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Heavy Metal Contamination and Remediation of Water and Soil with Case Studies From Cyprus

Mustafa Ertan Akün

Abstract

Some of the heavy metals, (arsenic, cadmium, chromium and nickel) tend to endanger public health, when found above critical limits in soil and water, becoming carcinogenic. The heavy metals are taken by humans through the food chain. As shown by numerous researchers all over the world, the heavy metal contamination mostly come from sewage waters and pesticides, as well as naturally. The natural resources come from the composition of the rock formations present at the area of study. One or all of the above mentioned sources of heavy metal contamination may be present. The study concentrates on the internationally accepted critical limits for soil and water, explains scientific methods of entering into vegetables and fruit, and also tries to shed light on the transfer factors of heavy metals imposing dangers on public health. Remediation of the contaminated soil and water is also discussed, and phytoremediation methods are brought forward, as compared with chemical methods. Details of different phytoremediation (phyto-accumulation, phyto-stabilization, phyto-degradation, phyto-volatilization, and hydraulic control) are also discussed. Actual case studies from North Cyprus are also provided, with real contamination levels observed. Different areas and soil/water/plant species were assessed in detail, displaying concentrations, critical limits, transfer factors, and recommendations.

Keywords: heavy metal, contamination, soil, water, critical limit, public health

1. Introduction

Public health necessitates concentrated efforts of researchers and public authorities and will be under risk if necessary and timely precautions are not undertaken. Soil and groundwaters are inputs for vegetables and fruits and thus animals and mankind as a whole. Sometimes, the sources of heavy metal contamination could as well be airborne. In certain cases, biomonitoring of airborne heavy metal contamination has been an important issue and has been carried out worldwide. Accordingly, during the last few decades, heavy metal contamination of biotic component of environment has attracted the attention of researchers. In this respect, biological materials were used as cheap indicators to determine airborne environmental pollution. Various types of plants (such as lichens, mosses, bark, and leaves of higher plants) were used to detect deposition, accumulation, and distribution of metal pollution and their accumulative potential [1].

Not only are the heavy metals carcinogenic, but many other diseases such as lung, liver, kidney, and similar diseases are also potential occurrences. Arsenic, cadmium, chromium, and nickel are accepted as group 1 carcinogens by the International Agency for Research on Cancer, and these heavy metals are at the same time utilized commercially [2]. Some other heavy metals are also carcinogenic in nature, and a relevant study listed cobalt, lead, and mercury in addition [3].

Although some of the heavy metals are known to be enhancing the immune system, the same heavy metals above critical limits and some others are hazardous heavy metals for human beings. The critical limits of heavy metals in soil and water are not only different, but they also differ from country to country. Although natural occurrences in different countries and the methods for contamination are the background reasons for this, it is at the same time dependent on the policy makers. Apart from the countries' legislations, some international organizations like the Environmental Protection Agency (EPA) and Food and Agriculture Organization (FAO) also announce and revise these limits periodically. **Table 1** shows critical limits for soils for different countries.

Critical limits of the EPA for water are given below in **Table 2**. The table explains maximum allowable contaminant levels for a wide range of chemicals, either carcinogen or resulting in different health problems.

Numerous researches arrived at scientific findings about the carcinogenic nature of some of the heavy metals and elements. Although not definite and including probability of being a carcinogen, studies reveal the imposed dangers involved, hinting precautions to be taken. Accordingly, the EPA has prepared specific results and cancer descriptors with relevant definitions. **Table 3** below explains cancer descriptors for certain elements.

The heavy metals and carcinogen elements enter the human body via the food chain. The food chain is the mechanism showing the route of heavy metals from soils and waters finally reaching plants, animals, and humans. **Figure 1** shows the journey of heavy metals via food chain.

Thus, public health necessitates to minimize the intake of hazardous heavy metals and elements and if possible to null the amounts. To render this possible, the methodologies by which these metals and elements enter the food chain must be understood correctly, and relevant precautions must be taken.

Country	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Australia	20	3	50	100	1	60	300	200
Canada	20	3	250	150	0.8	100	200	500
China	20–40	0.3–0.6	150–300	50–200	0.3–1.0	40–60	80	200–300
Germany	50	5	500	200	5	200	1000	600
Tanzania	1	1	100	200	2	100	200	150
Holland	76	13	180	190	36	100	530	720
NZ	17	3	290	>104	200	N/A	160	N/A
UK	43	1.8	N/A	N/A	26	230	N/A	N/A
USA	0.11	0.48	11	270	1	72	200	1100

Source: [4].

Table 1.
Regulatory standard of heavy metals in agricultural soil (mg/kg).

Chemicals	Maximum contaminant level (mg/L)	Cancer descriptor
Ammonia	—	D
Antimony	0.006	D
Arsenic	010	A
Asbestos	7 MFL	A
Barium	2	N
Beryllium	0.004	—
Boron	—	I
Bromate	0.01	B2
Cadmium	0.005	D
Chloramine3	4 ⁴	—
Chlorine	4 ⁴	D
Chlorine dioxide	0.84	D
Chlorite	1	D
Chromium	0.1	D
Copper	TT ⁶	D
Cyanide	0.2	I
Fluoride	4	—
Lead	TT ⁶	B2
Manganese	—	D
Mercury	0.002	D
Molybdenum	—	D
Nickel	—	—
Nitrate	10	—
Nitrite	1	—
Nitrate + Nitrite	10	—
Perchlorate2	—	L/N
Selenium	0.05	D
Silver	—	D
Strontium	—	D
Thallium	0.002	I
White phosphorous	—	D
Zinc	—	

Source: [5].

Table 2.
Standards of heavy metals in water and health advisories.

