Implementation of the cascade waste use principle by application of sewage sludge on lands disturbed by mining operations

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Abstract. Object of research - disturbed lands of Ingulets Iron Ore dressing Work (Ingulets GZK) The purpose of work - development and substantiation of technology of realization of principles of cascade waste use. Research methods – field experiment, comparative analysis, systems analysis. As part of the implementation of the cascade waste use principle, the results of research on the impact of the application of sewage sludge on formation of protosoils on the rocks of Ingulets GZK dumps are presented. The application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity.

Introduction

Implementation of the sustainable development strategy involves solving complex environmental problems. The problem of land desertification is becoming increasingly acute around the world and is recognized as global in international instruments ratified by Ukraine: Agenda 21, United Nations Convention to Combat Desertification. Desertification can be both natural and man-made. Desertification is facilitated by the extraction of minerals, which has led to the appearance of disturbed lands in Ukraine on an area of more than 160 thousand hectares. Creation of external dumps, dips and sludge storages contributes to the land degradation.

At the same time, huge amount of waste containing nutrients contributes to environmental pollution, exacerbating environmental problems of climate change. The negative impact of these objects on the environment is manifested in the form of destruction of fertile lands, changes in the hydrogeological regime and other forms. Thus, it is necessary to find non-traditional solutions, the main approaches to which are formed by the theory of sustainable development.

The main idea is the maximum use of natural energies, forces and phenomena. In his report to the Club of Rome, Gunter Pauli proposed that this approach should be considered as the only way of civilization development. It got a figurative name – the "blue economy". Such an economy should be based on technological processes that copy natural physical phenomena, and the waste from one industry should become raw material for another. Thus, the natural cascade principle of waste use in the environment is realized. Unfortunately, there is a shortage of scientific research in this direction.

Traditional notions of land restoration in Ukraine are limited to reclamation, which was widely used in Soviet times. However, because of the need to invest significant funds without real return, often unsatisfactory results of restoration and organizational problems, the traditional reclamation is basically no longer used.

Analysis of its results shows that the main reason for low efficiency is the attempt to create a quasi-natural technosystem based on simplified formal models that are not able to function as primary. The aim of the work is to develop new methods of rehabilitation of lands disturbed by mining operations on the basis of the cascade organic waste use principle.

The development of methods for the formation of secondary ecosystems which meet the requirements of sustainable development on the basis of resource and energy conservation is becoming increasingly important, especially for regions with high human impact. It is known that in energy and resource conservation the leading positions are occupied by the processes of functioning of living systems. In this regard, their involvement in solving technological problems, especially related to the elimination of environmental imbalances, is the most promising area of environmental harmonization.

The main tasks are as follows:

- to review of available methods of organic waste processing,
- to research of content of heavy metals, pathogens in technobiogeocenoses,
- to determine the impact of organic waste on the development of secondary vegetation.

Materials and methods

The research was carried out on the disturbed lands of Kryvbas at the Ingulets GZK. Studies of the structure of the surface and the state of ecosystems were performed using Landsat remote sensing data and ArcView and Google Earth services, which are publicly available.

The following scientific methods were used to solve the set tasks: graphoanalytical; analysis and generalization of statistical and cartographic data; mathematical modeling; system analysis.

Determination of heavy metals content was performed by atomic absorption method, determination of pathogens was performed by direct microscopy, humus content in technosols was determined by the Turin method. The method of squares was used to determine the projective vegetation cover. Its subject is a two-dimensional territorial element. A square with a side of 1 m has been used in geobotany since 1837.

