Ecological Assessment of Non-Target Impact on the Intensity of Human-Induced Changes in Gray Forest Soils

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Abstract. This article presents studies on determining the rate of anthropogenic influences on the gray forest soils sustainability. At present, various pollutants from the atmosphere affect soils. This leads to a decrease in soil fertility, water and air pollution, a decrease in crop yields, and deterioration of product quality. A study of the gray forest soils sustainability to anthropogenic influences incompatible with natural processes is of particular interest to select groups by the degree of anthropogenic transformation. Therefore, the objective of this study was to determine the rate of anthropogenic influences on the grey forest soils sustainability and the degree of their anthropogenic transformation. This requires determining the change in the agrochemical indicators of the fertility of gray forest soils disturbed by overburdened quarrying. Identifying the nature of changes in the texture and micro-aggregate composition of the disturbed soils. Assess the nature of changes in the heavy metals content in gray forest soils of the areas chemically polluted by unauthorized disposal of industrial wastes. Reveal the nature of technogenic load and ecological hazard of industrial waste on the fertile layer of gray forest soils in the chemically polluted area. The research was conducted on an agricultural land site, where soil samples of gray forest soils were extracted. As a result, the gray forest soils' sustainability to anthropogenic impact, incompatible with natural processes, was assessed. The rates of organic content reduction due to violation of the humus layer were proved. The decrease level of available phosphorus was proved, significant fluctuations for potassium in the soils were revealed. A significant decrease in soil acidity has been confirmed. The influence of chemical pollution of the soil cover by heavy metals has been found out. The intensity of anthropogenic load of industrial waste on the soil depending on the soil contamination levels of heavy metals was revealed.

1. Introduction
The transformation of landscapes by agricultural activity, amplified by the influence of urban industry, has a significant impact on the natural flows of matter and energy [17], [21]. Along with the positive
changes achieved by the farmer, the negative consequences of technogenesis are increasingly evident [16], [21]. Often, they exceed ecologically permissible limits and violate the ability of the ecosystem to self-regulate, which leads to their destruction [20], [15]. Generally, arable areas are characterized by significant changes in the flow of matter and energy, microclimate, topography, biodiversity, trophic chains, and interrelationships, both in the soil and in the soil-plant system, phytocenosis, and biocenosis as compared to natural areas [14], [19]. Soils transformed morphologically or analytically in soil properties by industrial activity are called anthropogenically modified soils [1], [13], [18].

The industrial activity becomes a major factor in soil formation as well as in changes in soil fertility across vast land areas [13], [15]. Currently, agricultural production is associated with significant local disturbances of the ecological environment [14]. This depends both on changes in the openness of the soil-plant system (plowing, exclusion of crop products from the field, introduction of fertilizers, ameliorants, toxic chemicals into the soil), and on the entry of external chemical components (heavy metals, sewage, etc.) into the soil [12], [16]. There is a widespread expansion of disturbed agricultural areas. The reasons are illegal excavations (quarrying, pipe or cable laying) and violations of their technology; high concentrations of pollutants in the water migrating from the fields, which causes the pollution and destruction of the fertile soil layer and requires remediation measures with significant economic, technical and time expenses [11], [17].

Meanwhile, the type of economic activity determines the main direction of soil change: many human actions may be similar to natural phenomena (planting of trees, mole drainage, etc.), but certain actions (soils irrigation) leads to incomparable conditions with the original soil formation conditions [10], [18]. On the other hand, a significant impact on the soils has a duration of anthropogenic actions, which can be a long or short-term impact or a single impact during construction work [9], [19].

The irreversible nature of anthropogenic interference with the soil means that it either fundamentally disrupts the very existence of the soil, up to its elimination, or fills the soil with extraneous substances that change its functioning [8], [20].

A significant part of the areal of grey forest soils is represented by erosional highlands. This, combined with rainfall precipitation and erosion-dangerous bedrocks - loess-like loams, determines the instability of these soils to anthropogenic impacts and erosion processes [7], [21].

Grey forest soils are characterized by the prevalence of old forms of carbonates in the form of cranes, tubes [6], [21]. The carbonation of grey forest soils is characterized by the deep carbonation of the bedrock, which limits the development conditions of lessivage [1], [5]. When using grey forest soils in arable farming it is possible to pull up the solutions with calcium carbonates along the capillaries to the surface. This leads to increased consolidation of humus, averaging the reaction of soil solution, and loosening of compacted horizons [2], [4].