Descriptor	Definition
A	Human carcinogen
B	Probable human carcinogen
B1	Indicates limited human evidence
B2	Indicates sufficient evidence in animals and inadequate or no evidence in humans
C	Possible human carcinogen

Descriptor	Definition
D	Not classifiable as to human carcinogenicity
E	Evidence of non-carcinogenicity for humans
H	Carcinogenic to humans
I	Inadequate information to assess carcinogenic potential
L	Likely to be carcinogenic to humans
N	Not likely to be carcinogenic to humans
L/N	Likely to be carcinogenic above a specified dose but not likely to be carcinogenic below that dose because a key event in tumor formation does not occur below that dose
S	Suggestive evidence of carcinogenic potential

Source: [5].

Table 3.
Cancer descriptors.

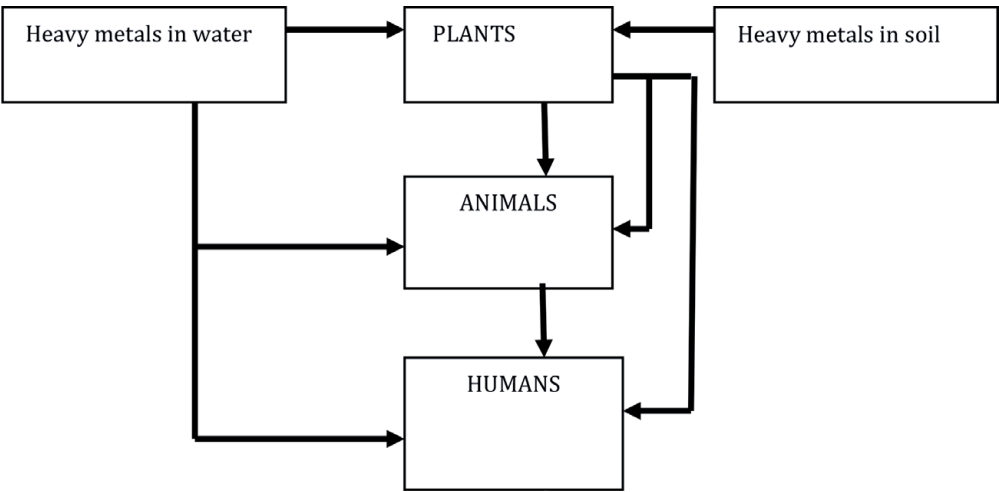


Figure 1.
Journey of heavy metals via food chain.

2. Soil and water contamination and remediation/precautions

There are numerous sources of heavy metal contamination of soils and water. These are briefly explained below:

- a. **Sewage waters:** This is an anthropogenic activity. The sewage waters are those collected via municipal, agricultural, and industrial origin [6]. The potential heavy metal inclusions from these sources are normally collected at treatment plants. Treatment results are never theoretically 100% efficient, and following the treatment process, disposed water is mostly utilized in irrigation of agricultural areas. The irrigation process then transfers the heavy metal content to soils and groundwaters.
- b. **Pesticides:** This is an anthropogenic activity. Many plants (vegetables, fruits, and trees) are under the attack of certain pests and are not only decreasing the quality of the products but also contaminating them with heavy metals, due to the presence of such. The research carried out on the heavy metal

levels of spinach [7] following the application of pesticides (DELVAP 1000 EC) displayed that the concentrations before and after the pesticide application changed significantly. The application of pesticides also contaminates the soil in the surrounding, and the included heavy metals may also reach the groundwaters.

c. **Natural resources:** This is a natural activity. Many elements and heavy metals can be naturally present in the surrounding, and erosion of these rock formations including such elements and heavy metals can be transformed into soil. Downward percolation of rain waters may as well result in the arrival of such to groundwaters. A related research forwards that under different and certain environmental conditions, natural emissions of heavy metals occur that may in turn lead to the release of metals from their endemic spheres to different environment compartments [8].

2.1 Types of remediation

The remediation methodologies can be chemical or biological in nature. Since heavy metal contamination itself is a chemical process, chemical remediation should be avoided, and biological processes should be introduced. The phytoremediation of heavy metals from the contaminated sites generally happens through any one or more of the following mechanisms or processes [9]: “phyto-accumulation,” “phyto-stabilization,” “phyto-degradation,” “phyto-volatilization,” and “hydraulic control.”

2.1.1 Phyto-accumulation

Phyto-accumulation is a mechanism through which heavy metals in soil and water at a specific region are accumulated in native plants and are disposed thereafter. In a research carried out in Pakistan [10], heavy metal accumulation in crops and soils from wastewater irrigation was realized via the usage of *Cannabis sativa* L., *Chenopodium album* L., *Datura stramonium* L., *Sonchus asper* L., *Amaranthus viridis* L., *Oenothera rosea* (LHer), *Xanthium stramonium* L., *Polygonum macalosa* L., *Nasturtium officinale* L., and *Conyza canadensis* L. Metal concentrations are in the order iron (Fe) > zinc (Zn) > chromium (Cr) > nickel (Ni) > cadmium (Cd). Most of the species accumulated more heavy metals in roots than shoots. Among species, the concentrations were in the order *C. sativa* > *C. album* > *X. stramonium* > *C. canadensis* > *A. viridis* > *N. officinale* > *P. macalosa* > *D. stramonium* > *S. asper* > *O. rosea*.

In this mechanism, bio-concentration factor (BCF) and biological absorption coefficient (BAC) are also important parameters to be considered. According to the international guidelines, “bioaccumulation” is the process where chemical concentration in an aquatic organism reaches a level that exceeds that in the water as a result of chemical uptake through all routes of chemical exposure. Bioaccumulation takes place under field conditions and is a combination of chemical bio-concentration and biomagnification.

