APPLICATION OF REMOTE-SENSING DATA IN GEOCHEMICAL STUDIES OF SOILS OF THE YERTIS RIVER BASIN WITHIN EAST KAZAKHSTAN

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Abstract: This article presents the results of field research, as well as the results of the use of remote-sensing data in the geochemical study of the soil cover of the Yertis River basin. In the work, the content of the gross form of heavy metals in the soil of the river basin was investigated. The atomic absorption method determined the content of the Poor configuration of elements of elements in soils. Statistical processing of the obtained data from N. A. Plokhinsky was carried out using the Statistica program. Also, using the performed indices in the remote sensing of clay minerals, iron oxides, and carbonates, the spatial distribution and comparison of pollutants in the soil cover of the river basin were revealed. The methods and means of image processing tested in this study can be used to create maps of the distribution of pollutants. Also, the data obtained reflect the patterns of distribution of heavy metals in the soils of the basin and can be used to optimize landscapes and improve the organization of ecological and geochemical monitoring.

Keywords: soils, river basin, heavy metals, indices, remote sensing

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Introduction

East Kazakhstan is one of the most industrially developed regions of the country, which has a high concentration of industrial sources of heavy metals entering the environment (non-ferrous metallurgy, mining, etc.). In these conditions, continuous monitoring of environmental changes and identification of negative factors affecting nature are necessary. With the help of remote sensing, it is possible to assess anthropogenic changes in the earth's surface, changes in geosystems in mining areas, as well as other manifestations of technogenesis that occur in some cases at high speed. Remote sensing of the Earth makes it possible to identify territories transformed by industrial and mining production, as well as to track changes in the natural environment over time (Grekhnev et al. 2015). The issues of detecting heavy metals by remote sensing were considered in the works of authors such as Dogan (2009), Sarajlic (2012), Zeilik and Tyugay (2015), Ducart et al. (2016), Peng et al. (2016), Krupnik and Khan (2020), Mammadaliyeva and Nasirova (2020).

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Multi-zone Landsat images have been successfully used to identify the distribution of certain metals in different regions of the world. Some minerals, including clay minerals, iron oxide, and carbonates, can be detected by multi-zone survey data due to their spectral characteristics (Trinh and Zablotskii, 2019).

While considering heavy metals such as manganese, the knowledge of their normal (background) content in soils and parameters of possible technical genetic pollution are important, as it has significant practical importance for the development of strategies for rational nature use and Enhancement of soil organization geochemical monitoring (Ozgeldinova et al. 2015, Mukayev et al. 2019, Ozgeldinova et al. 2019).

This paper presents the results of field studies of the soils of the basin, as well as the results of determining the distribution of clay minerals, iron oxide, and carbonates according to remote-sensing data based on the use of a multi-zone Landsat 8 image of the Yertis River basin of Eastern Kazakhstan.

The purpose of this study is to analyze the geochemical structure of the landscapes of the Yertis River basin using remote sensing.

Materials and methods

The objects of the study were soil samples taken from the territory of the Yertis River basin within Eastern Kazakhstan, its area being 76,726 km^2. The soils of the basin are represented by light chestnut, dark chestnut, mountain chestnut, brown soils, and chernozems.

The ‘envelope’ method was used to collect the mixed soil samples. It involves taking samples at five points along a diagonal or ‘envelope’ (four points at the corners and one in the center) on each plot, thoroughly mixing them, and selecting an average sample of weight no less than 1 kg.