Results and discussion

According to the European Parliament Directive and Council Directive 2008/98/EC (EPOC 2008) on waste, the following waste management hierarchy is proposed: prevention, preparation for re-use, recycling, other recovery, such as energy recovery, recycling. In many countries, the principle of preferential recycling of waste, rather than other ways of disposal, is declared at the legislative level. In Luxembourg, agriculture uses 90% of sewage sludge generated annually, in Switzerland – 70%, in Germany – 38%, in France – 23%, in Belgium – 10%, and the average for European countries and the United States is 32.4% [1]. The use of sludge in agriculture is regulated by Council Directive 86/278/EEC. Sludge should be used taking into account the nutritional needs of plants, and its use should not impair the quality of soil, surface water and ground water. Member states should regulate the use of sludge in such a way as to avoid exceeding the limit values due to the accumulation of heavy metals in the soil. The required rates of sludge application also depend on sludge fertilizer and soil properties. In Germany, liquid sewage sludge can be used in agriculture without dehydration, but the amount of sludge introduced into the soil is strictly controlled to protect groundwater from contamination. In Norway and the Netherlands, sewage sludge is treated by drying and granulating before being applied to the soil as a fertilizer. Prerequisites for the preparation of sewage sludge for disposal as fertilizer are the preliminary disinfection of sludge, as well as the cessation or significant restriction of acceptance by municipal sewage of industrial wastewater containing a significant amount of toxic substances [2]. According to [3], the most common method of sludge processing in the EU-15 in 2014 and 2015 was incineration (47.3% and 61.5% respectively) with subsequent reuse of sludge, including direct agricultural use and composting (48.2%, 38.2%). In Ireland alone, more than 70% of total sludge was disposed of in agriculture, in 7 countries the value ranged from 70% to 20% (over 50% in Bulgaria), in 10 countries less than 20% (0% in the Netherlands, Slovenia and Malta). Malta, the Netherlands and Slovenia belong to the group of countries with the strictest limit values for the main group of heavy metals in sludge. In Italy, disposal methods are distributed as follows: incineration – 20%, burial – 44%, use in agriculture – 36%; in the USA: incineration – 35%, burial – 30%, use in agriculture – 35%; in Poland: incineration – 44%, burial – 33%, use in agriculture – 23%; in Russia: incineration – 20%, burial – 74%, use in agriculture – 6% [4].

The European Union has adopted “End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals” developed by the Joint Research Center, where sludge was excluded from organic waste allowed for compost production “from waste”.

In Ukraine by the Order No. 342 from 12.12.2018 “On approval of the Procedure for reuse of treated wastewater and sludge subject to compliance with the maximum permissible concentrations of pollutants” the use of sewage sludge is regulated by the DSTU 7369:2013 “Requirements for wastewater and its sludge for irrigation and fertilization”. In accordance with the requirements of current legislation, it is recommended to provide for the use of treated wastewater and decontaminated and dewormed sludge in agriculture (as organic fertilizer) [5]. The design of treatment facilities does not include the final stage of disposal and application of treated sludge. The use of sludge in agriculture is a recommendation, so in Ukraine the most common method of waste management is placing sewage sludge in holding ponds or landfills. Facilities for the disposal of sewage sludge are sources of environmental pollution and require large territories. In this regard, in some European countries, such as Germany, it is prohibited by law to deposit sludge on drying beds [6]. Sludge can be classified as follows: coarse, retained by grates; heavy (sand), caught by sand traps; floating (fatty substances) accumulated in settling tanks; suspensions deposited in primary settling tanks; activated sludge of secondary settling tanks (microorganisms with adsorbed and partially oxidized contaminants removed from wastewater during biochemical treatment); anaerobic sludge fermented in metatanks; stabilized aerobic activated sludge or its mixture with sediment from primary settling tanks in structures such as aeration tanks; activated sludge or sediment in thickeners or concentrators; sludge

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dehydrated on mechanical devices, dried on sludge beds or thermally dried. The main part of dry residue in the sludge of the primary settling tanks (60–75% on average) and activated sludge (about 70–75%) are organic substances. The organic part of the activated sludge is mainly represented by substances of protein origin (up to 50%) with a fat and carbohydrate content of 30 and 10%, respectively. It contains about half as many proteins and 2.5–3.0 times more carbohydrates than in activated sludge. Possibilities of disposal of waste (changes of some derivative characteristics to receive a product suitable for the further useful application) are determined by its qualitative structure. The composition of sewage sludge largely depends on the composition of wastewater, but most of their components are traditional. Based on the composition, the most common worldwide is the use of sewage sludge as organic fertilizers. Value of such fertilizers in many cases is equivalent to manure and sapropels. The content of plant nutrients in the dry matter of sewage sludge is: 2–7% of N; 1.5–7% of P_2O_5; 0.15–0.35% of K_2O. The content of mummified organic matter improves the soil-forming qualities of disturbed lands. Under the influence of sewage sludge in the soil there is an increase in humus content, improvement of water-physical properties and provision of the main nutrients — nitrogen, phosphorus, potassium, etc [7]. Despite some negative claims, the use of organic sludge as a non-traditional fertilizer to increase soil fertility is one of the possible ways to solve the problem of their placement, as the return of processing waste to agricultural and urban lands is a significant factor in closing the cycle of substances in nature [8]. In Ukraine, out of 6–12% sludge, which is recycled, no more than 1/3 is used in agriculture. In addition to use for growing food plants, sewage sludge and compost from this sludge are used as fertilizers on lands set aside for planting trees and shrubs, creating nurseries, parks, growing perennial grasses for pastures, forage, silage, industrial crops, and also for the restoration of reclaimed lands. Utilization of sewage sludge for the purpose of restoration and cultivation of forests is promising, as the probability of getting heavy metals and pathogenic microorganisms into food chains is minimal [9]. For the forest industry, detailed methods of preparation of a number of organic fertilizers from various components of industrial, communal and agricultural wastes have been developed and recommended for implementation in nursery production [10]. The effectiveness of sewage sludge and the lack of negative impact on grass and woody plants have been proven during field studies in nurseries in the Moscow region [11].