On the other hand, metal accumulation is expressed by the metal biological absorption coefficient (BAC) or the plant-to-soil/water metal concentration ratio. Bio-concentration factors are used to relate pollutant residues in aquatic organisms to the pollutant concentration in ambient waters. Many chemical compounds, especially those with a hydrophobic component, partition easily into the lipids and lipid membranes of organisms and bioaccumulate.

BCF and BAC are described by the following formulas:

$$\text{BCF} = \text{CB}/\text{CWD} = k_1/(k_2 + k_E + k_M + k_G) \quad (1)$$

$$\text{BAC} = \text{CB}/\text{CWD} = \{k_1 + k_D (\text{CB}/\text{CWD})\}/(k_2 + k_E + k_M + k_G) \quad (2)$$

where CB is the chemical concentration in the organism (g/kg^{-1}), k_1 is the chemical uptake rate constant from the water at the respiratory surface ($\text{L}\cdot\text{kg}^{-1}\cdot\text{d}^{-1}$), CWD is the freely dissolved chemical concentration in the water ($\text{g}\cdot\text{L}^{-1}$), k_D is the uptake rate constant for chemical in the diet ($\text{kg} \times \text{kg}^{-1} \times \text{d}^{-1}$), and k_2 , k_E , k_M , and k_G are rate constants (d^{-1}) representing chemical elimination from the organism via the respiratory surface, fecal egestion, metabolic biotransformation, and growth dilution, respectively.

Phyto-accumulation for arsenic was adopted in India and Bangladesh by utilizing two different plant species, namely, *Pteris vittata* and *Chrysopogon zizanioides*. Laboratory scale studies gave way to observations regarding growth of these plants in different concentrations of 10–50 mg As/kg soil. Arsenic accumulation in leaves, stem, and root were analyzed at different time intervals, observing survival of plants. Results were encouraging, and it was observed that they could accumulate significant amounts of arsenic [11].

2.1.2 Phyto-stabilization

Phyto-stabilization comprises the establishment of a plant cover on the surface of the contaminated sites for reducing the mobility of contaminants within the vadose zone via accumulation by roots or immobilization within the rhizosphere, reducing off-site contamination [12]. The process includes transpiration and root growth that immobilizes contaminants by reducing leaching, controlling erosion, creating an aerobic environment in the root zone, and adding organic matter to the substrate that binds the contaminant.

Microbial activity related with the plant roots may accelerate the degradation of organic contaminants such as pesticides and hydrocarbons to nontoxic forms. Phyto-stabilization can be enhanced by using soil amendments that immobilize metal(loid)s combined with plant species that are tolerant of high levels of contaminants and low-fertility soils or tailings. Although effective in the containment of metal(loid)s, the site requires regular monitoring to ensure that the stabilizing conditions are maintained. Soil amendments used to enhance immobilization may need to be periodically reapplied to maintain their effectiveness.

2.1.3 Phyto-degradation

Phyto-degradation, which is also known as phyto-transformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant or the breakdown of contaminants surrounding the plant through the effect of enzymes produced by the plants. Plants are able to produce enzymes that catalyze and accelerate degradation. Hence, organic pollutants are broken down into simpler molecular forms and are incorporated into plant tissues to aid plant growth.

Figure 2 shows the degradation process. Enzymes in plant roots break down (degrade) organic contaminants. The fragments are incorporated into new plant material.

A relevant research [13] put forth that the phyto-degradation of organic compounds can take place inside the plant or within the rhizosphere of the plant.

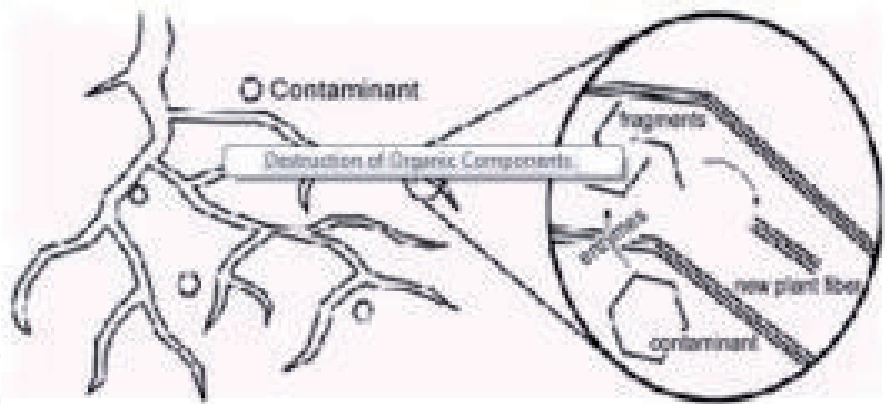


Figure 2.
Degradation process.

Many different compounds and compound classes can be removed from the environment by phyto-degradation, including solvents in groundwater, petroleum and aromatic compounds in soils, and volatile compounds in the air. Although currently a relatively new area of research, studies regarding the underlying science necessary for a wide range of applications for plant-based remediation of organic contaminants are continuing.

2.1.4 *Phyto-volatilization*

Phyto-volatilization is a process where plants take up contaminants from soil and release them as volatile form into the atmosphere via transpiration. The process occurs as growing plants absorb water and organic contaminants.

It is possible for plants to interact with a variety of organic compounds and affect the fate and transport of many environmental contaminants. Volatile organic compounds may be volatilized from stems or leaves (direct phyto-volatilization) or from soil due to plant root activities (indirect phyto-volatilization) [14]. Fluxes of contaminants volatilizing from plants range from local contaminant spills to global fluxes of methane emanating biochemically reducing organic carbon. In this article past studies are reviewed to differentiate between direct and indirect phyto-volatilization. Findings of the study revealed that compounds with low octanol-air partitioning coefficients are more likely to be phyto-volatilized. Reports of direct phyto-volatilization compared favorably to model predictions. **Figure 3** represents direct and indirect phyto-volatilization.

