Evaluation of the influence of slag heaps on the state of the urban residential area

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Abstract. The paper is concerned with the analysis of heavy metal content in soils depending on the distance from the considered source of pollution of Magnitogorsk and its suburbs. It was found that the main investigated heavy metals polluting soils are zinc, lead and copper. The main objective of this research work is to carry out the analysis of heavy metal content dynamics in soil from 2014 to 2017 taking into account environmental protection measures taken within the frame of the environmental program of the PJSC MMK. The slagheap of the III order located in the North of the city on the left-bank valley side of the river Ural was considered as the source of pollution. The research group calculated the following characteristic values: the total pollution index of soils and the ecotoxicological index of chemical pollution of soils with pollutants of different classes of hazard.

1. Introduction
Residential areas located in the vicinity of large industrial centers have to face strong man-caused impact due to, among other things, a huge amount of solid wastes formed by:

- industrial enterprises emitting gaseous, liquid and solid wastes including chemical and radioactive ones in the process of operation or in emergency situations;
- urban environment emitting wastes of the housing maintenance and utilities, wastes from vehicles, storm wastewater, snowpack etc.;
- living environment emitting liquid and solid wastes.

The following changes can be predicted for the near future:

- the world population will continue to increase steadily and in 2050 it will be approximately 9 billion people;
- per capita GDP will increase by 2-4% per annum on average;
- the amount of specific industrial wastes emission into environment will to a great extent depend on the way of waste screening and recycling.

Thus in the short term, the only way to reduce the amount of wastes is to cut down the specific value of wastes per unit of GDP and to make efficient use of natural resources by means of waste recycling [1].
Magnitogorsk is one of the largest industrial centers of ferrous metallurgy. A great number of industrial enterprises are located around the city.

So far, the PJSC “Magnitogorsk Iron and Steel Works” has developed a special ecological program to achieve objectives in the field of environment protection. In accordance with this program, 48 technical arrangements were fulfilled to reduce and prevent the negative effects on the environment in 2017. The actual costs to fulfill the PJSC MMK ecological program totaled to 4777.0 mln. roubles in 2017.

Total emissions of pollutants decreased from 219.1 to 199.3 thousand tons from 2014 to 2017; the unit value of pollutant emissions per 1 ton of metal product decreased from 18.80 to 17.58 kg/t.

The amount of wastes used by the PJSC MMK as secondary material resources in the sintering mixture in the ore dressing process was 2.35 million tons; 11.4 million tons of slag was recycled [2].

The accumulated wastes of metallurgical industry in the form of slag are considered as hazardous sources of soil pollution with heavy metals and the degree of impact of these sources on the environment increases annually due to such processes taking place within them as dissolution, migration interchange oxidation and deoxidation.

The main purpose of this research work is to carry out the analysis of heavy metal content dynamics in soil taking into account the measures taken within the framework of the ecological program of the PJSC MMK.

At present the sites where wastes are disposed are not meant for storage of metal-containing wastes, as a result they can turn into sources of repeated emission of pollutants and sources of industrial polymetal anomalies. A large amount of accumulated wastes of metallurgical industry resulted both in pollution of atmosphere with industrial pollutants and in accumulation of pollutants in soil. At the same time, this soil acts both as an accumulator of polluting substances and as the initial link in migration of toxic agents along the surface trophic chains and it also has certain transforming properties in relation to lots of pollutants and can serve as an indicator of the ecological state of the area [3-6].

The slagheap of the III order located in the North of the city on the left-bank valley side of the river Ural was considered as the source of pollution [1]. The territory of Narovchatsky state farm Agapovsky district, located at a distance of 40 km from the city, was considered as the reference point.

2. Experiment description

The pollution form of the soil adjacent the investigated industrial source of pollution with heavy metals was estimated by comparing the actual results of the research work with the admissible concentration limits and with approximate permissible concentrations (table 1) as well as with the corresponding parameters on the reference site.

| Metal | Cu | Zn | Mn | Ni | Pb | Cd | Co |
|-------|----|----|----|----|----|----|----|
| Total content | 55 | 100 | 1500 | 85 | 32 | 2 | 10 | ^a |

\(^a\) is approximate permissible concentration [11]; other values are admissible concentration limits [11].

Pollution of soil was evaluated by the summary/total index of pollution \(Z_c\):

\[
Z_c = \sum_{i=1}^{n} \frac{K_i}{K_p} - (n - 1)
\]

Where \(Z_c\) = the total index of pollution with heavy metals;
\(n = \) the number of the totaled elements;
\(K_i = \) the content of a certain element in soil. mg/kg;
\[ K_{\phi} = \text{the value of the local geochemical background element of a certain element: for Cu it is 30 mg/kg; for Zn it is 70 mg/kg; for Pb it is 10 mg/kg; for Mn it is 40000 mg/kg; for Cd it is 0.2 mg/kg; for Ni it is 1 mg/kg; for Co it is 1 mg/kg.} \]

The content of heavy metals in soil was investigated on the territory exposed to the industrial impact from the slagheap of III order. Comparison of average values of the total content of the investigated metals in soil from 2014 to 2017 made it possible to arrange them into the following decreasing series: Mn > Zn > Cu > Pb > Ni > Co > Cd.

