J Open
http://dx.doi.org/10.70728/jopen.be.0425.003

ARTICLE

Distribution and Interrelationship of Heavy Metals and Metalloids in Irrigated Soils

Avazbek T.Turdaliev [1,*], **Avazbek A. Ahmadjonov** [1], **Kamoliddin A. Askarov** [1] **and Iskandar I. Musaev** [1]

[1] Fergana State University, 19, Murabbiylar Street, Fergana City, 712000, Uzbekistan

Abstract

The article studies the content of heavy metals and metalloids in irrigated meadow saz soils and light gray soils (calcisols), their distribution dynamics and interrelationships. In the work, the migration and accumulation of heavy metals and metalloids in the genetic layers of meadow saz soils and light gray soils with different levels of irrigation were determined, and background values were developed. At the same time, the migration dynamics of heavy metals and metalloids in soil layers and the relationships between chemical elements were revealed through geochemical spectra.

Keywords: meadow saz soils, light gray soil (calcisols), heavy metals, metalloids, migration, accumulation, spectrum.

Citation
Avazbek T.Turdaliev, Avazbek A. Ahmadjonov, Kamoliddin A. Askarov, & Iskandar I. Musaev (2025). Distribution and Interrelationship of Heavy Metals and Metalloids in Irrigated Soils. J Open, 01(04), 14–19.

Submitted: July, 2025
Accepted: November, 2025
Published: December, 2025

Vol. 01, **No.** 04, 2025.
10.70728/jopen.be.0425.003

***Corresponding author:**
✉ Avazbek T.Turdaliev
avazbek1002@mail.ru

1 Introduction

In recent years, in many regions of the world, issues related to managing the quantity and balance of chemical elements in irrigated soils, conducting organic farming from an environmental purity standpoint, identifying various changes occurring in soils, preventing adverse processes within them, and establishing permissible threshold levels and background values of chemical elements have become among the most pressing scientific research challenges.

2 Literature Review and Methodology

It is well known that heavy metals are among the most significant pollutants of the environment. In particular, the soils of cities with a long history of industrial activity are heavily contaminated with these elements. Heavy metals emitted from metallurgical plants, coal-based thermal power stations, and other industrial facilities are dispersed over long distances through the atmosphere and subsequently deposited on agricultural lands. In addition, heavy metals enter agricultural soils through organic and mineral fertilizers, various ameliorants, and plant protection agents.

The forms, accumulation, and differentiation processes of heavy metals and metalloids in soils depend on various factors. In irrigated soils, the accumulation of chemical elements is mainly associated with the properties of the soils and soil-forming rocks, as well as the characteristics of the plant cover.

It is also important not to overlook the flux of elements originating from the atmosphere. According to G.A. Motuzova [1], the atmospheric emissions of As, Cd, Mn, Pb, Zn, Hg, Mo, Sb, and others are comparable to the quantities that naturally enter soils. Nevertheless, V.V. Dobrovolskiy [2] reports that, despite the global movement of elements, the resulting soil contamination remains extremely small.

The quantity, quality, and migration of chemical elements differ across soil types, subtypes, and varieties. Here, the diversity of soil-forming rocks must also be acknowledged. For instance, in the Fergana Valley, alluvial, alluvial-proluvial, and other deposits occur, differing in genesis and composition. They vary in carbonate and gypsum content and, in most cases, exhibit medium to heavy loamy granulometric composition, although light-loam parent materials are also found.

According to the literature, light-textured soils are characterized by weakly weathered primary minerals, whereas heavy-textured soils typically contain secondary clay minerals.

Motuzova G.V. [1] and others note that the elements constituting primary minerals tend to remain relatively conservative during soil formation.

In migration processes, the chemical and physical properties of elements—such as ionic radius, the number of electrons in the outer shell, electronic configuration, charge, ionization potential, and others—play a significant role. For example, Beus et al. [3] indicate that the isomorphic substitution of elements within primary minerals influences their migration.

During weathering, metals are released from primary minerals into the soil solution or onto mineral surfaces through desorption processes. Elements embedded within the internal structure of minerals, firmly fixed within their lattice, become mobilized and liberated as the minerals break down. Secondary minerals exhibit a considerably greater capacity for releasing elements.

