

Environmental impact assessment due to 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 is to determine natural radioactive and heavy element concentrations in Mersin drinking waters before commissioning of Akkuyu nuclear power plant and to collect data that will be reference for possible environmental contaminations in the future. Therefore, this study comprise whole of the province. Drinking water samples were taken from provincial center, districts and populated villages. Water samples were analysed to determine radioactivity and heavy metals concentrations. The annual effective dose equivalent taken from natural radioactive substances and cancer risks were calculated for each people living in the city. In addition, Hazar Index (HI) and cancer risk were calculated, which were caused by heavy elements. The mean gross alpha and beta radioactivity concentrations in drinking water were measured 0.059 ± 0.051 Bq/L and 0.120 ± 0.095 Bq/L, respectively. The annual cumulative effective dose for people was found as 30.83 μ Sv and the average estimated excess cancer risk related this exposure was calculated as 16.9×10^{-5} . Also, mean metal concentration of Cr, Ni, Zn, Cu, Ba and Cd in drinking water were determined as 1.33, 4.65, 54.8, 11.1, 26.3, 0.36 μ g/L, respectively. Pb and As in all water samples were determined lower than detection limits (LDL). The hazard quotient (HQ) of heavy metals was decreased in the order of Cd > Cr > Cu > Ni > Zn > Ba in water. Mean calculated Hazard Index (HI)

depending heavy metal concentration is found to be 6.8×10^{-1} for drinking water. Cancer risks of heavy metals are decreased in the order of $\text{Cd} > \text{Cr} > \text{Ni}$ for the region.

Keywords

Mersin; drinking water; cancer risk; gross alpha and beta activity; heavy metal

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 amount 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 is to be 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 be 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 cause to internal irradiation. Natural waters contain both α (e.g., U-238) and β (e.g., K-40) emitters in widely varying concentrations which are responsible for a generally small fraction of the total dose received from natural and artificial

radioactivity. 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 $^{234\text{m}}\text{Pa}$.¹

Heavy metals reach water systems in natural and anthropogenic way. 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 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 lip solubility and accumulation in sediment.⁵⁻⁶

The primary objective of this study, it is to determine the natural radioactive and heavy element concentrations in city drinking water before commissioning of Akkuyu nuclear power plant and to follow up the potential level of environmental pollution that may occur after operation of the power plant. Secondly, it is to calculate the non-carcinogenic (acute health problems, allergic reactions, kidney and liver dysfunction, excessive fatigue, respiratory problems, ext.) and carcinogenic health risks emerge from the natural radioactivity and heavy metal accumulation in Mersin drinking water.

2. 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 3.664 km². 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. Toroslar,

Mediterranean, Mezitli and Yenişehir districts were taken as central district in this study. The Province Center is located on the geographic coordinates of 36° 48' N and 34° 38' E.

A large portion of Mersin quite high, rugged cliffs and constitutes 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 Kırkkavak Fault in the west and the Ecemi Fay line in the east. Paleozoic, Mesozoic and predominantly Cenozoic rocks are essential components in the province.⁷ Akkuyu Nuclear Power Plant is to be constructed at the Akkuyu location of 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. Materials and methods

3.1 Determination of radioactivity in drinking water

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.⁸ 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 (three millilitres of 3 N nitric acid) was added to avoid any wall sorption onto 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-PC 10-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 results of gross alpha and gross beta radioactivity concentrations in drinking waters are given in units of Bq/L in Table 1. The calibration of the low-level counting system used in the measurements of gross alpha and gross beta was carried out with standard sources⁹ that contained known activities of ²⁴¹Am (219 Bq) for alpha and ⁹⁰Sr (382 Bq) for beta which were similar to the sample geometry. The following Equation 1 was used to calculate the effective dose (DR_w) due to drinking water radioactivity.

$$DR_w = A_w \times IR_w \times ID_F \times 2 \text{ (for both } \alpha \text{ and } \beta) \quad (1)$$

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 1 year. One person consumes an average of 2 liters of water per day. ID_F is the ingestion effective dose equivalent factor for 3.58×10⁻⁷ Sv/Bq

for alpha.¹⁰ Excess lifetime cancer risk value (ELCR) for 70 years of average life duration was calculated by using following Equation 2.

$$\text{ELRC} = \text{DR}_w \times \text{DL} \times \text{RF} \quad (2)$$

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.¹¹⁻¹² The calculated excess lifetime cancer risks rates from radioactivity materials in Mersin drinking water are given in Table 2.