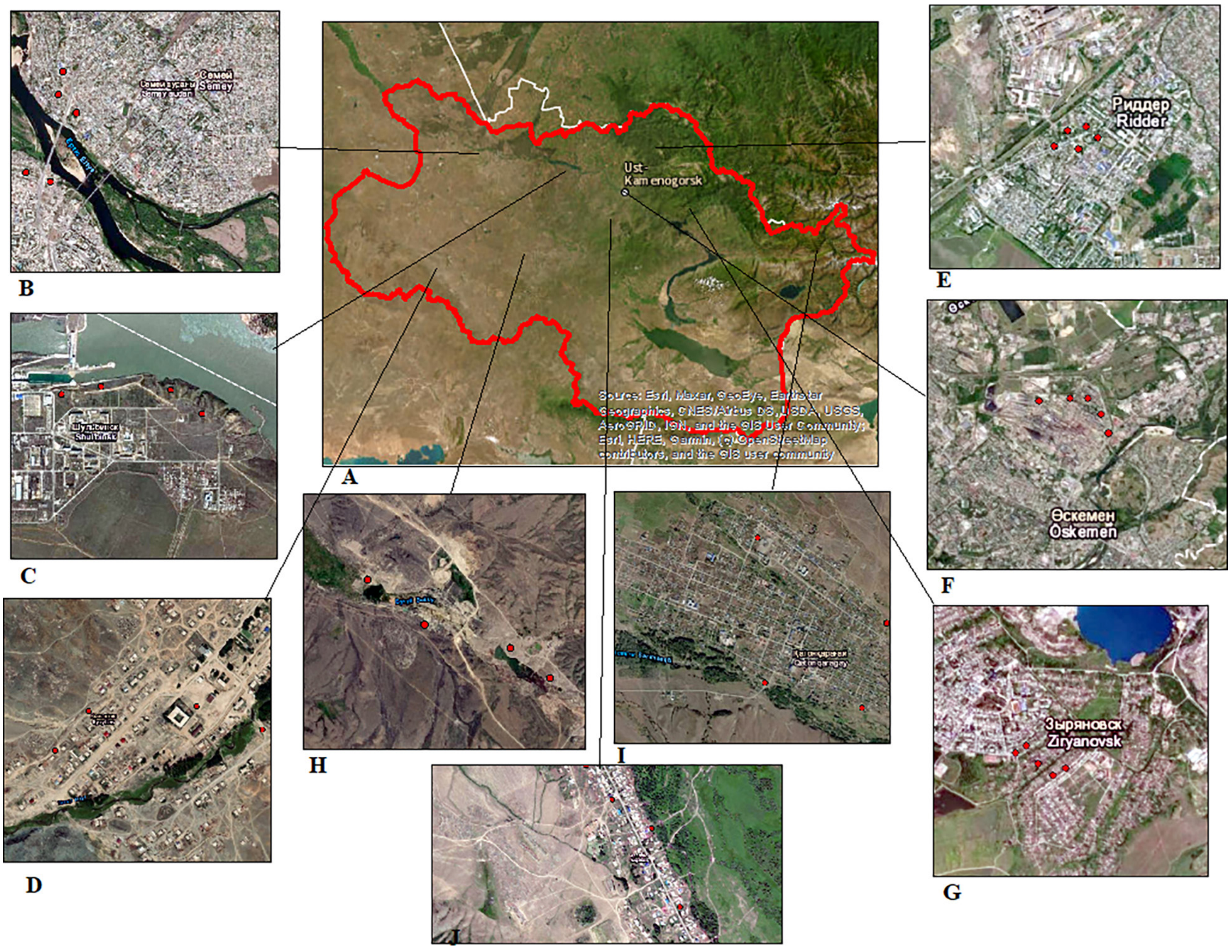

Fig. 1. Soil sampling points map. A – Map of Yertis River basin within Eastern Kazakhstan, B – Ust-Kamenogorsk, C – Ridder, D – Altay (Zyryanovsk).

We dug soil pits of a shallow depth (50–75 cm), exposing only the upper horizons of the soil profile. The content of the gross form of elements presented in the soils was determined using the atomic absorption method.

One of the research tasks was to select soil sampling points within the basin, characterizing the state of the soil cover at background sites and those likely located in the zone of anthropogenic contamination. During the reconnaissance process, 15 soil sampling points were identified, taking into account land use types and using Landsat 8 satellite imagery from 2022. The images were selected from the summer season with minimal cloud cover (Fig. 1).