Lanthanides possess the ability to undergo transformation during soil formation. Elements that enter the soil and its parent material typically form compounds that are thermodynamically less stable, as they encounter an environment fundamentally different from their original conditions. Consequently, the transformation of these compounds in the soil may yield relatively more stable forms.

The most critical phase in element transformation is the transition from the solid phase to the liquid phase, that is, into the soil solution. In many cases, this transition is irreversible.

Heavy metals, rare elements, lanthanides, and radioactive substances accumulate or migrate at various depths within soil horizons depending on several properties of the elements and the characteristics of the soils themselves. In some cases, these substances may even migrate beyond the soil profile.

Furthermore, the geochemical and biogeochemical properties of soils have been discussed in the works of A.I. Perelman [4], M.A. Glazovskaya [5], Kabata-Pendias [6], E.V. Abakumov [7], A.T. Turdaliev [8], K.A. Askarov [9], M.M. Khaydarov [10], and others.

Such information is limited for a group of elements (La, Ce, Nd, Sm, Eu, Tb, Yb, Lu, Th, U); for many of these, background concentrations in most soils have not yet been determined. Nevertheless, these data hold significant theoretical and practical importance for understanding current soil formation processes.

Field studies were conducted using V.V. Dokuchaev's method, that is, the morphogenetic approach. The total contents of heavy metals and metalloids in soils were determined at the Institute of Nuclear Physics of the Academy of Sciences of Uzbekistan using the neutron activation method. Correlations among chemical elements were analyzed through mathematical-statistical processing using the "Microelement" software, developed on the basis of Y.A. Dmitriev's [11] methodology.

3 Results and Discussion

Chemical elements within soil migrate through soil horizons and the surrounding environment, and in most cases, they accumulate within specific genetic layers of the soil. Numerous scholars have described the migration processes of elements among soil, soil solution, and plants in various ways.

Lanthanides—La, Ce, Nd, Sm, Eu, Gd, Th, Yb, and Lu—are generally present in rocks and soils in the +3 valence state. The concentrations of lanthanides and radioactive elements in the genetic horizons of irrigated meadow saz soils and light calcisols are presented in Table 1. As can be seen from these data, as the atomic mass of the elements increases, their concentrations decrease.

Table 1. Contents of Lanthanides and Radioactive Elements in Irrigated Soils, mg/kg

Profile No.	Depth, cm	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Th	U
Meadow Saz Soils											
4. A	0–32	30,8	46	12,6	3,95	0,81	0,52	1,8	0,19	8,9	3,8
	32–45	31,4	47	22,0	3,96	0,83	0,51	1,8	0,21	8,5	4,6
	45–58	23,0	36	15,9	3,21	0,64	0,41	1,5	0,15	6,7	3,5
	58–98	26,9	41	13,6	3,53	0,71	0,44	1,6	0,17	7,8	3,7
	98–114	20,2	31	10,8	2,38	0,71	0,37	1,4	0,15	5,4	2,4
	114–129	23,9	38	18,8	3,40	0,69	0,45	1,5	0,16	7,2	4,0
	129–192	28,6	44	15,2	3,47	0,77	0,50	1,7	0,20	12,0	3,9
11. A	0–27	28,3	45	29,5	3,80	0,78	0,54	1,8	0,21	8,4	4,9
	27–40	27,9	45	10,0	3,63	0,80	0,49	1,9	0,21	8,1	5,0
	40–66	28,8	45	30,7	3,70	0,68	0,47	1,8	0,18	8,8	3,3
	66–95	25,5	41	17,4	3,65	0,74	0,43	1,6	0,19	7,0	4,4
	95–118	26,8	42	15,6	3,83	0,78	0,45	1,7	0,20	7,5	3,1
	118–185	25,6	36	11,3	2,94	0,67	0,41	1,4	0,13	6,7	3,7
Average		**26,7**	**41**	**17,2**	**3,50**	**0,74**	**0,46**	**1,65**	**0,18**	**7,9**	**3,9**
Light Calcisols											
16. A	0–17	32,2	51	23,8	4,29	0,89	0,60	2,1	0,23	9,2	4,0
	17–34	30,8	54	21,2	4,10	0,91	0,56	2,2	0,26	9,5	4,2
	34–60	31,9	54	20,2	4,85	0,81	1,2	2,1	0,24	23,0	21,0
	60–95	26,3	52	13,5	3,58	0,89	0,57	2,0	0,20	8,4	3,7
	95–150	34,5	62	20,0	4,32	0,91	0,60	2,3	0,26	13,0	5,0
23. A	0–28	32,2	52	17,5	4,38	0,89	0,59	2,0	0,23	8,6	3,4
	28–40	37,8	68	21,6	4,36	0,87	0,59	2,0	0,061	12,0	3,8
	40–65	53,2	93	40,8	5,33	1,0	0,69	2,3	0,24	24,0	4,2
	65–140	42,7	83	36,9	4,42	0,89	0,43	2,1	0,096	17,0	3,9
Average		**35,7**	**63**	**23,9**	**4,40**	**0,90**	**0,65**	**2,1**	**0,20**	**13,9**	**5,9**
Lithospheric Clarke Value		**29**	**70**	**37**	**8**	**1,3**	**4,3**	**0,33**	**0,8**	**13**	**2,5**