3.2. Determination of accumulation of heavy metals in water

To determine the amount of trace elements in drinking water, calibration standard and water sample solutions to be analyzed were prepared by using 2% HNO_3 . Then, the solutions were analyzed by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES) (Perkin Elmer Optima 7000 DV) method with auto sampler by plotting calibration curves. Also, mercury (Hg) analyses were performed by ICP-OES Continuous Flow Hydride Generation (CFHG) method. 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" by organized.¹³ The quantity of National Metrology Institute (UME) and our laboratory results for mercury are given in Table 3 (ppm or $\mu\text{g/L}$). The amount of trace elements concentrations in Mersin drinking waters are given Table 4. The potential exposure pathways for heavy metals in drinking water are calculated by following Equation 3.¹⁴⁻¹⁶

$$ADI_{w\ ing} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (3)$$

Where $ADI_{w\ ing}$ is the average daily intake of heavy metals ingested from water (mg/kg-day). C is the heavy metal concentration in water ($\mu\text{g/L}$). IR is the daily intake of water, 2.2 L/day.¹⁴ ED is the exposure duration, 70 years.¹⁷ EF is the exposure frequency, 365 days/year.¹⁸ AT is the time period over which the dose is averaged, $365 \times 70 = 25550$ days for both carcinogens and non-carcinogens.¹⁷ BW is the body weight of the exposed individual (70 kg).

Non-carcinogenic hazards are characterized by a term called hazard quotient (HQ) and this quotient is obtained using Equation 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 5 for each heavy metal.^{14,19} HQ is a unitless number that is expressed as the probability of an individual suffering an adverse effect.

$$HQ = \frac{ADI}{R_{fD}} \quad (4)$$

For n number of heavy metals, the non-carcinogenic effect to 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 USEPA document.¹⁴ Equation 5 shows the mathematical representation of this parameter for heavy metals in drinking water.

$$HI = \sum_{k=1}^n HQ_k = \sum_{k=1}^n \frac{ADI_k}{R_{fDk}} \quad (5)$$

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 a lifetime as a result of exposure to the potential carcinogen. The Equation 6 is used for calculating the excess lifetime cancer risk (ELCR) due to heavy metals both in drinking water.

$$ELCR = \sum_{k=1}^n ADI_k \times SF_k \quad (6)$$

Where ELCR is a unitless probability of an individual developing cancer over a lifetime. ADI_k (mg/kg/day) and SF_k (1/(mg/kg/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 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.¹³

4. Results and Discussions

Water characterization, such as solubility, transport and sedimentation is increase natural radioactivity concentration and heavy element rates in the water. The source of radioactivity in water are the natural radionuclides such as ^{238}U daughters, ^{232}Th daughters and ^{40}K which exist in dusts, particulates and melted minerals. In addition, dust and particles in water cause to increase radioactivity and heavy elements when the water passes surface of ground

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 range 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 as 0.059 ± 0.051 Bq/L and 0.120 ± 0.095 Bq/L, respectively for the region. The main reason for the variation of activities observed between different locations of the region is the change of radiologic characteristic of underground origin of water resources and pathways. Moreover, the spatial distribution maps plotted for alpha and beta activity for the region demonstrated together with the location of sampling stations in Figure 2.

The health effects of ionizing background radiations in the research region have been investigated by determining the biological effective radiation doses and the related cancer risks. The annual cumulative effective dose for people living in the region due to radioactivity in drinking water was determined as $30.83 \mu\text{Sv}$ using the Equation 1. Also, the average estimated excess cancer risk value related this exposure was calculated as 16.9×10^{-5} using the Equation 2. High radioactivity concentration increase cancer risk. 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 values due to radiologic exposure caused by radioactivity in drinking water are given for each district in Table 2.

All water samples collecting from province were also analyzed to determine the heavy metal accumulation in the research region. Mean metal concentration of Cr, Ni, Zn, Cu, Ba and Cd in drinking water were determined as 1.33, 4.65, 54.8, 11.1, 26.3, 0.36

µg/L, respectively in the research region and the concentration of Pb and As in all water samples were determined lower than detection limits (LDL). The basic levels of all heavy metals concentration in drinking water in the province are given in Table 3. Cd element was detected just in 19 water samples. The highest concentration of Cd in the drinking water was found in Aladağlı village of Tarsus district. Cd concentration is slightly above of WHO limits, but below EPA limits. The highest Cr value was detected in Burunköy drinking water in Mut. Cu, Ni and Ba elements were detected in all drinking waters. Zn was measured in all drinking waters except 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 districts, respectively.