Returning to the qualitative composition of sewage sludge, it should be noted that its disposal in Ukraine is limited by two main factors: sanitary-epidemiological and sanitary-chemical. The epidemiological danger of sludge can be eliminated in many known ways, including such simple ones as drying on sludge drying beds according to DBN V.2.5-75:2013. But agro-ameliorative use of sewage sludge is also associated with the risk of contamination of soil and agricultural plants with chemicals, especially heavy metals, such as Cd, Cu, Ni, Pb, Cr, Zn, Hg, As, Mn, and in some cases Mo, Se, Co, Sr, B, Be, Ba. The content of the above elements in sewage sludge may exceed the background content in natural objects (soil, peat, bottom sediments). It depends on the level of development and profile of industry in the settlement, the technical culture of production, the characteristics of the geochemical province, the presence and area of technogenic landscapes. Sludge from domestic wastewater in cities and other settlements is a fertilizer that contains biogenic elements (nitrogen, phosphorus, potassium, their compounds), as well as micronutrient elements necessary for plant development. The most valuable organic fertilizer, especially rich in nitrogen and phosphorus, is activated sludge. Before use as a fertilizer, the sludge is dehydrated and disinfected. Dehydration is performed by mechanical means (vacuum filters, filter presses, centrifuges) and on sludge drying beds. The following methods are used for disinfection: thermal drying (at 80°C); three-day heat treatment at 55°C; composting at 55°C for 15 days; anaerobic fermentation at 35°C; alkaline treatment for 72 hours at pH 12 and a temperature of 50°C. The most effective disinfection of mechanically dehydrated sludge is achieved by their thermal drying. Drying can be direct (by flue gases, hot air, superheated steam) and indirect (through the heat transfer surface). Direct drying prevails and is carried out in units of various types, for example drum (diameter 1.0–3.5 m; length 4–27 m; direct flow of material and drying agent), fluidized (with mechanical stirring), vibrofluidized and spouted bed, combined. To eliminate the smell of emissions when drying sewage sludge, this operation is often preceded by the application of deodorizing additives. These can be, in particular, ground activated soft lignite coal and/or potassium chloride in the amount of 0.1–0.4 and/or 0.1–0.25 parts per unit mass of dry matter of waste, respectively [12]. To eliminate unpleasant odors, pre-liming of the fermented sludge before dehydration, in particular, by centrifugation, is also used. Additives not only suppress odors, but also destroy pathogenic bacteria by increasing the temperature of the mass to 50–55°C, as well as increase the power of centrifuges by 1.5–2.0 times (N-Niro method). A similar effect is achieved by mixing already dehydrated sludge with lime. The same deodorizing effects are obtained using a mixture of calcium carbide (CaC_2) and lime. Thermally dried sludge does not rot. It is a loose material free from helminths and pathogens with a moisture content of 20–50%, convenient for transportation and application to the soil. However, to avoid dusting, granulation is recommended. In the USSR, "Temporary specifications for thermally dried sludge" were developed. In order to prevent the accumulation of toxicants in the soil and plants, these specifications recommended to apply sludge once every 5 years assuming doses of 10–40 t/ha for sludge with moisture content of 50% or 5–20 t/ha for absolutely dry matter.