According to the table, the highest concentrations are associated with Ce and La. In the studied meadow saz soils soil horizons, Ce ranges from 31 to 47 mg/kg (average 41 mg/kg), and La ranges from 20.2 to 31.4 mg/kg (average 26.7 mg/kg). In light calcisols, their respective ranges are 51–93 mg/kg (average 63 mg/kg) and 26.3–53.2 mg/kg (average 35.7 mg/kg). The highest concentrations are found in long-irrigated light calcisols. These are followed by Nd, which averages 17.2 mg/kg in meadow saz soils and 23.9 mg/kg in light calcisols.

For the remaining lanthanides studied, no substantial differences in sequential concentrations are observed; overall, they range from 0.18 to 4.40 mg/kg across soil horizons. The lowest values correspond to Lu. However, Yb concentrations in all soil layers exceed the lithospheric Clarke values, indicating accumulation in both soil types.

The concentrations of radioactive elements such as Th and U are relatively low, ranging from 3.9 to 13.9 mg/kg. Nevertheless, uranium concentrations exceed the lithospheric Clarke values in nearly all soil layers, and in light calcisols, thorium levels are also slightly higher than the Clarke value. This indicates a potential risk of contamination by radioactive substances in these soils.

Overall, it was determined that the concentrations of all analyzed chemical elements are slightly higher in light calcisols compared to meadow saz soils (Figure 1). The concentration of La in light calcisols also exceeds its lithospheric Clarke value.

The forms in which elements occur determine the extent to which they migrate from soil into plants and water. For example, the total content of a chemical element in soil has been shown to demonstrate the high practical effectiveness of its hygienic standards [3].

In Western Siberia, where the arsenic content is significantly higher than its Clarke value, it does not pose a major hazard because, in 99% of cases, it occurs in insoluble or slightly soluble forms. However, it is emphasized that this physicochemical state is not constant; at present, it is rapidly changing, and soils are becoming more alkaline. This situation indicates that other elements—such as arsenic, antimony, and molybdenum—are becoming increasingly mobile [4].

Based on chemical analyses of lanthanides and radioactive elements in irrigated meadow saz soils and light calcisols, specific background (baseline) concentrations were developed for the study areas, and their geochemical spectra are presented below (10^{-4} %):

- for meadow saz soils:

$Ce_{41.0} > La_{26.7} > Nd_{17.2} > Th_{7.90} > U_{3.90} > Sm_{3.50} > Yb_{1.65} > Eu_{0.74} > Tb_{0.46} > Lu_{0.18}$;

- for light calcisols:

$Ce_{63.0} > La_{35.7} > Nd_{23.9} > Th_{13.9} > U_{5.90} > Sm_{4.40} > Yb_{2.10} > Eu_{0.90} > Tb_{0.65} > Lu_{0.20}$.