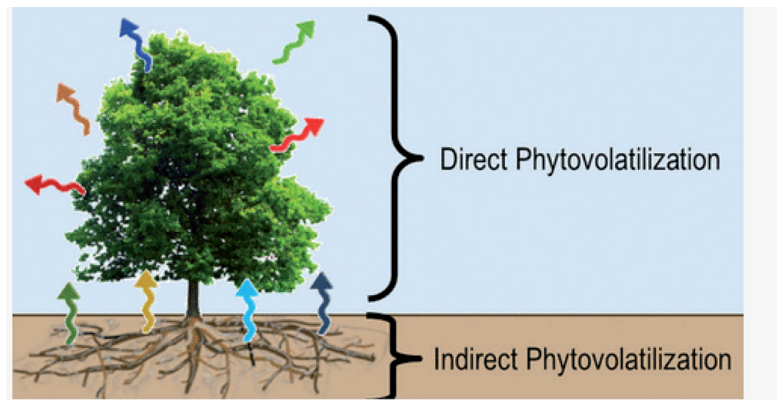


Figure 3.
Direct and indirect phyto-volatilization.

2.1.5 Hydraulic control

Hydraulic control is the method of phytoremediation, where the contaminated aqueous medium's flow direction is altered and contaminated flow is oriented. The relevant research study [15] designed such a system at the field.

The goal of this hydraulic capture model for remediation purposes was to design a well field so that the groundwater flow direction was altered. In so doing, halting or reversing the migration of a contaminant plume was made possible. Management strategies typically require a well design that will contain or shrink a plume at minimum cost. Objective functions and constraints can be nonlinear, non-convex, non-differentiable, or even discontinuous. Computational efficiency and accuracy is normally desirable and often affects the solution method.

2.2 Precautions against soil and water contamination

The precautions against contamination also differ according to the sources of contamination.

Accordingly, the precautions according to the sources are provided below:

- a. **Sewage waters:** The *municipal* sewage waters are those connected from houses at inhabited areas. Hazardous elements and heavy metals may enter the system from any location by any liquid or solid. The inhabitants must be trained about the disposal system at the start point to minimize their entrance into the system. Frequent analysis of input and output at the treatment plant must be carried out; methods of minimizing contamination levels must be employed; and output containing hazardous elements and heavy metals with lower than critical limits must be used for irrigation purposes. The *agricultural* sewage waters are those collected at the farms and greenhouses used for cleaning purposes. These may from time to time include disposed plant parts, some soil, and some fertilizers. Thus, probability of presence of hazardous elements and heavy metals is quite high, and serious precautions are necessary. These are also entering the treatment plants, and like municipal sewage waters, the relevant people must again be trained about the disposal system at the start point to minimize their entrance into the system. Frequent analysis of input and output at the treatment plant must again be carried out; methods of minimizing contamination levels must be employed; and output containing hazardous elements and heavy metals with lower than critical limits must be used for irrigation purposes. The most dangerous of the types of sewage waters is definitely *industrial* sewage waters. This group includes slaughterhouse waste, whey of milk processing factories, paint factory waste, animal breeding waste, and similar factory wastes. These also enter treatment plants, and again frequent input and output sewage analysis is required. The relevant people must again be trained about the disposal system to minimize their entrance into the system.
- b. **Pesticides:** Though the application of pesticides is connected with the quality of the agricultural products, the included heavy metals are in fact decreasing the quality and reliability. In many countries, many pesticide types are banned in conformance with the technological advancements and information regarding heavy metals. A study carried out in Nigeria showed the presence of heavy metals (Pb, As, Cd, Cr, and Zn) in different parts of the plants and at different concentrations, with some above the WHO/FAO permissible

limits [16]. At some instances, it may become must to apply the pesticide, and under such circumstances, the adequate dose must be applied by expert personnel.

c. **Natural resources:** Just like the areas polluted by anthropogenic activities, in case of natural occurrence of heavy metals also, bioremediation can be an effective precaution. A relevant research titled “**Heavy Metal Polluted Soils: Effect on Plants and Bioremediation Methods**” in 2014 applied bioremediation and analyzed the results [17]. Microorganisms and plants employ different mechanisms for the bioremediation of polluted soils. Using plants for the treatment of polluted soils is a more common approach in the bioremediation of heavy metal polluted soils. Combining both microorganisms and plants is an approach to bioremediation that ensures a more efficient cleanup of heavy metal polluted soils. However, success of this approach largely depends on the species of organisms involved in the process.

3. Case studies of soil and water contamination from Cyprus

3.1 Arsenic, cadmium, and lead distribution of Cyprus soils

Selected locations in Cyprus were investigated by the Cancer Research Fund and Frederick Institute of Technology in search of distribution of heavy metals. The collaborative research investigated for lead, arsenic, and cadmium [18]. The observations of cancer incidents triggered the research all over the island, and the findings displayed contamination at certain areas. To achieve an analytical distribution, 260 composite soil samples (140 from North Cyprus and 120 from South Cyprus) were investigated for the presence of heavy metal contamination. The soil samples were obtained from Güzelyurt Bostancı, Yuvacık, Lefkoşa, Karpaz, Alevkayası, Kırnı, and Mesarya in North Cyprus. The concentration of lead in these areas ranged between 8 and 45 ppm, while that of arsenic ranged between 8 and 15 ppm and that of cadmium ranged between 0 and 0.7 ppm. These findings are given in **Table 4**.

In South Cyprus, the soil samples were obtained from Dali, Sotira, Omodos, Acheleia, Polis, and Evrychou. The concentration of lead in these areas ranged between 6 and 53 ppm, while that of arsenic ranged between 6 and 19 ppm and that of cadmium ranged between 0 and 0.4 ppm, given below in **Table 5**.

