the most modern provinces in the southern part of Turkey, is the largest port in the Turkish Mediterranean region. It has an area about 3664 km^2. Mersin is the most populous city in the region. According to 2016 numbers, the population is 1,773,852. The province has 13 districts as can be seen in Figure 1. The Toroslar, Mediterranean, Mezitli, and Yenişehir districts were taken as the central district in the present study. The Province Center is located at the geographic coordinates of $36°48'$N and $34°38'$E. A large portion of Mersin is quite high, rugged cliffs and constitutes the western and central Taurus Mountains. Plain and slightly inclined areas have developed in the Province Center, Tarsus, and Silifke, where these mountains extend to the sea. Apart from this, the flat or slightly inclined areas are seen in the mountains in the north or in the high sections. Although Mersin dates only from the 19th century, it occupies an extremely ancient site. At Mount Yumuktepe the excavations proved that there had been twelve successive settlements beginning from the Neolithic Period. The province is located to the east of the Middle Toros zone, which is between the Kırkkavak fault in the west and the Ecemi fault line in the east. Paleozoic, Mesozoic, and predominantly Cenozoic rocks are essential components in the province.[16] Akkuyu nuclear power plant is to be constructed at the Akkuyu in the Büyükeceli Township, located in Gülnar district of Mersin Province. Construction is planned to be completed in 2023 and this will be the first nuclear power plant in Turkey.

3.2. Method and materials in radioactivity determination

In order to determine the radioactivity levels in drinking waters, the samples were collected from 42 different locations in the research area and analyzed. Samples were taken from the water lines and spring waters of the city center, districts, towns, and villages. The collected water samples at pre-determined stations were transported to the laboratory in 2.5-L capacity polystyrene bottles. A routine procedure outlined was followed to prepare the samples for radionuclide analyses.[17] Each water sample was passed through a paper filter (0.45 micron porous cellulose paper) to remove all foreign materials and then transferred to a beaker where a small amount of nitric acid (3 mL of 3 N nitric acid) was added to avoid any wall sorption into the container. After slow evaporation to near dryness, the sample was moved to a stainless steel counting planchette to be evaporated to dryness at low temperature (60 °C). After cooling and weighing for the dry residue, each sample was counted for gross-alpha and gross-beta radioactivities in a low-background proportional counter with gas flow (Berthold, LB770-PC10 Channel Low-Level Planchette Counter). The sample detectors are gas-flow window-type counters approximately 5 cm in diameter. The counting gas was a mixture of 90% argon and 10% methane. The system was commonly used for measuring environmental samples with low natural background radiation. The counting time was 1000 min and 100 min for gross alpha and gross beta, respectively. The calibration of the low-level counting system used in the measurements of gross alpha and gross beta was carried out with standard sources[18] that contained known activities of ^{241}Am (219 Bq) for alpha and ^{90}Sr (382 Bq) for beta, which were similar to the sample geometry.

3.3. Method and materials in heavy metal determination

To determine the amounts of trace elements in drinking water, calibration standard and water sample solutions to be analyzed were prepared using 2% HNO_3. Then the solutions were analyzed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) (PerkinElmer Optima 7000 DV) with an autosampler by plotting calibration curves. In addition, mercury (Hg) analyses were performed by ICP-OES continuous flow hydride generation (CFHG). It was provided that the correlation coefficient of the calibration curves was at least $r^2 = 0.999$. The accuracy of the analysis results was tested with the proficiency test material "KAR-G3RM-130.2016.02- Determination of elements in waste water".[19] The quantity of the National Metrology Institute (UME) and our laboratory results for mercury are given in Table 8 (ppm or μg/L).

4. Conclusion

In this study, the background level of radioactivity and heavy metal accumulation in drinking water were investigated in Mersin Province, where a nuclear power plant will be established in the near future. This study

Table 8. The quantity of UME and our laboratory results for mercury.

	Mercury (μg/L)	
	Result	Uncertainty
UME	81.72	8.17
Laboratory	81.64	0.49

reveals basic levels of natural radioactive and heavy element concentrations for the province before the plant is started. The background gross alpha and gross beta radioactivity concentrations in Mersin drinking waters were 0.011–0.161 Bq/L and 0.016–0.391 Bq/L, respectively. The basic levels of radioactivity and heavy metal concentrations in the province's drinking water samples are given Tables 1 and 3, respectively.

It is seen that the determined mean alpha/beta activity and heavy metal concentration in drinking water for the region are compatible with the studies carried out in other cities. The health risks related to radioactivity in drinking water are determined below the limit values recommended by the WHO. The HI value of heavy metal exposure is higher than the reference value of one in some parts of the region due to the excessive heavy metal accumulation of Cd and Cr in water. Cd was detected in just 19 water samples in the province. Cr was detected in 26 samples. The highest concentration of Cd was 3.03 μg/L in Tarsus district Aladağlı village. The highest value of Cr was 7.75 μg/L in Mut district Burunköy drinking waters. Cd concentration is slightly above the WHO limits but below the EPA limits. Cr concentration is also below the WHO and EPA limits.

It is assessed that Cd and Cr elements exist in drinking waters depending on the geological structure of the region, because there are no industrial factories in and around these two villages.

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