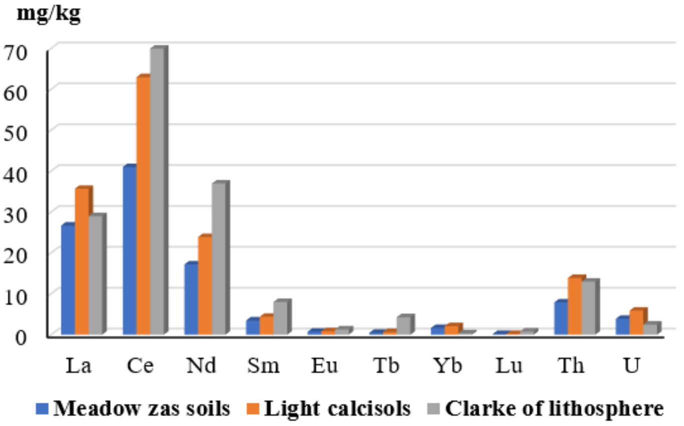

Figure 1. Dynamics of Lanthanide and Radioactive Element Concentrations in Irrigated Soils

The correlational relationships among the quantitative indicators of the studied lanthanides and radionuclides are presented in Table 2. According to the data, in irrigated meadow saz soils, strong correlations are observed between lanthanum and cerium, neodymium and samarium, and thorium and uranium, with correlation coefficients of +0.91, +0.98, and +0.93, respectively—indicating strong positive relationships.

The correlation between europium and terbium is +0.73, while the relationship between ytterbium and lutetium shows a correlation coefficient of +0.22.

Table 2. Correlational Relationships Among Elements

M_x, mg/kg	M_y, mg/kg	Average error, $\pm\delta$	Standard deviation σ	Degree of accuracy p, %	Coefficient of variation v, %	Number of observations n	Correlation coefficient r
In meadow saz soils							
Lanthanum and cerium							
26,70	41	1,03	2,30	3,84	8,60	12	**0,91**
Neodymium and samarium							
17,20	3,50	0,69	1,55	4,03	9,01	12	**0,98**
Europium and terbium							
0,74	0,46	4,89	0,11	6,61	14,78	12	**0,73**
Ytterbium and lutetium							
1,65	0,18	3,19	7,13	1,93	4,32	12	**0,22**
Thorium and uranium							
7,90	3,9	0,41	0,93	5,25	11,74	12	**0,93**
In light calcisols							
Lanthanum and cerium							
35,70	63	1,43	3,19	3,99	8,93	12	**0,95**
Neodymium and samarium							
23,9	4,40	0,65	1,46	2,73	6,10	12	**0,99**
Europium and terbium							
0,90	0,65	3,84	8,58	4,26	9,53	12	**0,65**
Ytterbium and lutetium							
2,10	0,20	0,22	0,49	10,52	23,52	12	**0,99**
Thorium and uranium							
13,90	5,90	0,67	1,50	4,82	10,78	12	**0,85**

In irrigated light calcisols, strong positive correlations are observed between lanthanum and cerium, neodymium and samarium, and ytterbium and lutetium, with correlation coefficients of +0.95, +0.99, and +0.99, respectively. The correlation between thorium and uranium is +0.85, while the relationship between europium and terbium shows a correlation coefficient of +0.65 (Figure 2).

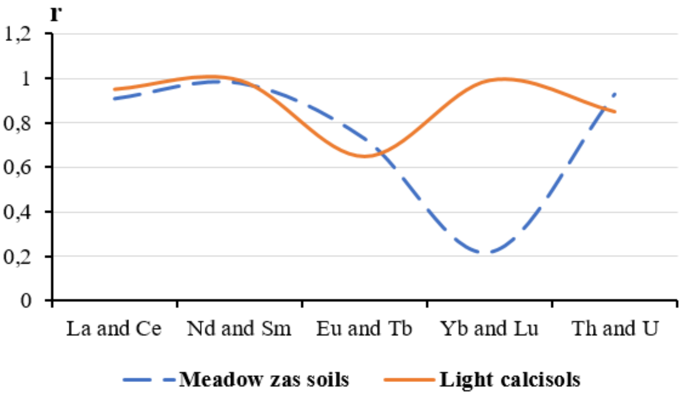

Figure 2. Relationships Among Chemical Elements in Irrigated Soils

It is evident that there are slight differences between soil types in the interrelationships of chemical elements. For example, the correlation between ytterbium and lutetium is +0.22 in meadow saz soils, whereas in light calcisols it reaches +0.99.