Area	Pb (ppm)	As (ppm)	Cd (ppm)
Alevkayası	32.58	11.25	0.34
Lefkoşa	44.29	11.87	0.69
Kırnı	40.51	14.63	0.47
Yuvacık	32.42	8.98	0.34
Bostancı	8.02	9.47	0.2
Mesarya	12.6	11.09	0.33
Karpaz	17.19	13.56	0.3

Source: [18]

Table 4.
Distribution of lead, arsenic, and cadmium in North Cyprus.

Area	Pb (ppm)	As (ppm)	Cd (ppm)
Dali	10.25	7.17	0.39
Sotira	14.02	11.68	0.26
Omodos	6.81	6.37	0.20
Acheleia	20.58	10.06	0.35
Evrychou	52.39	18.30	0.26
Polis	13.59	12.43	0.23

Source: [18]

Table 5.
Distribution of lead, arsenic, and cadmium in South Cyprus.

The regulatory standards given in **Table 1** hints that lead can be at safe concentrations but arsenic and cadmium need attention and may be regarded as present at above critical limits.

3.2 Heavy metal contamination of agricultural soils of Yedidalga abandoned copper mine

At Yedidalga harbor of abandoned copper mine at North Cyprus, agricultural soils were investigated for levels of soil contamination by heavy metals. **Figure 4** shows the study area and the sampling locations.

Copper, lead, chromium, cadmium, and zinc concentrations were investigated on samples collected at nine different locations. The heavy metal contents were

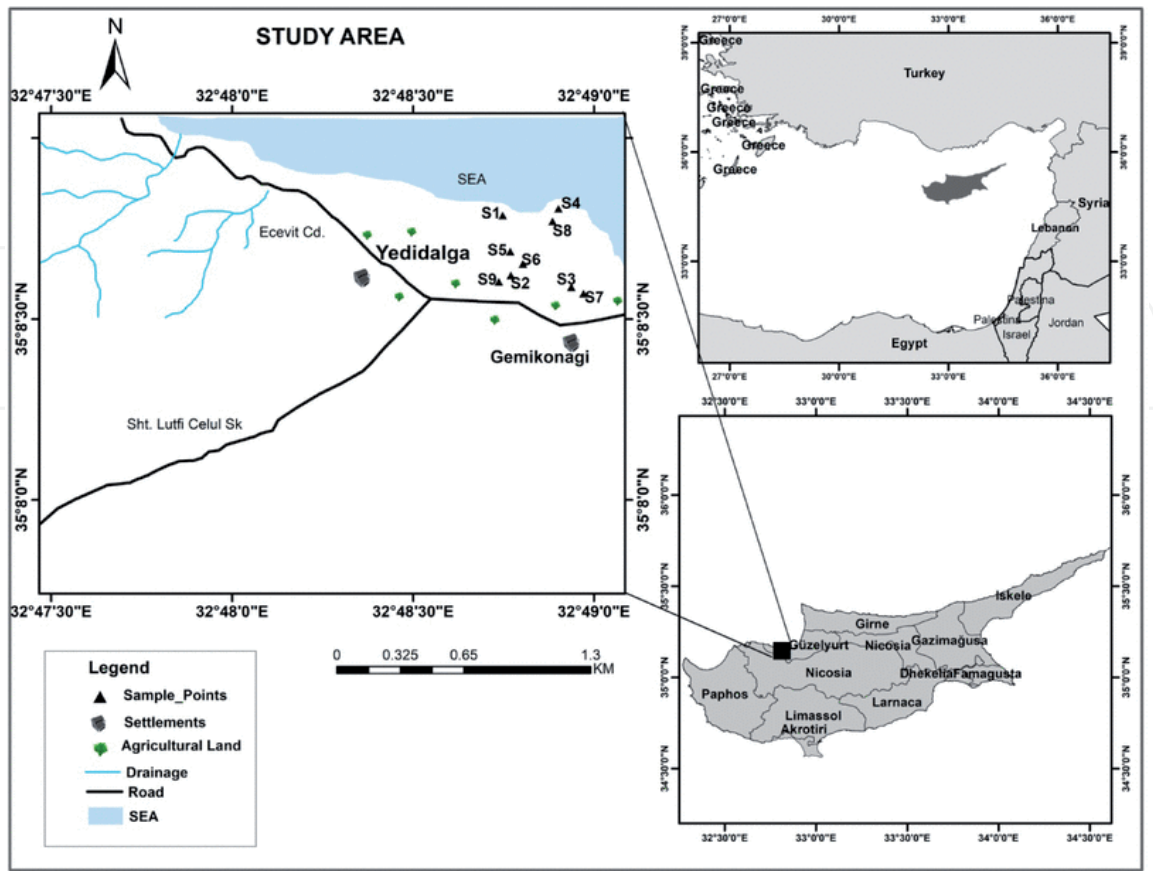


Figure 4.
Study area and sampling locations [19].

determined using atomic absorption spectrophotometer (AAS). The results obtained are presented in **Figure 5**.

The findings displayed average concentration levels (mg/kg) as follows: Cu, 208.4; Pb, 119.4; Cr, 18.38; Cd, 6.19; and Zn, 144.2. The corresponding critical limits of the same heavy metals are as follows: Cu, 13–24; Pb, 22–44; Cr, 12–83; Cd, 0.37–0.78; and Zn, 45–100. Accordingly, there is significant pollution of Cu, Pb, Cd, and Zn, while there is no pollution with respect to Cr.

The study also evaluated the level of contamination and assessed the potential ecological risk posed by heavy metals. Several quantitative indices were utilized to assess the soil pollution status. Results revealed that comparatively all heavy metals exceeded the background values. The peak values were observed in the soils from the locations close to the Yedidalga farming lands. Spatial distribution of pollution load index (PLI) and potential ecological risk index (RI) is given in **Figure 6**.