Therefore, determining the resistance level of grey forest soils to anthropogenic influences, the nature of their degradation changes, and anthropogenic transformation of agricultural soils is of importance for theoretical significance. It is also of topicality in assessing the features of occurrence and development of elementary soil processes on agricultural lands. Soils sustainability research represents the main subject of environmental programs, environmental impact assessment systems, and ecological expertise and monitoring, which is the main purpose of this research.

The objective of the study is to establish the role of anthropogenic influences on the grey forest soils sustainability and the level of their transformation caused by anthropogenic factors.

The following tasks are to be solved:

1. To determine the change rate of the fertility indicators in the grey forest soils disturbed by open-pit works (pHKCl; the amount of organic matter; the degree of endowment with available forms of K₂O and P₂O₅) and to determine the nature of changes in the texture (grain) and micro-aggregate composition of soils of the disturbed lands.

2. To analyze the pattern of changes in the presence of heavy metal in the grey forest soils in the chemically polluted area caused by the unauthorized disposal of industrial wastes.

3. To reveal the nature of technogenic load and ecological hazard of industrial waste on the fertile layer of grey forest soils in the polluted area.
2. Subjects and methods
The research was conducted on the samples taken at the depths of 0-5 and 5-20 cm from the agricultural plot of grey forest soil.

The pH of the salt extract was determined following GOST 26483-85 Soils. The salt extract preparation and determination of its pH by the CINAO method.

Mass proportion of elements in soil, ground, and sediment samples was measured by atomic emission and atomic absorption spectrometry for manganese and nickel (mobile forms) determination, M-MVI-80-2008.

The presence of heavy metals in soils and crop production was determined by methodological guidelines for copper, zinc, and lead (mobile forms), CINAO, Moscow, 1992.

Texture and micro-aggregate composition were determined according to GOST 12536-2014- Soils. Methods of laboratory determination of the texture (grain) and micro-aggregate composition of the soil.

The amount of organic matter was measured according to GOST 26213-91-soils. Method for organic matter determination.

Content of mobile compounds of exchangeable potassium and mobile phosphorus was performed according to GOST R 54650-2011 Soils. Determination of mobile compounds of phosphorus and potassium by Kirsanov method in the CINAO modification.

Sampling was completed according to GOST 17.4.3.01-2017 "Nature Conservation. Soils. General requirements for sampling". For sampling, we used a sharp-tipped digging shovel "GOST 19596-87".

3. Results and discussion
Results and discussion. Agricultural activities, mostly farming and relatively less livestock, have a long-term impact on the soil. The impact can be periodic, continuous, infrequent, or single-time. The cumulative effect, estimated as the memorization by the soil, is identified based on the duration and type of influences. Concerning soil, impacts are divided into direct and indirect ones. Direct impacts pursuing a certain goal (plowing, fertilizing, irrigation, drainage), and have a purposeful or direct non-targeted impact. Indirect impacts change the water and thermal regimes, groundwater level, caused an accidental or intentional change of soil-forming factors. Reversibility and irreversibility of impacts mean the preservation of newly formed properties in the soil profile, i.e. the ability of the soil to return to a state close to the initial one. The more quickly and more completely it is returned, the less stable results of influences. The reversibility of changes, or the ability to self-repair, depends on the buffering capacity of the soil and the type of impact. Most agricultural impacts are reversible, while anthropogenic impacts are generally irreversible. Thus, mechanical and chemical anthropogenic factors are alien to natural soil bodies and processes. For example, the entry of heavy metals into the soil is hazardous to many living beings, including humans.

