EurAsian Journal of BioSciences
Eurasia J Biosci 14, 347-354 (2020)

The ecological status of irrigated saline soils of the Shaulder massif of the Turkestan region

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Abstract

Despite the wide variety of soil cover of the irrigated areas of the Republic, the problem of establishing regional background levels of heavy metals and other pollutants in the irrigated soils remains unresolved. The study and systematization of data on heavy metals in irrigated soils at the regional level is very relevant and necessary for assessing the resilience and stability of irrigated ecosystems to global and regional anthropogenic impacts. In this regard, the content of total and mobile forms of heavy metals in the irrigated soils of the South Kazakhstan region (on the example of the Shaulder Irrigation Massif) was investigated. The study determined the percentage of total forms of Zn (44.6%), Ni (28.9%), Cu (16.3%), Pb (8.6%), Cd (1.7%) and mobile forms of Ni (43.4%), Pb (21.7%), Zn (17.7%), Cu (10.3%) and Cd (6.9%). Consequently, the process of irrigation of these soils leads to an increase in the mobile forms Cd, Pb, and especially Ni, and the proportion of the mobile forms Cu and Zn decreases. By statistical processing of the obtained analytical data (n = 348) the concentrations of the studied heavy metals (mg/kg) in soil of the area were determined: Zn – 3.4 ± 0.05; Cu - 1.7 ± 0.02; Pb - 4.7 ± 0.10; Cd – 1.3 ± 0.01; Ni - 8.4 ± 0.12. These values are proposed by us for adoption as background levels of heavy metals in the studied soils and will be used in monitoring the soil of the Shaulder Irrigation Massif.

Keywords: Kazakhstan, irrigated soils, soil information system (GIS), heavy metals, background concentration

Vyrakhmanova AS, Otarov A, Saparov AS, Suska-Malavska M, Duisekov SN, Poshanov MN, Tanirbergenov SI (2020) The ecological status of irrigated saline soils of the Shaulder massif of the Turkestan region. Eurasia J Biosci 14: 347-354.

INTRODUCTION

The main irrigated areas of Southern Kazakhstan are located on the large delta and delta alluvial plains of the Syr Darya, Ili, Shu, Talas and others. These regions are a closed inland continental region that does not have free flow into open oceanic basins, and are the region of the final geochemical flow of chemical elements, occupy geochemically subordinate hydromorphic landscapes, and as a result, are prone to salinization and pollution (Laiskhanov et al. 2016, Otarov et al. 2007, Tanirbergenov et al. 2016).

The results of our previous studies have shown contamination of soils of irrigated massifs with heavy metals, in particular Pb, Ni and Cu (Otarov et al. 2007). The deterioration of the soil-reclamation and environmental conditions of the irrigated massifs also led to a decrease in the protective capabilities of soils with respect to Pb by 3.3 times and by Ni by 4.1 times (Otarov). The waters of rivers and irrigation sources become more polluted due to the increasing anthropogenic pressure on the environment (Ibraeva and Otarov 2007, Otarov and Ibraeva 2007, Otarov 2014, Otarov et al. 2006). According to experimental results, the ecological state of the waters of the southern regions of the republic is of particular concern. They are characterized by a regular increase in the content of Pb and Ni from irrigation to groundwater (Otarov et al. 2007). Along with a decrease in the level of technological discipline, the general culture of agriculture, the degree of cultivation of soils, the quality of the obtained products is deteriorating (Tanirbergenov et al. 2016).

Currently, the problem of the ecological state of irrigated massifs has sharply worsened. Due to the loss of humus, basic nutrients, deterioration of the physical, chemical and biological properties of soils, their protective properties with respect to pollutants are reduced. Thus, the problems of pollution of irrigated soils today are relevant and acute, and its solution is one of