The results of the investigations carried out in 2014 made it possible to come to the conclusion that the total content of zinc and lead in the investigated soil of all sample plots exceeded the admissible concentration limit, while in 2017 only total zinc content exceeded it.

In 2014 soil was contaminated with cadmium within a radius of 200 m. Pollution with copper within 1.5 km is still preserved by the results of 2017 too.

The content of nickel and cobalt in this soil did not exceed the permissible rates either by the results of investigations of 2014 or 2017.

It should be noted that in 2014 the total content of cadmium and manganese in the soil of the listed sample plots was maximum near the source of pollution and gradually decreased with the increase of the distance from the source. At the same time the total content of cadmium exceeded the admissible concentration limit by 1.3 times, while for zinc this figure was exceeded by 5.2 times. In 2017 pollution with cadmium was not detected, while the excess of the admissible concentration limit for zinc was 4.71 times, for manganese it was 6.7 times and for copper it was 3.2 times.

In 2014-2017 no clear relationship was found between the content of other investigated metals and the distance from the source of pollution. In 2014 the highest value for Cu was found at a distance of 500 m (up to 4 admissible concentration limits), for Zn and Pb this distance was 1500 m (7 and 5.7 admissible concentration limits, respectively). In 2017 the content of nickel and cobalt in this soil did not increase the permissible rates and the highest value for nickel was found at a distance of 5000 m.

Calculated values of the total pollution index are given in table 2.

| Distance to the source of pollution | 2014  | 2017  |
|-----------------------------------|-------|-------|
| 200 m                             | 39.084| 32.123|
| 500 m                             | 34.574| 26.386|
| 1500 m                            | 27.691| 14.625|
| 5000 m                            | 4.652 | 2.343 |
| 40000 m                           | 2.525 | 0.617 |

As a result of the analysis of the calculation results, it was found that in 2014 the degree of soil pollution in the area exposed to the impact of the slagheap of the III order made it possible to refer the soil located within the range of 0.5 km from it to highly hazardous one, in all other cases it could be referred to the admissible category; in 2017, the soil located within the range of 0.2 km from the slagheap was considered to be highly hazardous, while in all other cases it was considered admissible.

The most significant characteristic of the ecological state of the territory is the ecotoxicological index (\( E_c \)) of the soil quality, which can be calculated as the relationship between the pollutant concentration and the admissible limit value [7]:

\[ E_c = K_1 + \ldots + K_n. \]

where \( K_n \) = the coefficient of pollution agent concentration in the soil, which is calculated as the relationship between the average concentration of the element in soil and its admissible concentration limit in accordance with the GN 2.1.7.2041-06 [8];

\( n \) = the number of elements taken into account.
In the process of the investigation, heavy metals were referred to the following classes of hazard: I class of hazard included zinc, lead and cadmium. II class of hazard included nickel, copper and cobalt; III class of hazard included manganese.

The total evaluation of the ecological situation of the region aimed at defining environmental emergency zones and zones of ecological catastrophe is given in the procedure. The criteria of the ecological state of soil are given in Table 3.

**Table 3. Criteria of the ecological state of soil.**

| Parameter | Ecological disaster | Situation of environmental emergency | Relatively satisfactory situation |
|-----------|---------------------|---------------------------------------|----------------------------------|
| Ecotoxicological index \((E_c)\) of the soil quality: | | | |
| I class of hazard | \(>3\) | 2-3 | <1 |
| II class of hazard | \(>10\) | 5-10 | <1 |
| III class of hazard | \(>20\) | 10-20 | <1 |

The obtained values of the ecotoxicological index of the soil pollution are given in Table 4.

**Table 4. Ecotoxicological index of the soil ecological state.**

| Chemical element | Distance from the source of pollution |
|------------------|---------------------------------------|
|                  | 200  | 500  | 1500 | 5000 | 40000 |
| Year 2014        |      |      |      |      |       |
| Zinc             | 5.175 | 5.775 | 7.025 | 1.438 | 1.273 |
| Lead             | 4.008 | 4.313 | 5.367 | 1.054 | 0.555 |
| Cadmium          | 1.250 | 0.875 | 0.750 | 0.125 | 0.125 |
| \(E_c\)          | 10.433 | 10.963 | 13.142 | 2.617 | 1.953 |
| Copper and Nickel| 3.223 | 3.914 | 1.541 | 0.991 | 0.791 |
| Cobalt           | 0.053 | 0.035 | 0.029 | 0.062 | 0.032 |
| \(E_c\)          | 3.626 | 4.224 | 1.820 | 1.353 | 1.073 |
| Manganese        | 8.537 | 7.088 | 3.080 | 1.138 | 0.902 |
| \(E_c\)          | 8.537 | 7.088 | 3.080 | 1.138 | 0.902 |
| Year 2017        |      |      |      |      |       |
| Zinc             | 4.950 | 4.330 | 2.500 | 1.150 | 0.997 |
| Lead             | 3.690 | 4.060 | 3.440 | 0.820 | 0.420 |
| Cadmium          | 0.976 | 0.730 | 0.540 | 0.090 | 0.090 |
| \(E_c\)          | 9.615 | 9.120 | 6.473 | 2.05992 | 1.508 |
| Copper and Nickel| 3.180 | 2.620 | 1.250 | 0.780 | 0.630 |
| Cobalt           | 0.040 | 0.028 | 0.024 | 0.050 | 0.030 |
| \(E_c\)          | 3.498 | 2.858 | 1.464 | 1.070 | 0.860 |
| Manganese        | 6.689 | 5.458 | 2.278 | 0.911 | 0.710 |
| \(E_c\)          | 6.689 | 5.458 | 2.278 | 0.911 | 0.710 |