| Sample No. | Sampling depth, cm | pHeCl, % | Organic matter, % | K₂O, mg/kg | P₂O₅, % | Texture (grain composition), % |
|------------|--------------------|----------|-------------------|-------------|---------|-----------------------------|
|            |                    |          |                   |             |         | >10 mm | >0.5 mm | >0.2 mm | >0.1 mm | >0.05 mm | >0.05 mm |
| 1          | 5-20               | 7.9      | 0.5±0.1           | 171±17      | 3.5     | 6.3   | 12.0  | 17.0   | 25.0   | 36.2     |
| 2          | 5-20               | 7.8      | 1.4±0.3           | 172±18      | 2.9     | 5.4   | 8.5   | 16.3   | 28.3   | 38.6     |
| 3          | 5-20               | 8.1      | 0.8±0.2           | 172±17      | 3.2     | 6.2   | 8.1   | 19.2   | 27.3   | 36.0     |
| 4          | 5-20               | 8.0      | 0.9±0.2           | 163±16      | 3.8     | 5.7   | 7.9   | 16.2   | 29.3   | 37.1     |
| 5 back      | 5-20               | 5.3      | 2.3±0.5           | 132±13      | 3.0     | 6.1   | 8.0   | 16.2   | 29.8   | 36.9     |

Table 1. Indicators of changes in the fertility of gray forest soil disturbed by quarrying.
Therefore, soils sustainability is their ability to withstand influences, i.e. to change weakly and relatively quickly return to the initial state. It determines the direction and stability of many processes and phenomena in nature and defines the concept of soil sustainability in general and applied aspects (Table 1).

The sample of grey forest soil disturbed by quarrying taken from the 5-20 cm layer was analyzed on the changes of fertility quantitative indicators. The results are proved that, compared to the sample taken from the same depth (5-20 cm) of undisturbed grey forest soils, the quantitative content of indicators characterizing the humus state of soil significantly changed (Table 1). The studies revealed that in the upper layer (5-20 cm) of the undisturbed grey forest soil, the amount of organic matter varies within 2.3±0.5%.

The anthropogenic impact of quarrying works on the soil not only caused the violation and destruction of the humus layer but also led to a sharp decrease in organic matter in soils. It is shown that violation of soil integrity by open-pit works was the reason for the deterioration of humus condition of grey forest soil: the amount of organic matter in soil samples with disturbed fertile layer decreased to the level of 0.5-1.4%. Its content varied from 0.5-0.9% to 1.4±0.3% in the test soil samples. The limits are 2.6-4.6 times lower than the control level of organic matter in undisturbed soils, and 1.6 times lower than the level of humus content in the background soil.

The sharp decrease of the organic matter content in the humus layer of anthropogenically modified gray forest soil indicates destruction of its fertile layer, and, consequently, a decrease in its productive capacity and environmental sustainability to natural-anthropogenic influences.

Anthropogenic impacts (quarrying) caused changes in physical and chemical properties and living conditions of arable grey forest soils mainly in the upper part of their profile. These are changes in the environmental reaction or its acidity-alkalinity level, the nutrient regime of grey forest soils, changes in texture, destruction of soil structure, changes in the hydrothermal regime, and the intensity of erosion processes. Significant changes in pH-level of the anthropogenically modified grey forest soils have been proved. In the samples of undisturbed (background) soils, the pH value of the salt extract was 5.3 and is estimated as "slightly acidic". Whereas in the samples of the anthropogenically changed soils, the pH value increases to 7.8-8.1, which is characteristic of a "slightly alkaline" reaction of the environment. Soil alkalinity reduces aggregative stability of soils, increases the solubility of organic substances, increases density, and deteriorates water-physical properties of soil and its sorption capacity.

The quarrying of agricultural lands caused changes in the soil formation conditions. For the anthropogenic-modified grey forest soils, they were mechanical, vertical, profile violation of soil integrity; extraction to the surface soil-forming rocks - loess-like loam containing calcium carbonates; destruction of the soil structure with subsequent consolidation of its profile, and intensification of anaerobic biochemical and microbiological processes.

The data of the grey forest soil texture (grain composition) confirms the predominance of 1 to 0.5 mm and smaller-sized fractions. Their total amount in the background undisturbed soil is 66.7% and in the samples of disturbed soil is 61.2-63.3%. At the same time, more favorable water-air properties are provided by the 10-11 mm fractions, whose amount varies in the soil samples taken in the territory of disturbed lands.

Soil nutritive regime is assessed by the quantity of exchangeable potassium K2O and mobile phosphorus P2O5. Results show that the content of exchangeable potassium compared with the background soil sample increased from 132 mg/kg to 177 mg/kg, which is 1.2-1.35 times. That means potassium regime change from "average" level of exchangeable potassium to "increased" in soil samples from the disturbed area.