The concentrations of Cr, Cu, Ni and Zn are quite below the limits of WHO and EPA. The amount 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 of variation in heavy metal concentration inside the region. The spatial distribution maps plotted for metal concentration in drinking water in Figure 3.

In terms of health risk due to heavy metal accumulation in the region, non-carcinogenic and carcinogenic health effects were investigated. The calculated mean HI and HQ values for HM in drinking water are presented for each district in Table 6. It was seen that the HQ values of heavy metals were 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 non-carcinogenic effects.¹³ Moreover, it is seen that the mean HI values for

drinking water are higher than the reference value of one in the district of Aydıncık and Tarsus. Also, ELCR values of heavy metals in drinking water are given in Table 6. It is seen that the cancer risk values of heavy metals investigated in drinking water are decreased in the order of $Cd > Cr > Ni$ for the region. Similar studies carried out on radioactivity and heavy elements in drinking waters in our country are given in Table 7 and Table 8. 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 city's waters are at the same level of other cities results. City drinking waters are below WHO's limit and at the drinkable level. Radioactivity and heavy elements concentrations found at a slightly higher level than the others in some districts and villages. We think the main reason of it is geologic formation.

5. Conclusion

In this study, the background level of radioactivity and heavy metal accumulation in drinking water were investigated in for the Mersin province where a Nuclear Power Plant will be established in the near future. This study 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 change 0.011-0.161 Bq/L and 0.016-0.391 Bq/L. The basic level of radioactivity and heavy metal concentrations in province drinking waters are given Table 1 and Table 4.

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 international organization of WHO. The Hazard Index (HI) value of heavy metal exposure is found to be 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 element was detected just in 19 water samples in Province. Cr element was detected in 26 samples. The highest concentration of Cd was measured as 3.03 µg/L in Tarsus district Aladağlı village. The highest value of Cr was found as 7.75 µg/L in Mut district Burunköy drinking waters. Cd concentration is slightly above of WHO limits, below EPA limits. Cr concentration is quite below of 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 aren't any industrial factory in and around of these two villages.

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Figure List

Figure 1. The research region of Mersin.