By the results obtained in 2014 it was found that:

- total ecotoxicological index for metals of I class of hazard is within the range of 1.953 and 13.142, which makes it possible to refer the investigated area to the zones with environmental emergency situation and to the zones with ecological disaster in the vicinity of the source of pollution;
• total ecotoxicological index of soil for metals of II class of hazard is within the range of 1.073 and 4.224, which makes it possible to refer the investigated area to the zones with the critical ecological situation;
• ecotoxicological index of soil for metals of III class of hazard is within the range of 0.902 and 8.537, which makes it possible to refer the investigated area to the zones with the critical ecological situation.

Thus, it was found that the territory of Narovchatsky state farm Agapovsky district, located at a distance of 40 km from the city, can be referred to the zones with a critical ecological situation ($E_C < 1$).

In 2017 the research group found that:

• total ecotoxicological index of soil for metals of I class of hazard is within the range of 1.508 and 9.615, which makes it possible to refer the investigated area to the zones with environmental emergency situation and to the zones with ecological disaster in the vicinity of the source of pollution;
• total ecotoxicological index of soil for metals of II class of hazard is within the range of 0.847 and 3.498, which makes it possible to refer the investigated area to the zones with the critical ecological situation;
• ecotoxicological index of soil for metals of III class of hazard is within the range of 0.710 and 6.690, which makes it possible to refer the investigated area to the zones with the critical ecological situation.

It was found that the territory of Narovchatsky state farm Agapovsky district, located at a distance of 40 km from the city, can be referred to the zones with a relatively satisfactory ecological situation ($E_C < 1$).

Calculations show that concerning the investigated heavy metals of II and III classes of hazard, the territory of Narovchatsky state farm Agapovsky district, located at a distance of 40 km from the city, can be referred to the zones with a relatively satisfactory ecological situation ($E_C < 1$).

Thus, in our research work, the following two indexes were calculated: the total index of soil pollution and the ecotoxicological index of chemical contamination of soil with pollutants of different class of hazard.

The analysis of the obtained data showed that the territory located at a distance of 1500 m from the source of pollution is not considered to be hazardous by the total pollution index in 2017. However, the calculated value of the ecotoxicological index of chemical contamination of soil with pollutants of I class of hazard also showed that by the characteristics of the soil state the territory mentioned above is referred to the zones of ecological disaster.

Calculation of the total pollution index cannot provide the complete evaluation of the positive dynamics of the content of heavy metals in soil taking into account the measures taken within the framework of the ecological program of the PJSC MMK.

In accordance with the procedural guidelines of 2.1.7.730-99 “Sanitary assessment of soil quality for populated areas”, the assessment of the degree of chemical contamination of soil must be made according to the indexes calculated by the combined geochemical and geohygiene surveys of the city environment with active sources of pollution.

Thus when the distance from the source of pollution increases, concentration of heavy metals in soil decreases significantly, which shows clearly the contribution of the residential areas to the pollution of soil.

Soil is the constitutional unit between the components of the biosphere as well as the biogeochemical barrier absorbing heavy metals and at the same time cleaning natural environment (atmosphere and hydrosphere) from them [10]. When exposed to blowing erosion and transport erosion, it can turn into the source of secondary pollution when the threshold value of heavy metal
concentration is exceeded and the self-cleaning ability is lost.

3. Conclusion

The chemical analysis carried out by the research group showed spatial non-uniformity of distribution of heavy metals in soil. No clear relationship was found between the indexes of soil quality.

Calculations showed that by the start of the research work in 2014 the territory of Magnitogorsk and its suburbs was referred to the zones with environmental emergency and ecological disaster in the vicinity of the source of pollution.

At present taking into account the measures taken within the frame of the ecological program of the PJSC MMK, only the territory at a distance of 200 m from the source of pollution is considered to be the zone with environmental emergency and moreover one can see obvious decrease of values of the calculated indexes.

Thus, it is very important to calculate both the total index of soil pollution and ecotoxicological index of chemical pollution of soil with pollutants taking into account their class of hazard. These calculated values make it possible to come to the conclusion about the decrease in the content of heavy metals in soil taking into account the taken ecological measures.

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