Along with that, the phosphate regime of soils is also significantly changed. While in the control sample mobile phosphorus content is "very high" - 358 mg/kg, in the samples of disturbed grey forest soils its amount is drastically reduced. The phosphate regime of disturbed soils undergoes considerable fluctuations from a "very low" phosphorus content of 25 mg/kg to an "average" content of 135-138 mg/kg, and a "high" content of 245 mg/kg of mobile phosphorus.
The disturbance of the land plot by quarrying destroyed the profile integrity of grey forest soils and the loss of the fertile humus layer of soil. Identified high heterogeneity of its cover had a significant influence on the groundwater regime changes. It causes deterioration of the water-air regime not only of the disturbed lands but also of the soil cover in the surrounding territories.

Of particular interest is the assessment of the sustainability of soil's humus horizon at a depth of 0-20 cm to anthropogenic influences, incompatible with natural processes within the area of chemical pollution. These influences on fertile soil layer distribution are accompanied by mechanical and chemical contamination, caused by the disposal of industrial wastes.

The samples of the soil taken from the depth of 0-5 and 5-20 cm were tested on the presence of heavy metals - manganese (Mn), copper (Cu), nickel (Ni), lead (Pb), and zinc (Zn) in mobile form. The results showed that violation of the studied land area, namely, disturbance and overburdening of various kinds of industrial and household wastes, accompanied by mechanical disturbance of the soil, caused deterioration of the fertile layer and reduced resistance of grey forest soil to contamination by heavy metals (Table 2).

**Table 2.** The impact of chemical pollution of gray forest soils on the accumulation of heavy metals mobile forms.

| Soil anthropogenic transformation degree | Sampling depth, cm | pH_{KCl} | Mobile forms, mg/kg | Mn | Cu | Ni | Pb | Zn |
|----------------------------------------|-------------------|----------|-------------------|----|----|----|----|----|
| Undisturbed (control)                  | 0-5               | 5.8      | 0.47              | 0.18 | 0.45 | 0.30 | 1.78 |
|                                        | 5-20              | 5.8      | 0.49              | 0.19 | 0.48 | 0.35 | 1.92 |
| High                                  | 0-5               | 7.5      | 13.10             | 0.44 | 1.15 | 1.26 | 41.60 |
|                                        | 5-20              | 7.5      | 13.57             | 0.42 | 0.69 | 1.02 | 40.90 |
| Medium                                | 0-5               | 7.6      | 11.11             | 0.27 | 0.71 | 0.91 | 28.90 |
|                                        | 5-20              | 7.5      | 11.22             | 0.26 | 0.65 | 0.70 | 26.85 |
| Low                                   | 0-5               | 7.8      | 7.63              | 0.22 | 0.54 | 0.53 | 16.74 |
|                                        | 5-20              | 7.7      | 7.20              | 0.21 | 0.63 | 0.50 | 15.50 |
| PDC                                   | ≤100              |          | 3.0               | 4.0  | 6.0  | 23.0 |

From the physicochemical point of view, the absorption of heavy metals by the soil depends on the solubility of the formed sediments of heavy metals, which determines the degree of their fixation in the soil and the transformation of the resulting compounds. The degree of accumulation of the analyzed heavy metals was evaluated according to the criteria of the ecological situation of the territory. Three categories of soils differing in the degree of anthropogenic transformation were identified: "low", "medium" and "high" compared to undisturbed control soil. The research results demonstrated reliable excess of the maximum permissible zinc concentration in all soil samples of "high" and "medium" levels. Compared to the amount of movable zinc in control soil samples (1.78-1.92 mg/kg), its content increases 9.4 times (up to 16.74 mg/kg) in the "low" soil contamination. At the same time, in the "average" soil contamination, the amount of mobile zinc rises to 28.9 mg/kg in the 0-5 cm layer and 26.85 mg/kg in the 5-20 cm layer. It exceeds the control level by 16.2 times in the 0-5 cm layer and by 14 times in the 5-20 cm layer. Of note, for the "medium" category it is proved that the maximum allowable content of mobile zinc in soils exceeds acceptable level by 1.3 times in the 0-5 cm layer and 1.2 times in the 5-20 cm layer. In the conditions of a "high" degree of anthropogenic transformation of soils, the highest degree of soil pollution by mobile zinc has been revealed. Its amount in the very surface soil layer increased to 41.6 mg/kg, and in the 5-20 cm layer to 40.9 mg/kg. The identified level of zinc accumulation exceeds the maximum permissible concentration 1.8 times both in the 0-5 cm and 5-20 cm layer. Out of all analyzed soil samples, 68% are characterized as soils with the mass fraction of zinc as a pollutant. Soil contamination with zinc is known to cause specific diseases such as toxicosis, gastrointestinal pathologies, nervousness, depression, decreased sense of smell and sight, immune system disorders, intoxications, skin diseases, as well as plant diseases, and reduced crop yields. In the rest 32% of the samples, the content of
mobile zinc exceeded the control level by 8.7 times. Such high levels of fluctuations in the content of mobile zinc cause body abnormalities and poisoning. The established changes in the content of mobile zinc and alkalinization of the soil environment may be the result of the disposal of wastes polluted with zinc-containing pesticides on the studied land area.