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

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

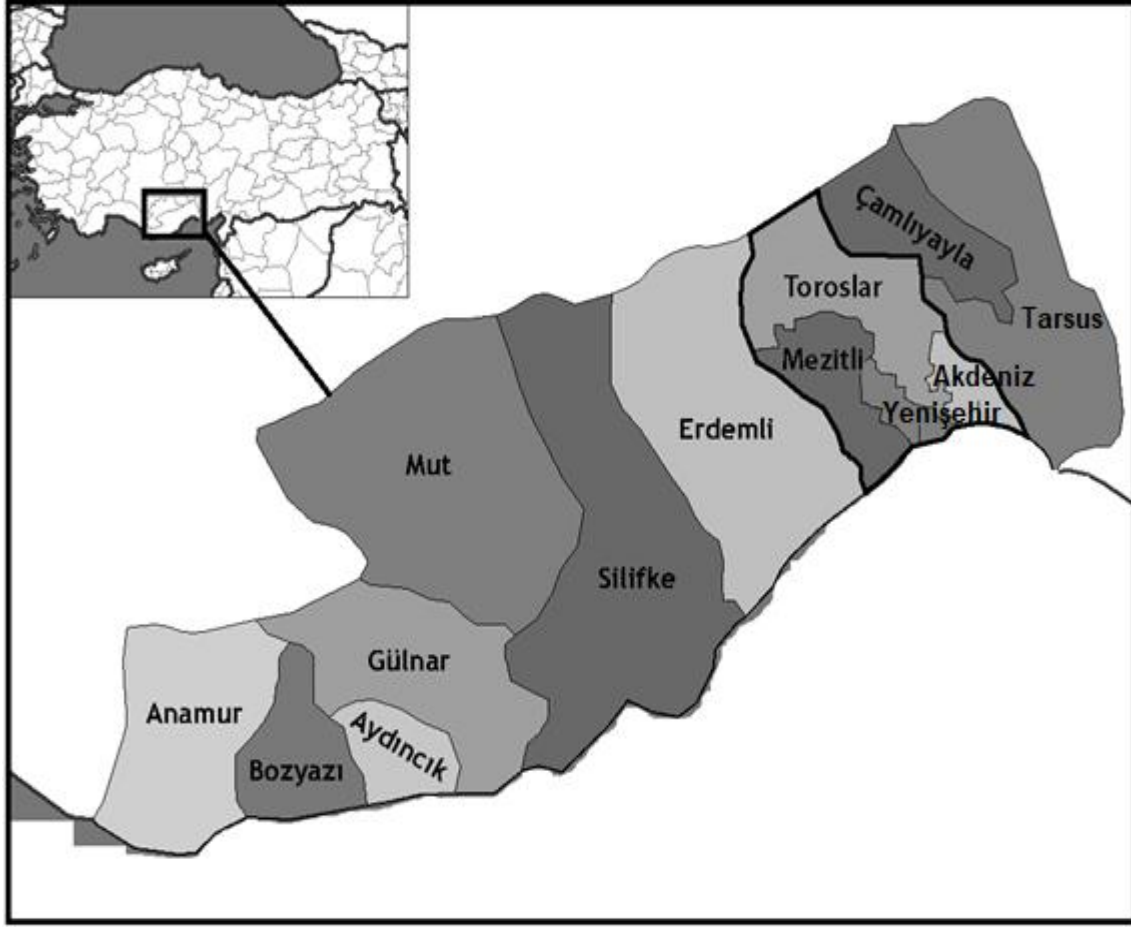


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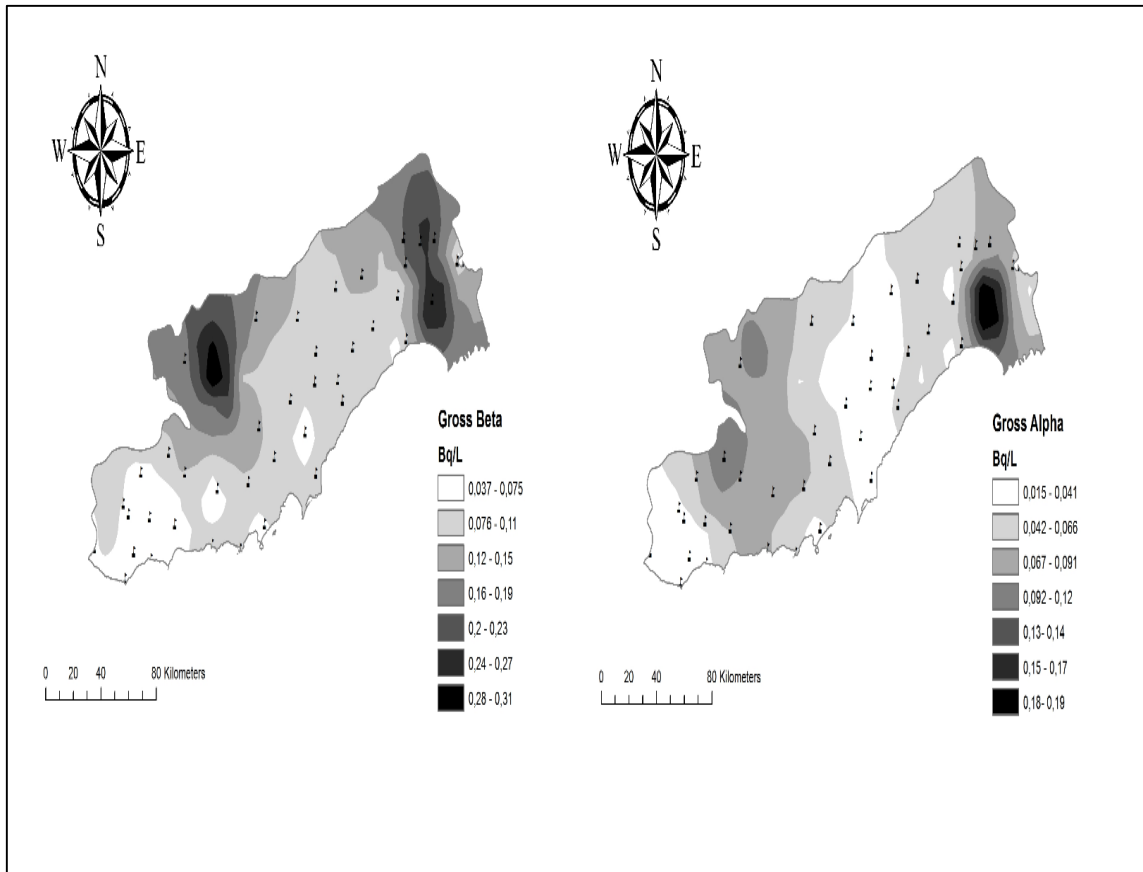


Figure 2. Relative distribution of water radioactivity in the region.