Received: November 2019
Accepted: February 2020
Printed: March 2020

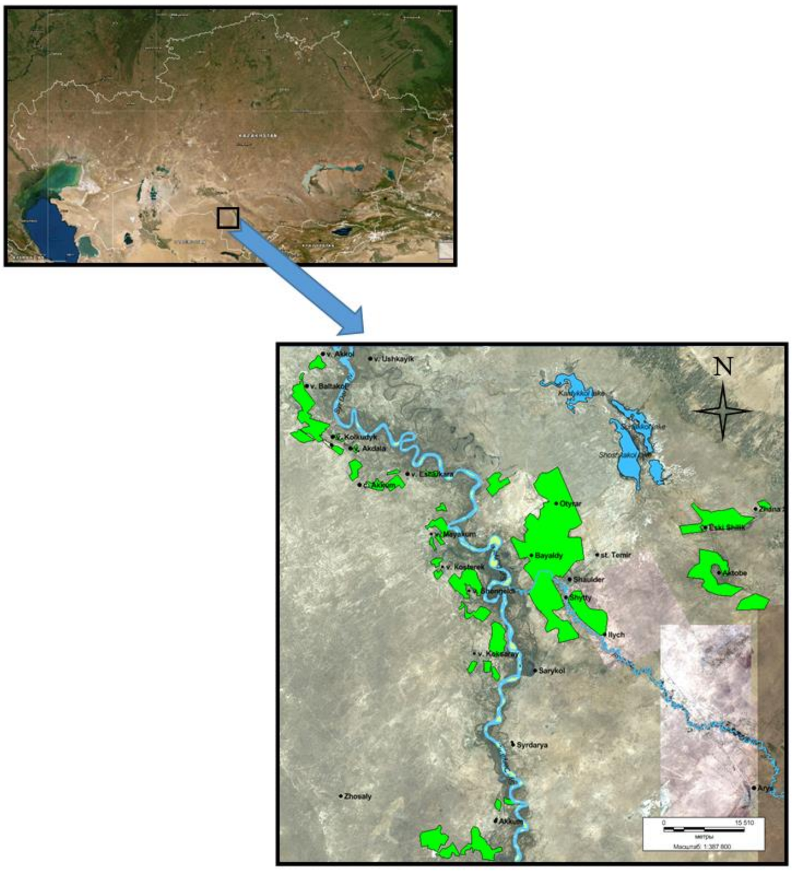

Fig. 1. Scheme of research object location

the priority tasks of soil and biological science, which have both fundamental and applied importance.

The results of the studies are of particular importance in connection with the transition of the country ‘s agro-industrial complex to the Green Economy and Kazakhstan ‘s accession to the World Trade Organization, where food and agricultural products are subject to the 1994 “Agreement on the Application of Sanitary and Phytosanitary (ASP) Measures” designed to ensure food safety (The World Bank 2007). When entering the WTO, the natural choice consists in the desire to use an internationally recognized and actually “objective” standard. These international standards, based on the results of a scientific analysis of human health risks, have been adopted by the following authorities: the Codex Alimentarius Commission for the Implementation of the Joint FAO and WHO Food Safety Standards Program (Codex Alimentarius Commission 2015), the International Epizootic Bureau (IEB), and the World Convention of Plant Protection (WCPP).

In this regard, the research results will enhance the expert potential of the irrigated areas of the republic.

The work was carried out by the U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry jointly with the Institute of Botany of the University of Warsaw in the joint project “Monitoring of the concentration of heavy metals and organic pollutants in irrigated soils using GIS and development of methods to increase soil protective properties in relation to pollutants” with grant support of the Target Program “Conservation and reproduction of soil fertility in Kazakhstan.”

MATERIALS AND METHODS

The research object is the soil surface of the Shaulder irrigation massif (the ancient Otyrar oasis). In the south and southeast, ancient over-flood plain terrace of the Syr Darya River serves as the natural boundary; in the east and north it borders with the Arys-Turkestan irrigation massif, in the west it borders with the left-bank floodplain of the Syr Darya River (**Fig. 1**).

Most of the territory is used as pastures for grazing agricultural animals. Irrigated arable lands are located mainly in the sub-command area of the Arys and Bugun rivers.

The relief of the massif is represented by a slightly wavy or horizontal surface with a poor and monotonous flora. This is dominated by different types of flooring, saltwater, jantak. Valleys of rivers are rich in meadow herbs, rosehips, here there are groves of poplar and caragache. Salt arak meadows are located on the outskirts of floodplains.

The climate of the region is sharply continental, deserted. In winter, the temperature drops to -25 °C. Syr Darya usually freezes in early December, the ice remains until March.

The leading crops are fodder crops - maize for grain, alfalfa, rarely cereals and vegetable cabbage. Cotton is not practically grown.

The main source of irrigation water is the water of the Arys and Bugun rivers. The water supply is represented by the main canal and irrigators of various orders of the open type, laid in natural soil and are an additional source of replenishment of groundwater.