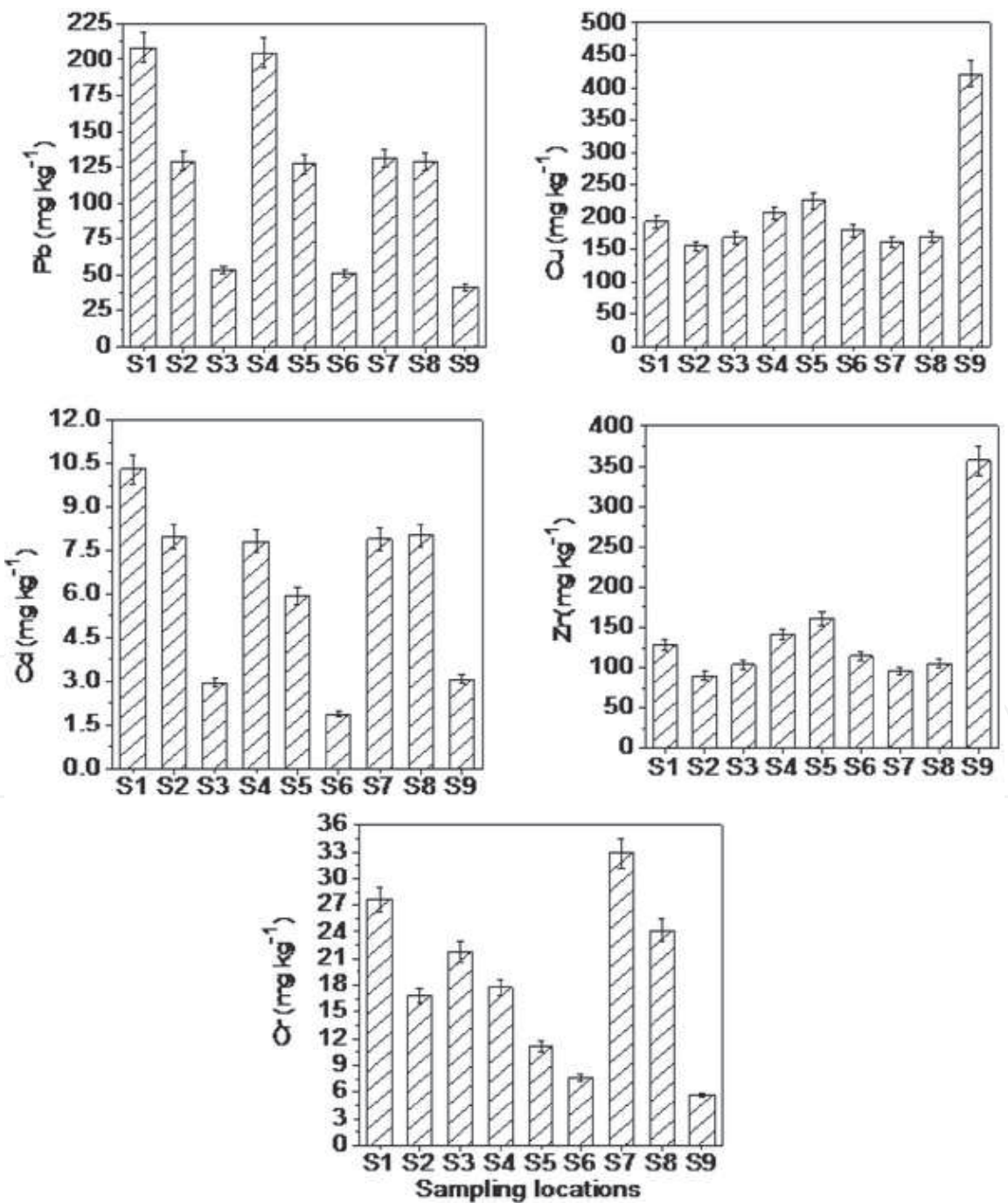


Figure 5.
Heavy metal contamination levels at Yedidalga harbor [19].

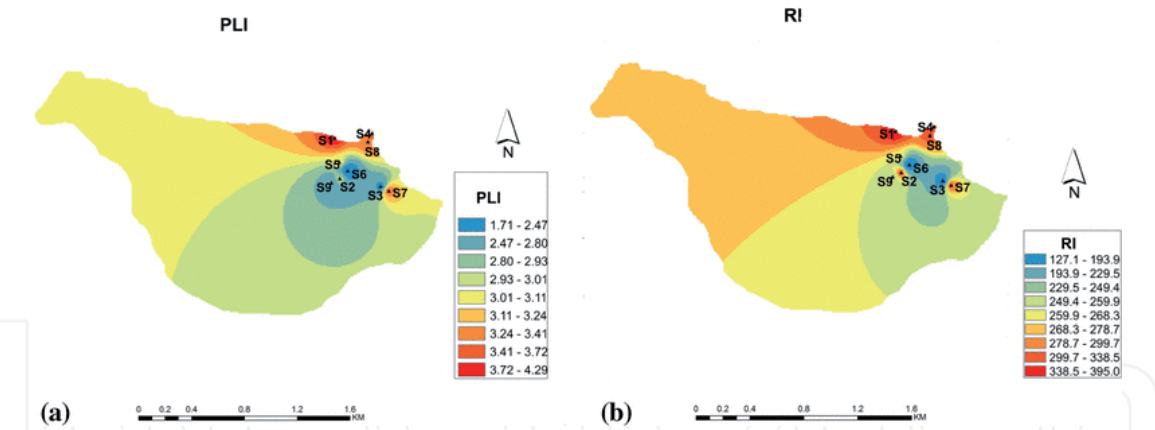


Figure 6. Spatial distributions of PLI and RI [19].