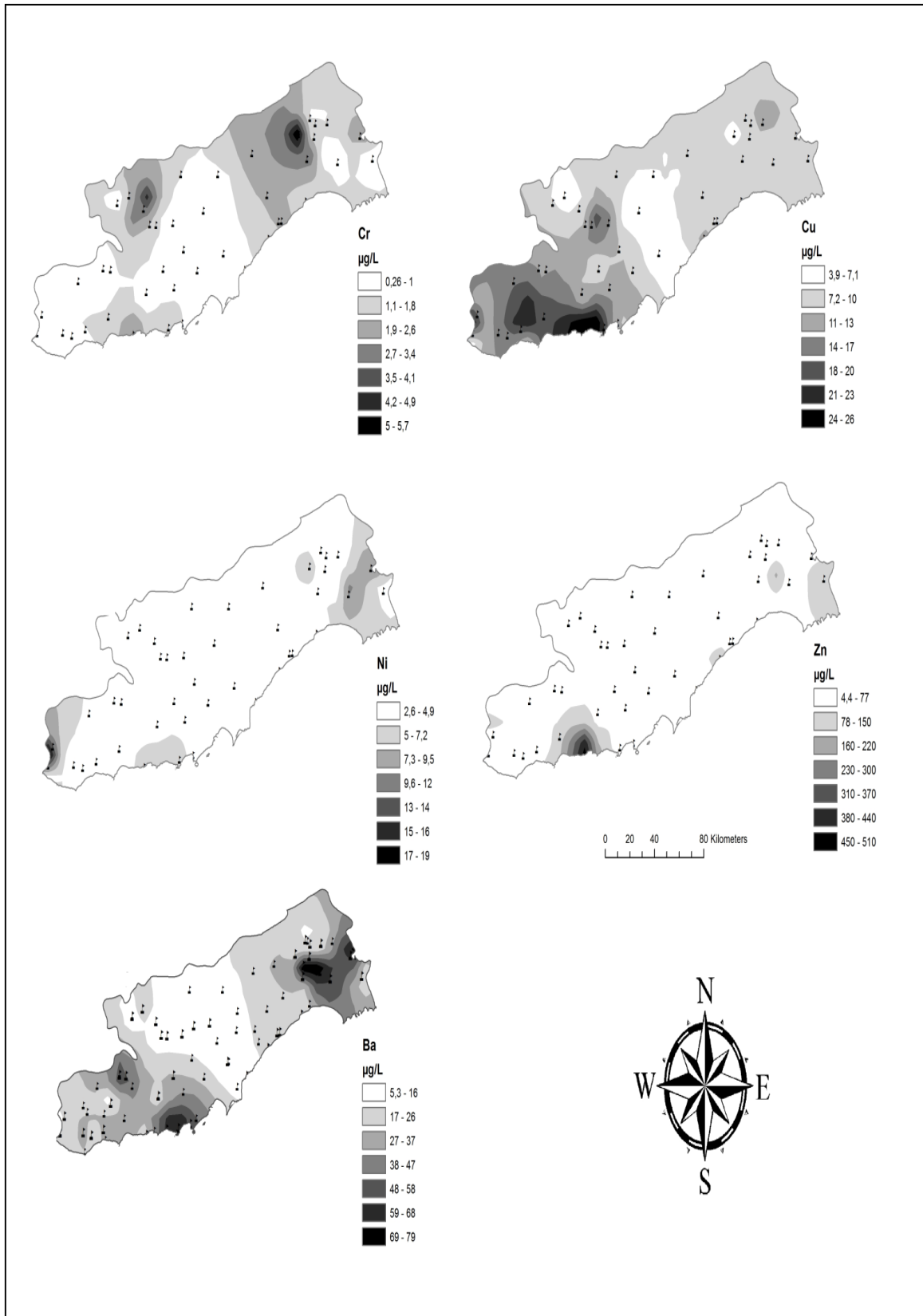


Figure 3. Relative distribution of heavy metals in drinking water of the region.