Statistical processing of the data obtained during the study was carried out by employing N. A. Plokhinsky's method using the Statistica software. This method of mathematical statistics is widely employed in processing and analyzing numerical results of chemical elements obtained in field research.

The following statistical indicators were used in data processing: n, number of samples; arithmetic mean and its error; (mg kg^{-1}); CV, coefficient of variation (%); Lim, limits of fluctuations (mg kg^{-1}); σ, standard deviation (mg kg^{-1}) and r, correlation coefficient.

The study also used multi-spectral satellite images – Landsat 8 (OLI) – downloaded from the US Geological Survey website, with clouds <10%. The periods from July 2020 to July 2022 were considered.

Spectral indices were used to detect clay minerals, iron oxides, and carbonates according to the multi-zone image of Landsat 8 (2022 y). Spectral bands were correlated with the Landsat-8/OLI bands to detect groups of minerals with strong absorption bands at similar wavelengths. The results of the band ratio were integrated into the class image. The band ratio is a method that has been used in remote sensing for many years to efficiently display spectral variations. (Melendez-Pastor et al. 2011). It is based on highlighting spectral differences that are unique to the displayed materials. Identical surface materials may give different brightness values due to topographic tilt and aspect, shadows, or seasonal changes in the angle and intensity of sunlight. These differences affect the viewer's interpretation and can lead to erroneous results. Consequently, the band ratio may be able to transform data without reducing the impact of such environmental conditions (Le and Varvarina 2013). It is well known from theoretical knowledge about the spectral properties of the mineral that the ratios of the Landsat TM bands equal to 6/7, 4/2, and 10/11 are analyzed for clay minerals, iron oxides, and carbonates, respectively (Table 1)

Table 1. Spectral indices.

No	Name of indexes	Index formulas
1	Clay minerals	Claymineralsratio = SWIR_1/SWIR_2
2	Iron oxides	IronOxideRatio = Red/Blue
3	Carbonates	Carbonateratio = TIRS_1/TIRS_2

Results

The objects are the soils of the basin. The analysis of the content of individual ingredients of pollutants was carried out in the certified laboratory 'National Center for Expertise and Certification' of Semey by atomic absorption spectrometry.

The gross copper content in the soils of the region varies from 12,809 ± 3155 mg kg^{-1} with an average CV of 110.1%. The average copper content in the entire set of soil-forming rocks is 0.14–48.3 mg kg^{-1}, which is higher than its Clark in the earth's crust. Clark copper in the lithosphere is 47 mg kg^{-1}. For the leached podzolized chernozems of Ust-Kamenogorsk, an excess of the MPC content (35.6 mg kg^{-1}, 48.3 mg kg^{-1}) of the total copper content in the upper soil horizon was revealed.

The average zinc content is 0.31–65.6 mg kg^{-1}, which is higher than its Clark in the earth's crust. Zinc Clarke in the lithosphere is 8.3 mg kg^{-1}. For the leached podzolized chernozems of the city of Ust-Kamenogorsk, an excess of the MPC content from the total zinc content in the upper soil horizon (38.6 mg kg^{-1}, 45.11 mg kg^{-1}) was found. Also, the excess of the MPC is observed in the soils of the city of Ridder (4 8mg kg^{-}1, 51 mg kg^{-1}).

The gross lead content in the soils of the region varies from 22.036 ± 4.395 mg kg^{-1} with an average CV of 89.2%. The average lead content in the entire set of soil-forming rocks is 0.16–98.9 mg kg^{-1}, which is higher than its Clark in the earth's crust. Clarkof lead in the lithosphere is 1.6 mg kg^{-1}. The maximum concentration of

Table 2. Statistical parameters of the content of elements in the soils of the basin.