Note that the land plot is located in conditions of high moisture (semi-hydromorphic soils). It is caused by high groundwater levels and subsequently increased surface moisture. That is confirmed by the increased amount of mobile manganese in comparison with the control soil samples. Thus, the amount of mobile manganese in soil samples with a "high" level of contamination exceeded the control level of uncontaminated soil by 27.8 times. In the soil of "average" level of pollution content of mobile manganese decreases to 11.11 mg/kg, and with "low" level to 7.2 mg/kg. In all investigated soil samples taken from the contaminated area, the amount of mobile manganese of its maximum permissible level in the soil (≤100 mg/kg) is not exceeded.

Heavy metal toxicity for the "soil" system is determined by their activity, duration of exposure, the possibility of leaching outside the system, and tolerance to a particular toxicant. Studies have found that the content of mobile forms of copper, nickel, and lead in the selected soil categories exceeds the reference level for copper 2.4 times for the "high" category of pollution and 1.4 and 1.2 times for the "average" and "low" categories respectively. This confirms the technogenic origin of pollutants and the formation of anthropogenic geochemical anomaly, proven by exceeding the mean content of the element in the studied land. Thus, the mean content of mobile forms of nickel and lead increases compared to the control level by 2.6 times for nickel, 4.1 times for lead in the conditions of the "high" category of soil contamination. For the soil of the "medium" category, the content increased by 1.6 and 2.5 times for nickel and lead respectively. For the soil of the "weak" category, the amount of mobile nickel exceeds the control level by 1.2 times, and for mobile lead by 1.6 times.

The change of soil environment reaction from slightly acidic in control soil samples (pH 5.8) to neutral and slightly alkaline in soil samples contaminated with soil wastes (pH 7.5-7.8) was revealed. This circumstance makes the situation of metal accumulation and migration both in the 0-5 cm and 5-20 cm soil layers and in deeper soil layers and ground waters even more dangerous.

To identify soil contamination degree and their ecological hazard, a coefficient of pollution concentration ($K_c=\frac{C}{S_r}$, where $C$ is the concentration of the chemical element in the contaminated sample, mg/kg; and $C_r$ is the background content of this element). To assess the poly-element anomalies in the disturbed areas of land - the total pollution index ($Z_c=\sum K_c(n-1)$, where $K_c$ is the concentration factor of pollution > 1; $n$ is the number of chemical elements with $K_c>1$) (Table 3).

### Table 3. Assessment of the contamination degree of grey forest soils.

| Soil anthropogenic transformation degree | Sampling depth, cm | Metal concentration rate, $K_c$ | Total pollution index, $Z_c$ |
|----------------------------------------|-------------------|--------------------------------|---------------------------|
| High                                   | 0-5               | 27.87 2.44 2.56 4.20 23.37     | 56.44                     |
|                                        | 5-20              | 27.69 2.21 1.44 2.91 21.30     | 51.55                     |
| Medium                                 | 0-5               | 32.64 1.50 1.58 3.03 16.24     | 41.99                     |
|                                        | 5-20              | 22.90 1.37 1.35 2.00 13.98     | 37.60                     |
| Low                                    | 0-5               | 16.23 1.22 1.20 1.77 9.40      | 25.82                     |
|                                        | 5-20              | 14.69 1.11 1.31 1.43 8.07      | 22.61                     |

Table 3 shows that the highest level of pollution found for soils of "high" and "medium" degree of anthropogenic transformation relative to the content of manganese and zinc mobile forms. The concentration ratios of pollutants varied depending on the level of metal accumulation and the depth of soil contamination.