Table List

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

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

Table 3. The quantity of UME and our laboratory results for mercury.

Table 4. Heavy metal concentrations in province drinking water samples.

Table 5. Reference dose and cancer slope factors for heavy metals.

Table 6. Health risk levels due to heavy metal concentration in province drinking waters.

Table 7. Water radioactivity studies carried out in different cities of Turkey.

Table 8. Heavy metal investigation studies carried out in different cities around the world.

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	Aydıncık Merkez	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	Erdemli	0.051±0.01	0.095±0.029
	Kargıpınarı Kasabası	0.040±0.009	0.094±0.017
	Tömük Kasabası	0.039±0.009	0.073±0.033
Gülner	Bardat	0.130±0.014	0.100±0.025
	Büyükeceli Kasabası	0.047±0.009	0.082±0.016
	Köseçobanı Kasabası	0.089±0.012	0.129±0.018
	Gülner	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 Kasabası	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 Kasabası	0.031±0.008	0.093±0.030
	Yeşilovacık Kasabası	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
Center	Alanyalı	0.037±0.009	0.081±0.016
	Darı sekisi	0.029±0.008	0.052±0.014
	Fatih Kasabası	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

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Table 2. Health risk levels due to water radioactivity in 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}
Center	19.65	10.8×10^{-5}
Çamlıyayla	28.40	15.6×10^{-5}
Erdemli	22.65	12.4×10^{-5}
Gülнар	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}

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Table 3. The quantity of UME and our laboratory results for mercury.

	Mercury ($\mu\text{g/L}$)	
	Result	Uncertainty
UME	81.72	8.17
Laboratory	81.64	0.49

Table 4. 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	Aydıncık	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
	Kızılcı	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
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 Area	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 Kasabası	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
	Çamlı Yay. Mrkz.	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 of Erdemli	LDL	1.39±0.15	11.72±0.08	4.44±0.10	150.3±0.2	20.84±0.11

G�lnar	Bardat P. K�y�	LDL	LDL	12.00�0.27	3.67�0.19	3.49�0.12	58.47�0.13
	B�y�keceli	0.41�0.03	2.17�0.05	16.90�0.14	6.15�0.22	69.79�0.31	77.35�0.96
	G�lnar	LDL	LDL	8.10�0.18	3.29�0.19	11.08�0.07	15.79�0.16
	K�se�obanı	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	Burunk�y	0.48�0.09	7.75�0.24	3.89�0.61	3.53�0.36	23.01�0.19	7.56�0.03
	��melek	LDL	LDL	5.14�0.68	2.84�0.09	62.08�0.11	8.73�0.07
	Dı�ta�	0.37�0.06	2.04�0.04	3.84�0.08	4.01�0.18	21.57�0.16	24.43�0.12
	G�ksu	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
	Kar�ıyaka	0.51�0.12	LDL	8.06�0.22	2.93�0.20	43.06�0.86	8.42�0.06
	Kelcek�y	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
	Ke�lit�rkmenli	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
	Ye�ilovacık	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	Alada�lı	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

Table 5. Reference dose and cancer slope factors for heavy metals.

Heavy Metal	Reference Dose Values (R_{fd}) (mg/kg.day)			Cancer slope factors (SF) 1/(mg/kg/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
Cd**	1.0×10^{-3}	1.0×10^{-3}	1.0×10^{-5}	3.8×10^{-1}	6.3	3.8×10^{-1}
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

Table 6. Health risk levels due to heavy metal concentration in province drinking waters.

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}

1 **Table 7.** Water radioactivity studies carried out in different cities of Turkey.

Location	<u>Activity in Water (Bq/L)</u>	
	<u>Gross-α</u>	<u>Gross-β</u>
Istanbul, ⁸	0.023	0.070
Kırklareli, ²⁰	0.069	0.067
Çankırı, ²¹	0.250	0.260
Adana, ¹	0.010	0.086
Artvin, ⁹	0.046	0.091
Mersin	0.059	0.120
WHO, ²²	0.500	1

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1 **Table 8.** Heavy metal investigation carried out in different cities around the world.

Concentration in Drinking Water ($\mu\text{g/L}$)							
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	10046	-	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