The massif is dominated by meadow-gray-earth saline (solonchak, in some places solonchakous) soils, which occupy medium-level surfaces and are formed on saline, weakly layered loamy and clay sediments under conditions of average occurrence of mineralized groundwater under the depth (4-6 m) under sparse cereal-halophytic shrubby vegetation with ephemera and wormwood (Zhikhareva et al. 1969).

There are also meadow-gray-earth (or semi-hydromorphic) solonchak solonetzes, which occupy mid-level surfaces and microrelief depressions beneath the halo-fitno-wormwood, wormwood-halophytic and halophytic vegetation with the participation of ephemers, as well as takyr-like solonchaks located on microrelief 30 (up to 50) cm of relative height under sparse halophyte vegetation (mainly itsegek).

Here also occur meadow-gray (or semi-hydromorphic) solonchak solonetz soils which occupy intermediate-level surfaces and micro relief depressions, under halophyte-wormwood, wormwood-halophytic and halophytic vegetation with ephemera, and also solonchak residual takyr-like, located on microrelief elevations, reaching 20-30 (up to 50) cm of relative height under the thinned halophytic vegetation (mainly itsegek). Salt and salt marshes here are formed on heavier and saline rocks under conditions of strong mineralization of medium-deep groundwater.

In depressions of the relief with close (up to 3 m) groundwater, the following forms are formed: meadow-bog saline soils under meadow-bog vegetation in very close (up to 1.5 m) weakly mineralized waters; gray-earth meadow solonchak solonetzes under halophytic and cereal-halophytic vegetation in nearby weakly and medium-saline waters; meadow salt marshes under halophytic and cereal-halophytic vegetation in nearby (1.5-3 m) weakly mineralized waters; common salt marshes under halophytic vegetation (sarsazan) in nearby highly mineralized groundwater.

When occurring in complexes and combinations, salt marshes usually occupy elevated areas of micro- and mesorelief relative to other soils. The prevailing type of salinity is chloride-sulfate and sulfate-chloride, sometimes with the presence of normal soda. All soils of the massif are carbonate and are characterized by high alkalinity (pH 8-9). Water-physical, physical, physico-chemical properties of soils depend on the degree of salinization and salinization.

According to nutrition conditions and outflow of groundwater, the area of the massif belongs to hydro-geological area of intensive external inflow and difficult outflow of groundwater and due to this fact, the soil of this massif is inclined to secondary salinization and pollution. The former on-farm canals, collectors, and vertical drainage wells remained uncontrollable, and often ownerless, their parameters do not correspond to the design parameters, which also contributes to an increase in groundwater levels and, accordingly, to secondary salinization and pollution of soil.

It is also known that in conditions of irrigation, the processes of soil formation are taking place quite intensively, and they are also characterized by a fairly high rate of mobilization and migration processes. In this regard, monitoring of the level of fertility of irrigated soils should be conducted regularly and with a wider range of determined soil properties. The work is based on the use of modern methods of geoinformation technologies (GIS) and soil digital mapping - the creation of a soil-ecological information system of the irrigated massif with corresponding spatially coordinated attributive database. Along with this, traditional methods for studying soils, such as comparative geographic, profile, soil key, etc., have also been used.

Soil-environmental survey was carried out in accordance with officially existing guidelines and instructions (Nosina, 1973, Guidelines for conducting large-scale soil survey in the Kazak SSR 1979) and with the requirements of official state standards (GOST 17.4.3.03-85, GOST 17.4.3.01-83). Field work was done using global positioning systems. GPS 18 “Garmin” paired with the netbook “ASUS” was used to refine soil contours from space imagery, and GPS global positioning system “Garmin 62s” was used to determine the coordinates of soil cut points.

The determination of heavy metals in soils was carried out according to requirements of the Methodical recommendations regulating work on a research of soils at the general and local pollution (Methodological recommendations for conducting field and laboratory studies of soils and plants in the control of environmental pollution by metals 1981, Methodological guidelines for the determination of heavy metals in soils of farmland and crop production 1989). Heavy metals were determined by atomic absorption spectrometer AA-6200 by Shimadzu (Japan). Acid decomposition of “royal’s vodka” soil samples was used to determine heavy metal forms, and mobile forms were recovered by an acetate-ammonium buffer phase with a pH of 4.8.