4 Conclusion

Today, conducting monitoring of irrigated soils, scientifically and practically investigating the properties of chemical elements, and identifying their migration, accumulation, and differentiation play an important role in improving soil fertility as well as enhancing the yield and quality of crops.

Based on the results obtained in this study, it becomes possible to develop agroecological and agromeliorative measures aimed at preventing the contamination of irrigated soils and cultivated plants with heavy metals and metalloids, thereby ensuring the production of environmentally clean agricultural products.

Author Contributions: Conceptualization, A.T.T.; methodology, A.T.T.; software, A.A.A., K.A.A., I.I.M.; validation, A.A.A., K.A.A.; formal analysis, K.A.A.; investigation, I.I.M.; resources, I.I.M.; data curation, A.A.A.; writing—original draft preparation, A.A.A.; writing—review and editing, A.A.A.; visualization, K.A.A., I.I.M.; supervision, A.T.T.; project administration, A.T.T.; funding acquisition, A.T.T. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funds, grants, or other financial support were received during the preparation of this manuscript.

Institutional Review Board Statement: This research did not include any experiments involving human participants or animals, so Institutional Review Board (IRB) approval was not necessary.

Informed Consent Statement: This study did not involve human subjects; therefore, informed consent was not required.

Data Availability Statement: Data supporting the report's findings can be found here.

Acknowledgments: The authors express their sincere gratitude to Associate Professor (PhD) **Zokir Isomiddinov** of Kokand State University for his valuable review of the study's results and his contributions to its publication.

Conflicts of Interest: The authors declare no conflicts of interest related to this study.

References

[1] Motuzova, G.V., Bezuglova, O.S. (2007). Ekologicheskiy monitoring pochv [Ecological monitoring of soils]. (In Russian). [Google scholar]

[2] Dobrovol'skiy, V.V. (2003). Osnovy biogeokhimii [Fundamentals of biogeochemistry]. Moscow: Akademiya. 400 p. (In Russian). [Google scholar]

[3] Beus, A.A., et al. (1976). Geokhimiya okruzhayushchey sredy [Environmental

geochemistry]. Moscow: [publisher not specified]. 243 p. (In Russian).

[4] Perel'man, A.I. (1989). Geokhimiya [Geochemistry]. Moscow. 419 p. (In Russian).

[5] Glazovskaya, M.A. (1964). Geokhimicheskie osnovy tipologii i metodiki issledovaniya prirodnykh landshaftov: Uchebnoe posobie [Geochemical foundations of typology and methods for studying natural landscapes: Textbook]. Moscow: Moscow State University. 230 p. (In Russian). [Google scholar]

[6] Cabata-Pendias, A. (2010). Trace elements in soils and plants (4th ed.). Boca Raton, FL: CRC Press. 548 p. [Google scholar]

[7] Abakumov, E., Yuldashev, G., Darmonov, D., Turdaliev, A., Askarov, K., Khaydarov, M., Mirzayev, U., Nizamutdinov, T., & Davronov, K. (2022). Influence of Mineralized Water Sources on the Properties of Calcisol and Yield of Wheat (Triticum aestivum L.). Plants, 11(23), 3291. [Scopus]

[8] Turdaliev, A., Yuldashev, G., Askarov, K., & Abakumov, E. (2021). Chemical and Biogeochemical Features of Desert Soils of the Central Fergana. Agriculture (Pol'nohospodárstvo), 67(1), 16–28. [Scopus]

[9] Turdaliev, A. T., Askarov, K. A., & Mamazhonov, G. G. U. (2022). AGROECOLOGICAL STATE OF HYDROMORPHIC SOILS OF CENTRAL FERGANA. . (Scientific Review. Biological Sciences), №2 2022, 66–70. [Crossref]

[10] Turdaliyev, A., Askarov, K., & Haydarov, M. (2022). Sug'oriladigan tuproqlarni ekologik jihatdan baholash [Ecological assessment of irrigated soils]. Scientific Journal of the Fergana State University. (In Uzbek). [Crossref]

[11] Dmitriev, E.A. (1995). Matematicheskaya statistika v pochvovedenii [Mathematical statistics in soil science]. Moscow: Moscow State University Press. 321 p. (In Russian).