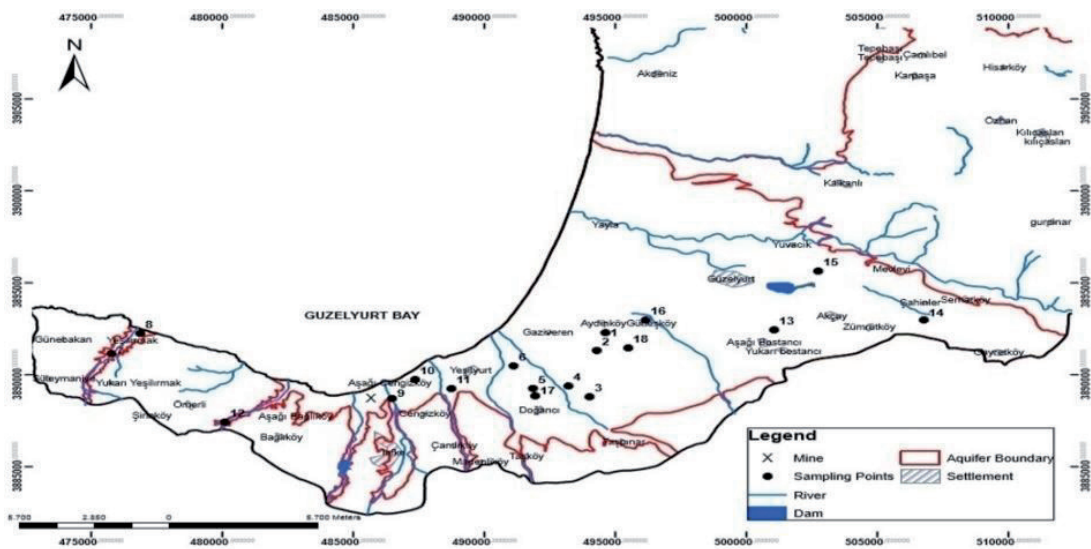


Figure 7. Sample collecting locations [20].

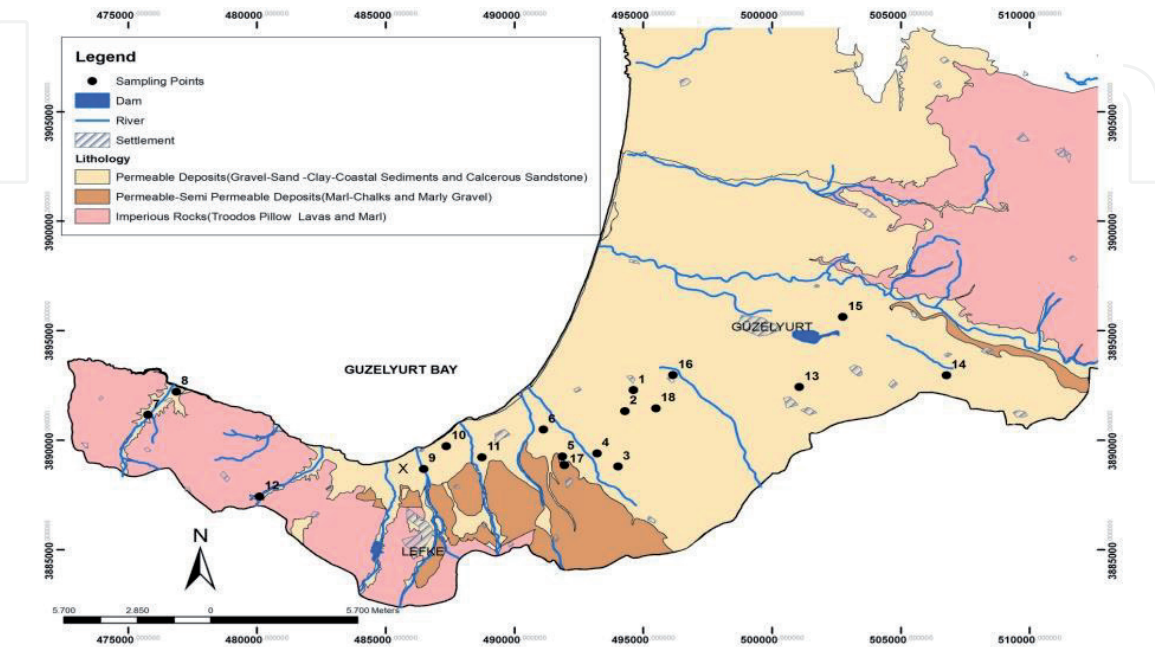


Figure 8. Geological nature of study area [20].