Parameters	X±Sx	lim	σ	CV, %	n
Cu	12.809±3.155	0.14–48.3	14.104	110.1	15
Zn	15.98±3.747	0.31–65.6	16.748	104.8	15
Pb	22.036±4.395	0.16–98.9	19.648	89.2	15

1 n – number of samples; 2 X±Sx – average ± error of average; 3 σ – standard deviation; 4 lim – scope of limits; 5 CV % – coefficient of variation.

lead (98.9 mg kg^{-1}) is higher than the MPC; it was found in the upper soil horizon of the city of Ridder, and there is also an excess of the MPC in the city of Ust-Kamenogorsk.

Cadmium was not detected in all the samples we obtained.

The average concentration of lead exceeds the background level by 1.4 times, copper by 2.6 times, and zinc by 1.3 times (Table 2).

To compare the results obtained by us with the processed results of satellite images, several ratios of Landsat-8/OLI bands were tested to identify metal-containing zones in the studied area.

By identifying the indices of clay minerals and carbonates, it is possible to determine the features of the distribution of non-ferrous metals, since metallic minerals of clay rocks include 1 − iron, 2 – cobalt−nickel, 3 − copper ores, 4 – gold, and 5 – rare earth elements (Savko 2016). Carbonate minerals by mass make up 1.7% of the weight of the earth's crust. The most common of them are calcium, magnesium, iron, sodium, barium, and strontium carbonate. Many carbonates are formed by exogenous processes. They compose strata of sedimentary and metamorphic rocks. Carbonates of Pb, Zn, Cu, and other heavy metals accumulate in the oxidation zones of ore deposits. Thus, the results of calculating the clay minerals and carbonate indices make it possible to identify the presence of non-ferrous metals in the study area.

When determining clay minerals, the formula used was:

$$Claymineralsratio = SWIR\_1/SWIR\_2$$

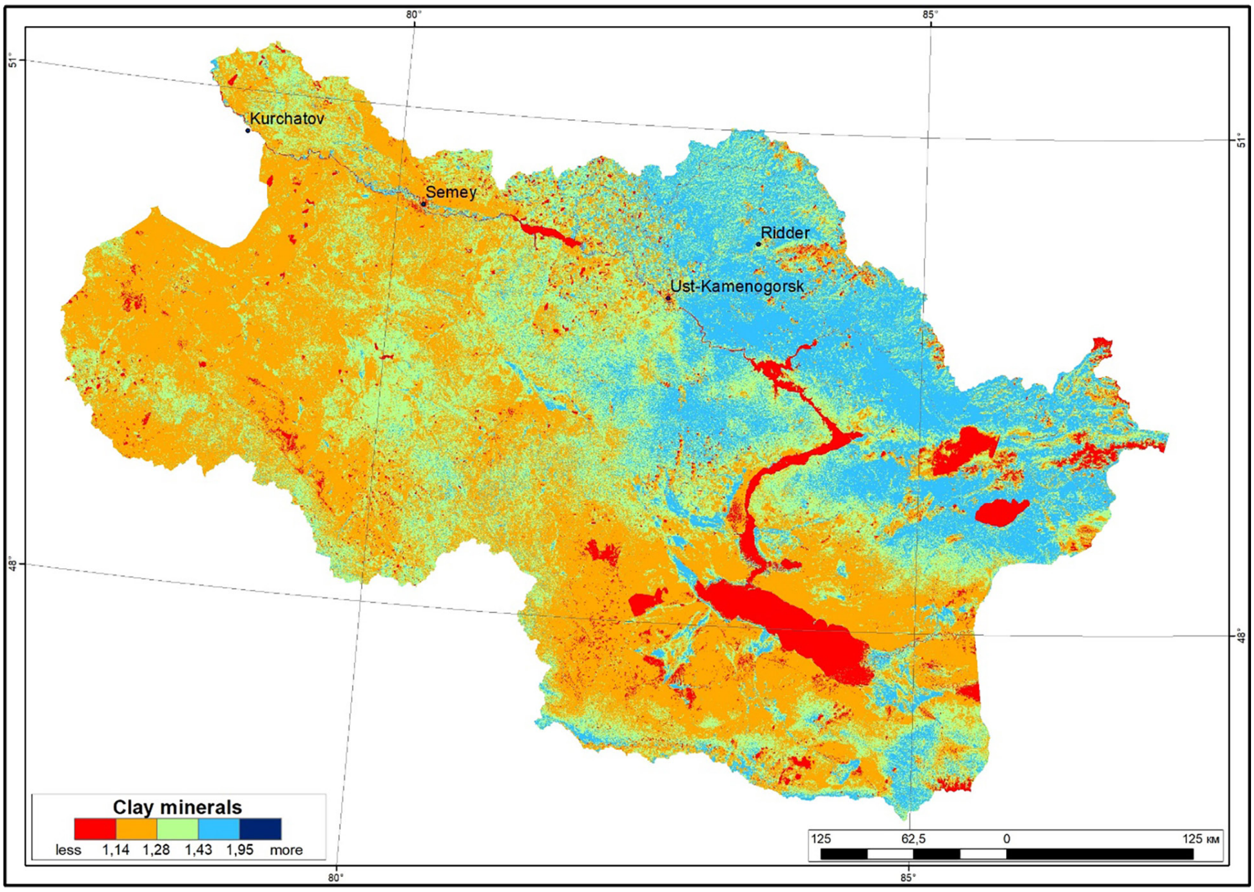

Fig. 2. Distribution of clay minerals in the territory of the Yertis River basin within Eastern Kazakhstan.

where:

- SWIR 1 – the pixel value of the channel images 6;
- SWIR 2 – the pixel value of the channel images 7.

Based on the calculations from using this formula, images are constructed indicating areas with a high content of clay minerals in the basin (Fig. 2).

According to the spatial distribution of clay minerals, the most widespread areas include the mountainous regions of Ore and Southern Altai in the northeastern part and the Tarbagatai ridge in the southern part of the basin.

The western and south-western parts of the basin territory and hilly-rocky areas of the Kalbinsky ridge territory can be attributed to the following distribution.

The least common indicators of clay minerals include the southern and southwestern alluvial and denudation plains of the basin.

Since clay minerals are common precisely on the territory of the location of deposits and extraction of non-ferrous metals, in cities such as Ust-Kamenogorsk and Ridder, the data obtained from satellite image indexes confirm the results we have tested.

The presented method was also used to determine the sites containing iron compounds. The following indexes were used.

The iron oxide ratio index is used to determine the content of trivalent iron (Fe^{3+}) compounds and is calculated using the following formula:

$$IronOxideRatio = \mathrm{Red/Blue}$$

where:

- Red, pixel values from the red channel – band 4;
- Blue, pixel values from the blue channel – band 2 (Fig. 3).

According to the spatial distribution of iron oxides, the most widespread areas include the denudation hilly plains in the western part of the basin and the intermountain Aeolian plains near Lake Zaisan.