Statistical processing of the received digital data was carried out by generally accepted methods of mathematical statistics described in (Dmitriev 1995, Savich 1972) with the use of the program package analysis “Excel - 2013” and “Atte Stat”.

Thus, to study the concentration of heavy metals in soil of the massif and develop a map of their concentration in soils, all necessary methods and methodologies for studying soils are involved.

RESULT AND DISCUSSION

Currently, organization of storage and analysis of soil data based on informational systems (GIS) is a new promising direction in soil science, which makes it possible to have an operative access to the retrospective and new incoming data accumulated by soil science. The soil informational system becomes the most effective means of obtaining, storing, processing and using information on soil properties and their spatial distribution. The role of soil informational system in organizing and conducting soil monitoring is particularly important.

It is known that control over the level of soil fertility is carried out by conducting complex monitoring. In complex soil monitoring, an important role belongs to soil-ecological monitoring as a system for monitoring soil ecological state for the purpose of their rational use and protection. Management of ecological status of irrigated massifs (pollution of irrigation water, soils and production) in modern conditions requires the use of advanced digital information technologies.

We assume that the created ecological informational system will serve as the initial start of the local ecological monitoring system of Shaulder irrigation area. This will make it possible to conduct regular and unlimited time and space control of irrigation water, soils and products, which provides the necessary information to assess their past, current state and forecast of changes in the future. The created information system will allow to assess the current state of soils and to identify any negative factors of soil fertility and crop yield reduction which in turn will improve existing and develop new technologies for increasing soil fertility and crop yields

Therefore, the work was started with the development of the electronic basis of the array information system. For drawing up an information system of an object of a research of the Shauldersky massif of irrigation sheets of topographic maps (K-42-28, K-42-29, K-42-40, K42-41, K-42-42, K-42-52, K-42-53, K42-54 and K-42-65) 1:100000 scales were used, scanning and digitization in the environment of GIS with use of the MapInfo professional program was carried out them. The geographic themes have been established - human settlements, roads, rivers, irrigation, irrigated land, boundaries of elementary areas, name and boundaries of rural districts, which are an integral part of any information system. It is known that most sheets of topographic maps are now out-of-date, the cartographic situation in most cases does not reflect the current state of the territory. Therefore, to clarify the boundaries of irrigated lands, irrigators, new roads, settlements, etc., space images of the satellite Landsat 8OLI were downloaded and used (digitized) from open source. Thus, in the beginning of the work the electronic basis of information system (GIS) of the surveyed territories was prepared.

Soil is the main and the first link of the food chain, soil-plant-animal-human and ecological safety of food products largely depends on its ecological purity. Currently, special attention is paid to environmental safety of food products in our country and in the world.

To date, despite great variety of soil surface in the irrigated areas of the Republic, the problem of determination of the regional background levels of concentration of heavy metals and other contaminants in irrigated soils remains unresolved. In this regard, the study and systematization of data on the background concentration of heavy metals in irrigated soils at regional level is very relevant and necessary for assessing the stability of irrigated ecosystems to global and regional anthropogenic influences. In addition, it is also known that at present time the problem of their ecological state has sharply worsened on irrigated areas. Due to the loss of humus, basic nutrients, deterioration of physical, chemical and biological properties of soils, their protective properties decrease in regard to pollutants.

Thus, the problems of contamination of irrigated soils are urgent and acute, and its solution is one of the priority tasks of soil and biological science, having both fundamental and applied significance.

In this regard, in order to map the content of heavy metals in the soil, a ground-based soil-ecological survey was carried out annually during 3 years on the territory of the Shaulder Irrigation Massif. Samples of soils were selected from three rated depths - 0-20, 20-50 and 50-100 cm. Spatial and coordinate points of sampling of soils are shown in **Fig. 2**.

When studying the features of the content and spatial variation of soil properties or the average content of certain elements in certain types of soils, the use of statistical data analysis methods is of great importance to increase the reliability of the data and conclusions obtained. In addition, the use of statistical analysis also increases the interpretative capabilities of the data obtained. It should be recognized that all conclusions on the absolute values of soil properties made on one or several typical sections without statistical processing can often be unreliable and can lead to incorrect interpretation of the data (Dmitriev 1995).

Among the constants characterizing the distribution of certain elements in soils, a special place is occupied by the arithmetic mean, which determines the average level of their content, the establishment of true background content is the main goal of most works.