Compared to thermal methods, disinfection of sewage sludge in natural conditions on sludge beds is less effective. It requires a lengthy period of time — at least 3.5 years since the last filling. In addition, the distribution of such sediment (with a humidity of 75–80%) on the fertilized areas causes significant difficulties. A new method of disinfection using solar energy is the drying of sludge in greenhouses, which has been used in Germany since 1994. The pre-dehydrated sludge is evenly distributed on the surface of the greenhouse (8–10 m wide) and moved along it by means of an automatic unit of constant agitation and longitudinal movement of the sludge along the front equal to the working width of the greenhouse. The final humidity of the material is close to 10%. On the evaporated moisture specific productivity is 700–800 kg/m2 of the greenhouse at an electric power consumption of 20 kWh/t and prime cost of 100–180 German marks for 1 t.

Along with thermal disinfection and disinfection at sludge drying beds, iodine radiation is used (USA, 1979). The sludge is disinfected in an underground room in stainless steel containers. The source of gamma radiation is cesium-137 (dose of 1 MKu). As a result, all pathogenic microorganisms die, while the nutrients of the sludge are preserved. The total cost of processing 1 ton of dry or combined sludge did not exceed $9.

After dehydration and disinfection, sewage sludge is taken to agricultural fields. Its agronomic application is one of the old and widespread types of disposal. In Germany, when using sludge as fertilizer on arable land, the rate is 5 t/ha per year, and on pastures it is 2.5 t/ha (on a dry matter basis). The experience of joint application of mineral fertilizers with sewage sludge shows a significant increase in the yield of sugar beet, wheat, oats in comparison with the application of only mineral fertilizers. In Australia (Adelaide) sludge from aeration treatment plants is used as fertilizer for gardens and orchards located on sandy soils: application up to 24 t/ha on a dry matter basis increases the yield of vegetables in greenhouses and open ground, improves the structure of soil. Experiments by Polish experts have shown that with the annual introduction of optimal amounts of sludge into the soil, the yield of grass crops increases by 30% and rice by 18%. The predominant use of sludge in urban wastewater as a fertilizer also occurs in other countries (France, Canada, Great Britain, Finland, Japan, etc.).

Sediments can also be processed to obtain soil substitutes. For this purpose, they are placed on sites where reeds and other species of higher aquatic vegetation were planted, and which are equipped with systems for drainage, wastewater separation and its disposal to treatment facilities. The processing depends on the specific conditions and lasts up to 6 years or longer. The obtained material is not inferior in quality to natural soils, has physical and chemical stability and can be used in land reclamation in horticultural farms, etc. [13]. After five years of storage on sludge beds, sewage sludge becomes a soil-like mass with a moisture of 50–60%, which contains 36% organic matter (on a dry matter basis), up to 2.24% of total nitrogen, up to 1.26% of gross phosphorus (P_2O_5), up to 0.3% of potassium (K_2O), a rich set of micronutrient elements. Special requirements apply to the content of heavy metals in sediments in accordance with DSTU 7369:2013 “Requirements for wastewater and its sludge for irrigation and fertilization”.

In the USSR, municipal sewage sludge was successfully used in agriculture until the 1990s. For example, the application to the soil of thermally dried sludge of the dry fertilizer shop of the treatment facilities of Orekhovo-Zuyevo in the amount of 30–40 t/ha increased the yield of winter wheat from 3.9 to 33.3 q/ha on raised-bog peat quarry soils. A number of collective farms and state farms in the Moscow region when using sludge as fertilizer increased crop yields by 1.5–2.0 times. There also was an improvement in soil structure. For more than 15 years, the garden and park administration of Moscow has widely used fermented sludge with a moisture content of 80%, removed from the sludge beds: 40–80 t/ha for perennial and annual crops, 100–200 t/ha when laying lawns. Thermally dried lime-containing sludge has become effective means for soil deoxidation. In the areas of development of former peat quarries with the application of thermally dried sludge in doses, which were gradually increased up to 80 t/ha at a humidity of 50%, the reaction of the medium in the soil during the year varied from pH 2.7–3.3 to neutral. Similar results were observed on other less acidic soils at lower doses of sludge. In some southern regions of the USSR, fermented sludge, dried on sludge beds, was used to fertilize vineyards and tea plantations.

In the early 1990s in Russia, the use of urban wastewater as fertilizer in agriculture was prohibited by law. The reason was the increase in the amount of heavy metals and their compounds in sludge.