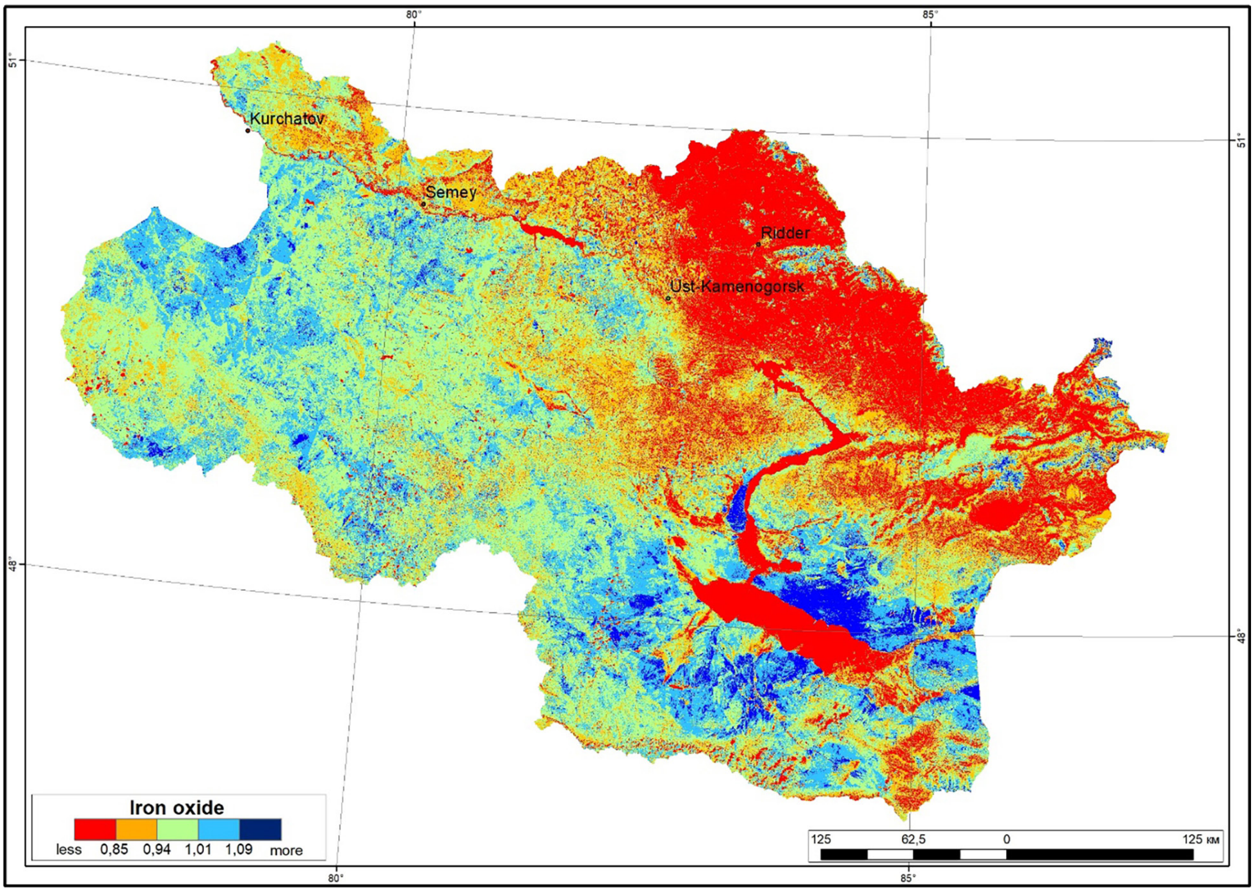

Fig. 3. Distribution of iron oxides on the territory of the Yertis River basin within Eastern Kazakhstan.

The main part of the territory of the basin can be attributed to the following distribution and they are distributed in shallow foothills, hilly-steep low mountains, and folded-mountainous mid-mountains in the central and extreme southern parts of the basin.

The least common indicators of iron oxides are in the mountainous areas of the basin.

The carbonate index is used to determine the content of carbonate compounds that are part of ferrous and non-ferrous metals. There are about 80 types of carbonate minerals. By mass, they make up 1.7% of the weight of the earth's crust. The most common are calcium and magnesium carbonate. Iron, sodium, barium, strontium carbonates, and non-ferrous metals such as copper, lead, and zinc are known as others. They were identified by the following formula:

$$Carbonateratio = \mathrm{TIRS\_1/TIRS\_2}$$

where:
– TIRS_1 – Thermal Infrared band 10;
– TIRS_2 – Thermal Infrared band 11 (Fig. 4).

According to the spatial distribution of carbonates, the most widespread areas include the mountainous regions of Ore and Southern Altai in the northeastern part and the Tarbagatai ridge in the southern part of the basin.

The following distribution includes the western and south-western parts of the basin territory and hilly-rocky areas of the Kalbinsky Ridge.

The least common indicators of carbonates include alluvial and denudation plains of the basin.

Since carbonates are common precisely on the territory of the location of deposits and extraction of non-ferrous metals, in cities such as Ust-Kamenogorsk and Ridder, the data obtained from satellite image indices confirm the results we have tested.