Based on this, a variational-statistical processing of the obtained analytical data on the content of heavy metals in the soils of in the soils of the Shaulder irrigation

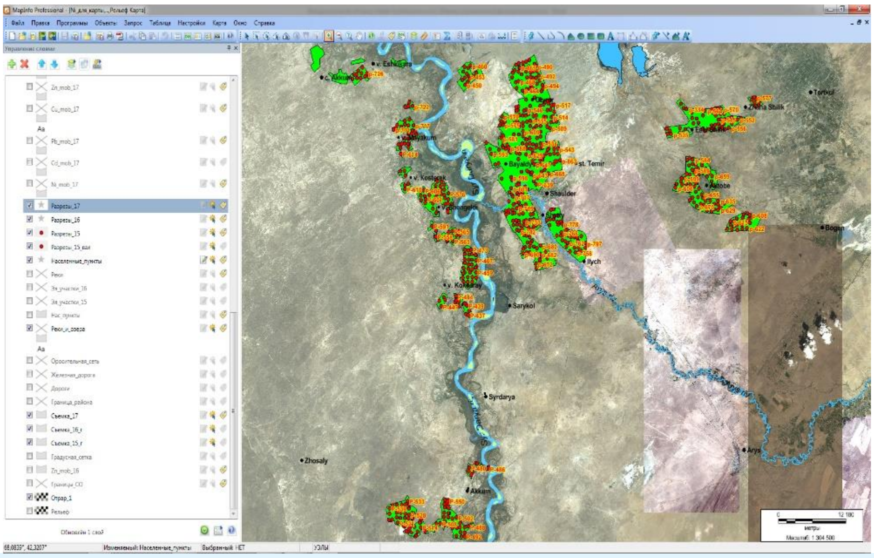

Fig. 2. Soil sampling points (red dots show the location of the sections and drilling of wells)

Table 1. Variational-statistical indicators of the concentration of the heavy metals in the horizon A_{arab} of the soils of the Shaulder irrigation massif

Metals		Statistical indicators					
		n	M±m	t-criteria		± $t_{0,05}$ * m	V, %
				$t_{fact.}$	$t_{0,05}$		
Total	Zn	309	67.2±0.88	76.3	1.96	1.7	23.1
	Cu	309	24.5±0.38	64.1	1.96	0.8	27.4
	Pb	309	12.9±0.20	65.4	1.96	0.4	26.9
	Cd	309	2.5±0.05	50.1	1.96	0.1	35.1
	Ni	309	43.6±0.54	80.7	1.96	1.1	21.8
Mobile	Zn	716	3.1±0.05	76.3	1.96	1.7	23.1
	Cu	716	1.8±0.02	64.1	1.96	0.8	27.4
	Pb	716	3.8±0.06	65.4	1.96	0.4	26.9
	Cd	716	1.2±0.01	50.1	1.96	0.1	35.1
	Ni	716	7.6±0.09	80.7	1.96	1.1	21.8

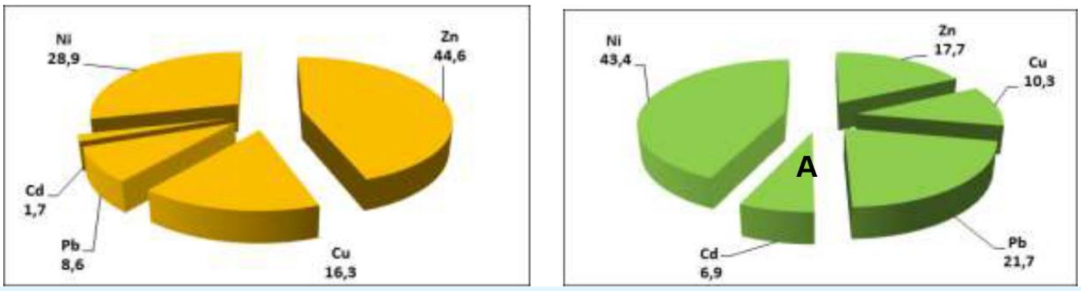

Fig. 3. The share of heavy metals in the "metallic" background of soils of the research object (left - total and right - mobile forms)

area was carried out. As can be seen from the obtained data, the calculated values of Student's t-test for all studied soils at the 95% significance level are much higher than t_{tab} (**Table 5**).