[12] Ilyin, V.B. (2012). Tyazhelye metally i nemetally v sisteme pochva–rasteniye [Heavy metals and nonmetals in the soil–plant system]. Novosibirsk: Publishing House of the Siberian Branch of the Russian Academy of Sciences. 220 p. (In Russian).

[13] Vodyanitskiy, Y.N. (2008). Tyazhelye metally i metalloidy v pochvakh [Heavy metals and metalloids in soils]. Moscow: GNU Soil Institute named after V.V. Dokuchaev, RAS. 86 p. (In Russian). [Google scholar]

Turdaliev Avazbek Turdalievich Doctor ofBiological Sciences, Professor

Avazbek Turdaliyevich Turdaliyev is the author of morethan 220 scientific works, including 1 textbook, 6 teachingmanuals, 4 instructional-methodological guides, 4 monographs,4 recommendations, and over 200 scientific articles (publishedin journals listed by the Higher Attestation Commission and ininternational journals), as well as numerous theses.

Under the supervision of Professor Avazbek TurdaliyevichTurdaliyev, 2 researchers have obtained the degree of Doctorof Philosophy (PhD) in Biological Sciences, and 2 researchershave earned the PhD degree in Agricultural Sciences. He is alsocurrently supervising 5 researchers and 4 master's students.

Avazbek Turdaliyev has served as a senior researcher in onefundamental project and as the head of two applied projects withinthe framework of state scientific–technical programs.

Ahmadjonov Avazbek Akmaljon ugli is a doctoral candidate at the Department of Fruit and Vegetable Growing of Fergana State University.

Ahmadjonov Avazbek Akmaljon ugli was born on August 3, 1993, in an educated family in the Fergana region. In 2020, he graduated from the Fergana Polytechnic Institute with a degree in "Technology of Storage and Primary Processing of Agricultural Products," and in 2022, he completed the specialization in "Technology of Storage and Primary Processing of Agricultural Products (by product types)" at the same institute.

He has 3 years of work experience in educational institutions, including 3 years of pedagogical activity at a higher educational institution.

Ahmadjonov Avazbek Akmaljon ugli has authored more than 30 scientific works, including 1 monograph, around 30 scientific articles (published in local journals included in the Higher Attestation Commission list and in foreign journals), as well as conference abstracts.

Askarov Kamoliddin Abduganievich holds a Doctor of Philosophy (PhD) in Biological Sciences.

He is currently carrying out scientific and pedagogical activities as the Dean of the Joint Agrarian Faculty at Fergana State University.

Askarov Kamoliddin Abduganievich was born on September 21, 1985, in an educated family in the Fergana region. In 2009, he graduated from Fergana State University with a degree in Ecology, and in 2012, he completed the specialization in Environmental Expertise.

He has been engaged in scientific and pedagogical activities in higher education institutions for 13 years.

Askarov Kamoliddin Abduganievich has authored more than 72 scientific works, including 1 textbook, 4 teaching manuals, 3 methodological guides, 1 monograph, 56 scientific articles (published in local journals included in the HAC list and in foreign journals), as well as conference abstracts.

Within the framework of state scientific-technical programs, Askarov Kamoliddin Abduganievich has worked as a senior researcher in one fundamental project and as a project leader in one applied research project.

Musaev Iskandar Ibragimovich holds a Doctor of Philosophy (PhD) in Biological Sciences.

He is currently serving as the Deputy Dean for Academic Affairs of the Joint Agrarian Faculty at Fergana State University and as a senior lecturer at the Department of Fruit and Vegetable Growing, where he conducts pedagogical activities.

Musaev Iskandar Ibragimovich was born on July 9, 1989, in Kuva district of the Fergana region. In 2016, he graduated from Fergana State University with a degree in Agronomy, and in 2021, he completed the specialization in Soil Science.

He has 6 years of experience in educational institutions and has been engaged in pedagogical activity at a higher education institution since 2021.

Musaev Iskandar Ibragimovich has authored more than 20 scientific publications, including scientific articles (published in local journals included in the HAC list and in foreign journals) as well as conference abstracts.