Thus, the highest was concentration coefficients of mobile manganese in of "high" and "medium" categories of contamination, and the values ranged from 22.9 to 32.64. The identified pattern is also typical for the intensity of the mobile zinc accumulation. The coefficient values varied from 16.24 to
23.37. This characterizes a high and very high level of contamination intensity. The intensity of the grey forest soils contamination by metals as copper and nickel are characterized by minimal and low levels of pollution with the concentration coefficient values ranging from 1.11 to 2.44 for copper and 1.2 to 2.56 for a nickel. For mobile lead, the intensity of contamination is ranged from 1.43 to 4.2. That reflects the minimum and average level of soil contamination. Separate toxicants can increase or weaken the effects of each on the objects under study. Still, it is necessary to have an assessment of polyelement anomalies occurring in the centers of contamination of the landscape. Therefore, the total pollution index (Zc) is used. It reflects the total technogenic load of all the studied chemical elements with high concentrations on the studied landscape. The levels of pollution of the studied soils according to the values of the total concentration index corresponds to the following gradations: "medium" pollution level Zc = 22.61-25.82 characterizing the moderately dangerous category of land pollution with a "low" degree of anthropogenic soil transformation. "High" pollution level Zc = 37.6-56.44 is typical for lands with a dangerous category of soil pollution in conditions of "medium" and "high" degree of anthropogenic soil transformation.

Conducted researches made it possible to illustrate the anthropogenic contribution in soil formation and the processes of meta-pedogenesis provoked by human activity occurring with a higher rate in anthropogenically transformed soils and characterized as soil destroying with acrogenic evolution of soils.

4. Conclusions

1. The assessment of the sustainability of the agricultural grey forest soils to anthropogenic impact has been established. The actions, incompatible with natural processes are pollution of the territory by industrial wastes of various kinds and destruction (deterioration) of the fertile soil layer because of irreversible anthropogenic influences.

2. The organic content decrease by 2.6-4.6 times comparison with undisturbed background due to the disturbance of the humus layer of soil by quarry works. The decrease in the quantity of accessible phosphorus in the anthropogenic-disturbed soils is 14.3 times lower than in the background soil. Significant fluctuations for exchangeable potassium in anthropogenic-transformed by irreversible interferences gray forest soils have been revealed.

3. Significant decrease of acidity of grey forest soils, irreversibly transformed by quarry works, from “slightly acidic” pH 5.3 to "slightly alkaline" pH 7.8-8.1 has been confirmed. The influence of heavy metal pollution on the change of grey forest soil reaction from "slightly acidic" (pH 5.8) in undisturbed soil to a "neutral" and "slightly alkaline" environment (pH 7.5-7.8) in soils of contaminated territories has been established.

4. The intensity of technogenic loading of industrial wastes on the soil depending on the levels of pollution with heavy metals. On the values of the total concentration index: Zc = 22.61-25.82 corresponding to "moderately hazardous" category of pollution; Zc = 37.6-56.44 is the "hazardous" category of land pollution for soils with "low ", "medium" and "high" degrees of anthropogenic transformation.

5. Studies have established the highest values of concentration ratios for mobile manganese (22.9-32.64) and zinc (16.24-23.37) characterizing the high and very high intensity of soil contamination. The lowest levels of accumulation factors for copper, nickel, and lead (from 1.11 to 4.2) confirming the low and medium levels of soil contamination.

6. The fact of deterioration and reduction of the qualitative state of fertility and deterioration of the fertile layer of grey forest soil caused by quarrying works and pollution by industrial wastes requires reclamation works on the territory of the disturbed lands has been established.

7. The specificity of anthropogenic influences on evolutionary changes of elementary soil processes, forming features of composition and properties of the grey forest soils with arable horizon disturbed by erosion-mechanical influences and ingress of chemical compounds of pollutants, has been proved.
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