The analysis of the degrees of variability of concentration of heavy metals in soils of the research object shows that the determined average statistical values of the concentration of metals in soils are statistically stable, which is confirmed by their variation coefficients values, which correspond to the limit from small to medium in the scale of gradation.

Based on the analysis of the obtained statistical constants, it can be concluded that the calculated average values correctly reflect the statistically significant true values of the average content of the studied metals in the soils of the Schaulder Irrigation Massif. Based on this, we propose that the average values of the content of heavy metals in soils given in **Table 1** be taken as their background levels in the soils of the Shaulder irrigation massif.

Then, using the average background obtained data, the contribution of each metal to the general "metallic" background of soils in the research object was calculated (**Fig. 3**).

It was found that the compositions of mobile and total forms of heavy metals in the soils of the research object

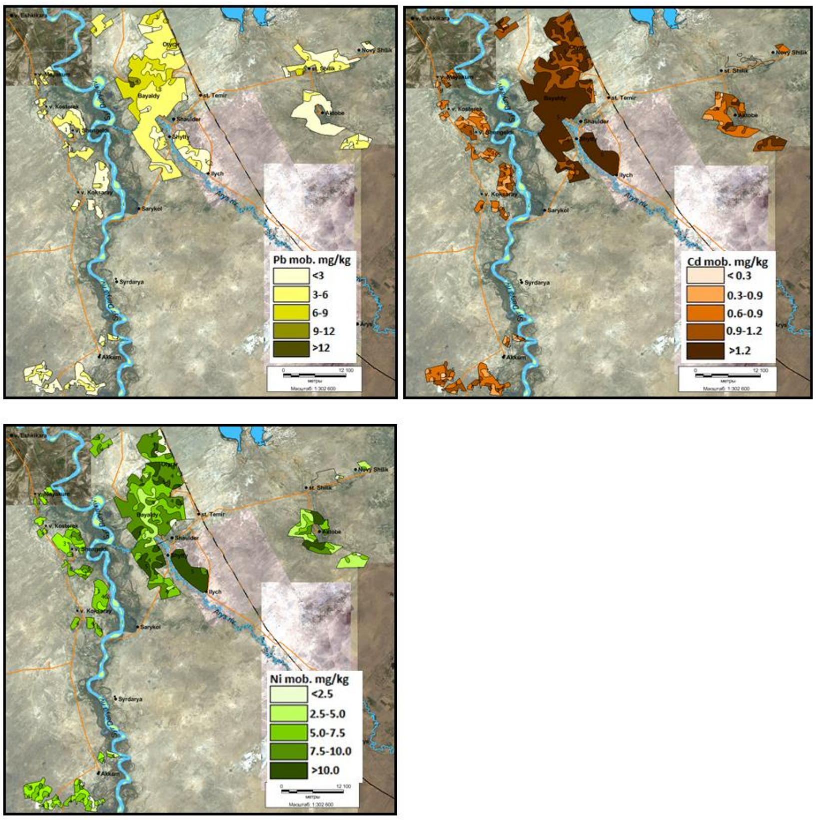

Fig. 4. Maps of concentration of mobile forms of heavy metals in soils of the Shaulder Irrigation Massif

vary significantly. Among the total forms of the studied metals, zinc has the largest share (44.6%), followed by nickel (28.9%). And copper and lead, respectively, 16.3% and 8.6%, cadmium's share is only 1.7%.

The background levels of heavy metals in soils of the agrolandscape is mainly formed due to their concentration in the original soil and anthropogenic input from outside - inflow with irrigation water, mineral fertilizers, various meliorants, chemicals for plant protection, aerial intake and other types. Heavy metals adapted into agronomic terrains are quickly incorporated into the bio-geochemical migration cycles, move in time and space, become permanent components of the soil chemical composition and living matter of agri terrains. The direction of migration of heavy metals and its rate are largely determined by soil physical-chemical properties and heavy metals themselves, the specifics of technology of crop cultivation and a number of other anthropogenic and natural factors. Therefore, for farmers and agricultural producers, the area of distribution is important as well as the total amount of heavy metals in soils, i.e. diversity of soils in terms of concentration of various heavy metals. In this case, the farmer will know on which soil contours it is necessary to take measures to reduce their entry into plants, and on the scale of irrigated massif, similar data are needed by the government bodies (local governments, agricultural administrations, environmental services, etc.) to take managerial decisions. Therefore, drawing up a map of concentration of heavy metals in soils of the research object is also one of the actual trends in soil science.