Sample no	As (µg/L)	Cd (µg/L)	Cr (µg/L)	Hg (µg/L)	Pb (µg/L)	Fe (µg/L)
1	2.95 ± 0.02	<0.01	6.97 ± 0.19	0.11 ± 0.006	<0.01	1266.9 ± 11.55
2	0.71 ± 0.03	<0.01	12.16 ± 0.06	0.03 ± 0.01	0.24 ± 0.01	305.24 ± 0.88
3	0.47 ± 0.03	<0.01	5.79 ± 0.06	0.03 ± 0.01	1.09 ± 0.01	310.57 ± 4.26
4	0.41 ± 0.00	<0.01	5.78 ± 0.18	0.01 ± 0.01	1.25 ± 0.03	260.57 ± 9.67
5	0.93 ± 0.04	<0.01	14.46 ± 0.10	0.02 ± 0.01	<0.01	186.57 ± 6.84
6	1.43 ± 0.05	<0.01	8.10 ± 0.03	0.03 ± 0.01	1.40 ± 0.05	392.24 ± 1.76
7	0.05 ± 0.01	0.02 ± 0.01	0.32 ± 0.01	<0.01	0.21 ± 0.01	294.90 ± 14.64
8	0.61 ± 0.02	0.03 ± 0.01	0.57 ± 0.01	0.01 ± 0.01	<0.01	602.24 ± 3.48
9	0.19 ± 0.01	0.03 ± 0.01	0.85 ± 0.01	<0.01	0.01 ± 0.003	600.90 ± 25.48
10	1.12 ± 0.01	0.04 ± 0.01	7.44 ± 0.08	0.03 ± 0.01	<0.01	686.90 ± 1.53
11	0.18 ± 0.01	0.01 ± 0.01	9.31 ± 0.12	0.01 ± 0.01	0.03 ± 0.01	313.90 ± 2.89
12	0.12 ± 0.01	0.01 ± 0.01	0.13 ± 0.01	<0.01	0.26 ± 0.01	532.90 ± 7.55
13	0.92 ± 0.01	0.08 ± 0.01	9.55 ± 0.30	<0.01	0.71 ± 0.02	2253.57 ± 61.73
14	0.32 ± 0.03	0.01 ± 0.01	1.17 ± 0.09	<0.01	0.63 ± 0.01	302.90 ± 4.16
15	0.88 ± 0.01	0.03 ± 0.01	2.25 ± 0.02	0.01 ± 0.01	2.79 ± 0.03	370.24 ± 3.76
16	1.49 ± 0.02	<0.01	12.42 ± 0.07	0.02 ± 0.01	0.33 ± 0.03	577.90 ± 0.58
17	0.63 ± 0.01	0.01 ± 0.01	13.39 ± 0.17	0.01 ± 0.01	0.67 ± 0.02	386.90 ± 6.08
18	3.07 ± 0.02	<0.01	11.86 ± 0.01	0.03 ± 0.01	0.68 ± 0.01	754.24 ± 3.84

Table 6.
Heavy metal distribution of Güzeyurt agricultural waters.

Pollution load index graded the overall studied area as moderately–heavily contaminated level. Potential ecological risk analysis forwarded that the ecological risk level indicated that 55.6% of sampling locations exceeded 300 ($RI > 300$). These study results definitely suggest that pollution precautions must be implemented. The main cause of accumulation of these metals is found to be related with the presence of mine wastes at Yedidalga mine harbor.

3.3 Quality and heavy metal contamination of Güzelyurt agricultural waters

The most active agricultural region of Güzelyurt in North Cyprus was investigated with respect to agricultural quality and heavy metal content. At the same time, the aim of the research is to shed light on the irrigation water management in the said region and to assess the groundwater quality. The management methodology was studied, and representative groundwater samples collected from different villages (**Figure 7**) were analyzed for physicochemical parameters and contamination [20].

Within the scope of the study, the geological nature of the study area is also effective and is given in **Figure 8**.

The research put forth that the concentration of heavy metals was all below the FAO guideline threshold limits, following the order $Fe > Cr > As > Pb > Hg > Cd$. **Table 6** displays the distribution of heavy metals at the study area.

Main cations, on the other hand, indicated $Na^+ > Mg^{2+} > Ca^{2+} > K^+$, while that of anions displayed $Cl^- > HCO_3^- > SO_4^{2-} > CO_3^{2-}$ that comply with irrigation water standards. Seawater intrusion was determined by Revelle index; piper diagram indicated $Ca^{2+} + Mg^{2+} + Cl^-$ as the major hydro chemical facies; and USSL salinity diagram was also used for salinity and sodium hazard. Irrigation water quality was evaluated by sodium adsorption ratio (SAR), residual sodium carbonate, percent of sodium, magnesium adsorption ratio (MAR), Kelly's index, total hardness, permeability index, residual Mg^{2+}/Ca^{2+} ratio, and electrical conductivity. Only SAR values displayed perfect groundwater quality, while others showed good quality, except for MAR, which was unsuitable.

In conclusion, the study put forth in general the safe use of the groundwater for the purpose of irrigation. High amounts of Mg^{2+} in water resulted in unsuitable MAR values. Majority of groundwater samples were in the field of $Ca^{2+} + Mg^{2+} + Cl^-$ water types. Lack of water management policies brings problems to farmers.

4. Conclusion

Heavy metal contamination of water and soil is dangerous to human life; but the issue becomes much critical when the region in question is an agricultural region. The reason behind this is the entrance of natural or anthropogenic potential hazardous heavy metals into the human body via food chain. Not only conventional diseases but various cancer diseases are also observed as a result of research studies.

Consequently, agricultural soil and water must be carefully investigated before the initiation of the agricultural activities. Acceptable sampling and laboratory analyses should be executed and evaluated accordingly. In this respect, sources of contamination (natural or anthropogenic) have to be identified and analyzed for the presence of contamination.

In case of presence of contamination of soil and water by heavy metals, and if the concentrations are above the acceptable limits, necessary and timely precautions must be taken. Of the general biological and chemical methods of remediation, the former should be preferred, so as not to introduce new chemicals to the medium.

The method of remediation must be selected among *phyto-accumulation*, *phyto-stabilization*, *phyto-degradation*, *phyto-volatilization*, and *hydraulic control*. There are numerous researches which discuss different types of plant species getting rid of heavy metals through different methods, without introducing new chemical contaminations.

Such research should not only be left on paper and must be implemented in agricultural regions all over the world, with the objective of enhancing the health and well-being of the humans. Creating necessary awareness in areas of potential contamination through social responsibility projects will enhance such studies.

Author details

Mustafa Ertan Akün

Faculty of Engineering, Cancer Research Foundation, Biotechnology Research Center, Environmental Research Center, Cyprus International University, Turkish Republic of North Cyprus, Turkey

*Address all correspondence to: eakun@ciu.edu.tr

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