Discussion

The features of the distribution of heavy metals in the soil cover are influenced by the mechanical composition of the soil-forming rocks

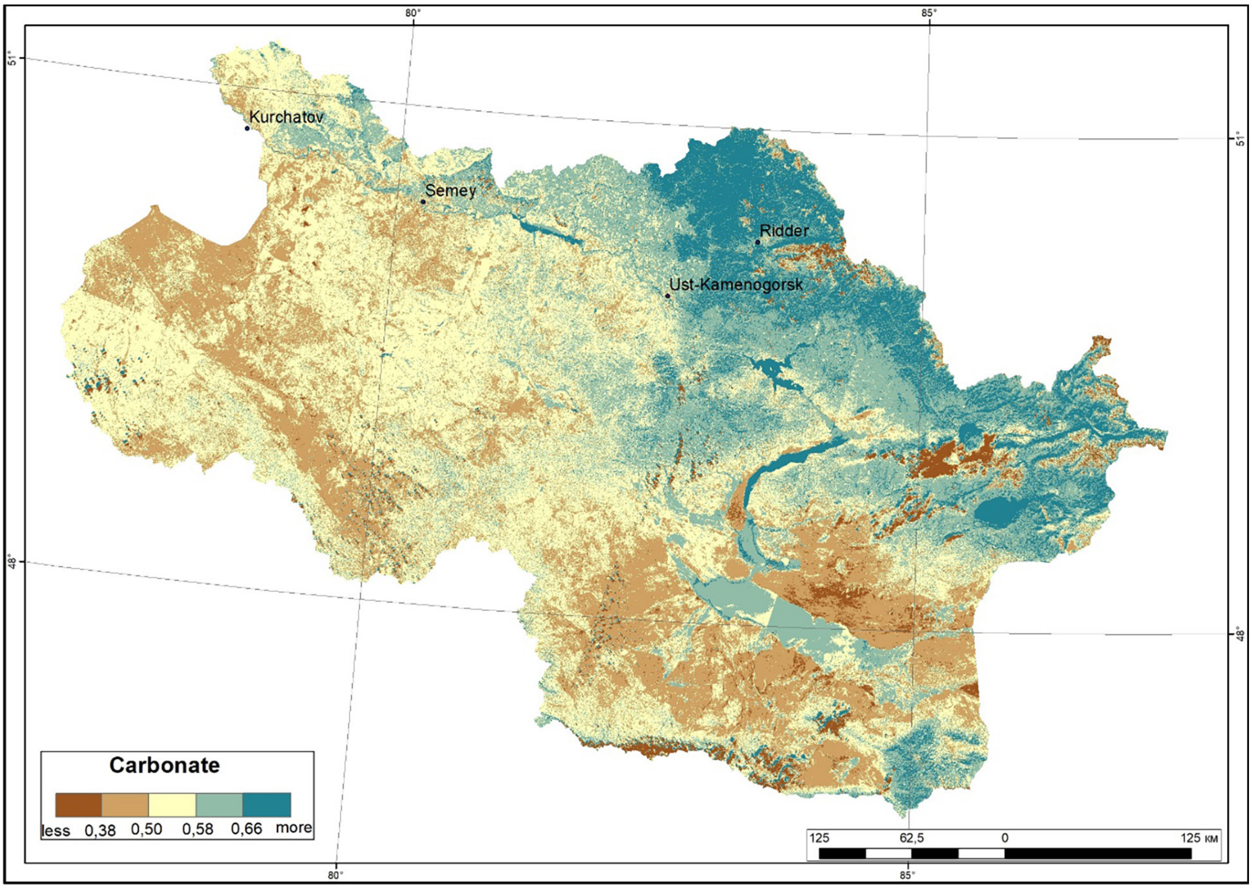

Fig. 4. Distribution of carbonates on the territory of the Yertis River basin within Eastern Kazakhstan