To develop a map of heavy metal concentration in soils, the obtained analytical data are entered into the spatially coordinated electronic database of the project. Further, using the developed project database and the MapInfo professional computer program in the GIS environment, maps of concentration of environmentally hazardous, mobile forms of heavy metals accessible to plants in the soil of the Shaulder irrigation area were developed (**Fig. 4**). Analyzing the cartographic materials, we can say that in the Shaulder massif of irrigation, zinc mainly prevails in soils of the 5th group which occupy 67.5% or 30368.3 ha of the surveyed area. In case of copper, soils of groups 3 and 2 predominate, occupying respectively 25.9 and 37.5 percent, or 11663.1 and 16871.3 hectares of the surveyed area.

As for lead, on the contrary, soils with a low content of this element of group 2 prevail which occupy 52.7% or 23735.4 hectares of the surveyed area. By concentration of cadmium, soils of groups 4 and 5 predominate, occupying respectively 30.8 and 49.0 percent, or 13874.3 and 22035.1 hectares of the massif. And for nickel - 3 and 4 groups which occupy, respectively, 28.4 and 37.3 percent or 12787.9 and 16797.1 hectares of the surveyed area.

Table 2. Number of soil contours occupied by different groups of studied metals, pcs.

Metals	Soil contour quantity by groups					
	1	2	3	4	5	Total
Zn	1	7	24	40	34	82
Cu	17	38	38	40	33	166
Pb	36	30	6	3	1	76
Cd	1	10	33	41	43	128
Ni	6	16	42	47	22	133

We also estimated the distribution of the studied metals over the territory of the massif by the total number of contours occupied by different soil groups according to the content of each metal (**Table 2**). Copper, nickel and cadmium, having 166, 133 and 128 contours, respectively, are distinguished by the variegated content in the soils of the massif.

Among the metals studied, lead and zinc are distinguished by a relatively smaller number of contours.

Among the studied metals, lead and zinc differ in relatively fewer contours. Among the surveyed rural areas of Otyrar district, the soils of Otyrar, Talapta, Kogam and Kargalinsky rural districts have high concentration of zinc, cadmium - in Otyrar, Talapta and Kogam rural districts, nickel - in Otyrarsky and partly Talapta and Aktobe rural districts. The remaining two metals (Cu and Pb) are distributed throughout the massif almost uniformly.

CONCLUSION

1. According to the results of the variational-statistical analysis of the obtained analytical data, the following statistically reliable true values of the average content of the studied metals in the soils of the Schaulder irrigation massif (mg / kg) were established: Zn - 3.1 ± 0.05; Cu - 1.8 ± 0.02; Pb - 3.8 ± 0.06; Cd - 1.2 ± 0.01; Ni - 7.6 ± 0.09. These values can be recommended as the background content of mobile forms of heavy metals in the soils of the Schaulder irrigation massif and later be used for local monitoring of the massif soils.

2. It was established that among the total forms of the studied metals, Zn occupies the largest share (44.6%), followed by Ni (28.9%), Cu and Pb occupy 16.3% and 8.6% respectively. Cd accounts for only 1.7%. Among the mobile forms of the studied metals, Ni occupies the largest share (43.4%), followed by Pb (21.7%) and Zn (17.7%), Cu and Cd occupy 10.3% and 6.9%, respectively. Consequently, the irrigation process of these soils leads to an increase in the fraction of mobile forms of Cd, Pb, and especially Ni, while the fraction of mobile forms of Cu and Zn, on the contrary, decreases.

3. Analyzing the cartographic materials, it can be concluded that in the territory of the Shaulder massif of irrigation, by concentration of Zn mainly soils of the 5th group dominate, which occupy 67.8% of the surveyed area. By Cu, soils of groups 3 and 2 predominate, which have 25.9 and 37.5 percent, respectively. By Pb, on the contrary, the soil with a low concentration of this element of group 2 prevail or 52.7%. The concentration of Cd prevails in soils of the 5-group, and by Ni-4-group which occupy, respectively, 70.2 and 42.2 percent of the surveyed area. By the number of occupied contours (by variegation), Cu, Ni and Cd are outlined, which have 166, 133 and 128 contours, respectively.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Agriculture of the Republic of Kazakhstan (grant nos. 0115RK02027; BR06349612).

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