and the direction of the soil-forming process. Natural regions where soils of light mechanical composition predominate are provided with Heavy metals more detrimental than their neighbors with heavier soils (Panin 2000). The soils of the territory where the MPC exceedances were found are composed of loamy and heavy loamy deposits. The highest content of copper, lead, and zinc is characteristic of clay and heavy loamy deposits. Also, the gross content of Zn, Pb, and Cu is maximum in soil samples taken in the cities of Ust-Kamenogorsk and Ridder, which may be due to the presence of large industrial enterprises there that carry out the maximum amount of emissions in the city (Kazzinc JSC, Ulba Metallurgical Plant, CHP, titanium-magnesium plant, etc.). It is on the territory of the Ore Altai that there is a pronounced presence of clay minerals and carbonates in large quantities, which is associated with a large number of deposits in this region.

Using satellite images of the territory of the Yertis River basin, maps of the distribution of indices of clay minerals, iron oxide, and carbonates were compiled. The lowest mineral values are common in alluvial and denudation plain areas, as well as hilly and rocky areas of the basin, where pastures and specially protected areas are widespread.

The highest distribution rates include the mountainous areas of the northeastern part of the Ore and Southern Altai, as well as the southern part of the Tarbagatai ridge, where areas such as mining and non-ferrous metallurgy are developed. The center of the polymetallic complex of Ust-Kamenogorsk and Ridder, where large enterprises of non-ferrous metallurgy are located, is located in this area.

The polymetallic belt of the Ore Altai passes through the territory of the region, with unique deposits of polymetallic ores containing non-ferrous metals. The results of processing satellite images showed that polymetals are common in the territory of the Ore Altai in the northern and northeastern parts of Eastern Kazakhstan. Using the results of satellite images and data obtained from soil samples of the studied area, comparative analysis and identification of common indicators of heavy metals were carried out. According to the results of this analysis, it can be said that it is on the territory of the Ore Altai that a large distribution of heavy metals is observed.

Conclusion

Concentrations of heavy metals in the soils of the basin have been identified. The gross copper content in the soils of the region varies from 12,809 ± 3155 mg kg^{-1} with an average CV of 110.1%. In Ust-Kamenogorsk, an excess of the MPC content (35.6 mg kg^{-1}, 48.3 mg kg^{-1}) of the total copper content in the upper soil horizon was revealed. The average zinc content is 0.31–65.6 mg kg^{-1}, which is higher than its Clark in the earth's crust. Zinc Clarke in the lithosphere is 8.3 mg kg^{-1}. In Ust-Kamenogorsk, an excess of the MPC content from the total zinc content in the upper soil horizon was found (38.6 mg kg^{-1}, 45.11 mg kg^{-1}). Also, an excess of the MPC is observed in the soils of Ridder City (47.08 mg kg^{-1}, 51 mg kg^{-1}). The gross lead content in the soils of the region varies from 22.036 ± 4.395 mg kg^{-1} with an average CV of 89.2%. The maximum concentration of lead (98.9 mg kg^{-1}) is higher than the MPC; it was found in the upper soil horizon of the city of Ridder, and there is also an excess of the MPC in the city of Ust-Kamenogorsk.

The indices that are characteristic of the basin territory are calculated, and the data of the geochemical study of field studies and the results of processing satellite images are analyzed.

Maps of the distribution of heavy metals in the territory of the Yertis River basin have been compiled based on satellite images using remote-sensing methods

The information obtained reflects the patterns of distribution of heavy metals in the soils of the Ertis River basin and can be used to develop a strategy for rational nature management and improve the organization of ecological and geochemical monitoring.

Multi-zone Landsat 8 images and mineral indexes can be used to efficiently detect and predict the spread of metals.

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Author's contribution

Taking part in field works – Ulykpanova M.M.; variational-statistical analysis – Ulykpanova

M.M. and Zhanguzhina A.A.; a analysis of received works – Ulykpanova M.M., Auyezova Z.T., Mussabayeva M.N., and Ramazanova N.E.

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