Studies of substrate properties of overburden dumps have shown the prospects of their use for soil formation. The electrical conductivity of the aqueous extract does not exceed 10 mSm/cm (indicates the absence of salinity), pH values are close to the neutral (6.5–7.0). The absence of phytotoxic properties of rocks is evidenced by the results of biotesting of overburden by germination of radish seeds. The availability of the P and K nutrients promotes self-restoration of biogeocenoses. The development of natural growth processes of communities is inhibited by nitrogen deficiency (N), which underlies the mineral nutrition of plants. The application of organic fertilizers can compensate for the lack of mineral nitrogen and at the same time ensure the stability of its content in the substrate. The source of all forms of mineral nitrogen is the organic matter of sewage sludge. Due to microbiological processes at soil moisture of 25–30% and a temperature exceeding +10°, mineralization of organic matter occurs. Such conditions in the soils of Kryvbas are formed with the beginning of the growing season (early April) and persist for 2–3 months depending on climatic conditions. Sewage sludge has huge reserves of organic matter, the mineralization of which without mixing with rocks less saturated with organic matter can take decades. The main limiting factor in the restoration of biogeocenoses in the steppe zone of Ukraine is soil moisture. Plants experience a lack of moisture for most of the growing season. The formation of secondary biogeocenoses on the dumps of Kryvbas quarries begins with the stages of the “industrial desert”. Optimization of humidification conditions is a key task in activating self-healing processes. The study of water-physical constants of the considered substrates shows that rocks of dumps have the lowest volumetric moisture content of withering, which can provide them with the largest range of active moisture. At the same time, the ability of rock dumps to condense moisture from the air significantly exceeds similar abilities of sand, which makes it possible to meet the minimum needs of plants in the dry season. The ability of dump rocks to condense moisture is determined by their mineralogical composition, which is dominated by quartzites. The accumulation of organic matter in the process of self-renewal should promote the aggregation of rocks and the accumulation of moisture. Based on the known equation of water balance, there is an obvious need to ensure the advantage of inflow values over outflow. Excluding from consideration cases of influence of ground waters which on the disturbed lands apeear at depths of more than 5 meters and do not influence development of soil-forming processes, we compare outflow and inflow. Then, based on the fact that in the steppe zone the total amount of precipitation is equal to the sum of evaporation and desuction, by simple transformations we obtain:

$$A = I_{surf} + I_{sub} + I_c - O_{surf} - O_{inf} - O_{sub} \quad (1)$$

where A is the amount of moisture accumulation; I_{surf} is the amount of inflow due to surface runoff; I_{sub} is the amount of inflow due to subsurface runoff; I_c is the amount of inflow due to condensation of moisture; O_{surf} is the amount of outlflow due to surface runoff; O_{inf} is the amount of outflow due to infiltration; O_{sub} is the amount of outflow due to subsurface runoff.

Obviously, the right part of the equation contains values that can be regulated by engineering methods by creating the necessary geological conditions and reclamation structures. Protosoils formed on rocks of degraded lands have porosity indicators significantly lower than natural analogues (light chernozems by 2.8 times, chernozems in eluvium of sandstones and shales by 2.5 times). Due to this, the filtration coefficient is significantly lower in protosoils: 0.2 mm/min. With such water permeability, the formed soils cannot ensure the absorption of all precipitation that falls, and lose some of them with surface runoff. Analysis of particle size distribution according to the classification of N.A. Kachinskiy allows to classify protosoils as strongly granitic. Granitic soils are most common in mountainous areas. They have several features (short profile, gritty consistency), however, which did not prevent them from forming their fertility, the ability to self-restoration, self-regulation. Protosoils of degraded lands, as a rule, develop from coarse clastic soils, which are a mixture of various mechanical elements of stones and boulders (200 m), gravel (40–400 mm), rotted rock (2–4 mm), loam. Humidity of coarse clastic soils is determined by the humidity of the clay aggregate. The accumulation of moisture can help plan the artificial relief of moisture accumulation. On flat areas it is necessary to evenly plan porous accumulative forms in the form of holes, rollers on the edge of the slope, etc. On the slope cracks and furrows along the horizontal relief should be formed. Stimulation of moisture accumulation in the protosoils of degraded lands is one of the promising areas for activating the self-restoration of biogeocenoses. In stony soils, processes of dew formation (absorption of moisture from the air) are created. Limestone rocks, having hygroscopicity, absorb moisture from the air, and then gradually release it into the soil. The movement of atmospheric air brings atmospheric moisture from the seas and water bodies. Changes in atmospheric pressure, the difference in temperature of stones and air led to condensation of water and its accumulation in the soil. Condensation allowed to receive from air in stony soils up to 60 mm of precipitations annually during the growing season. Such moisture reserves allowed the plants to overcome the dry season and maintain their viability in harsh conditions. Application of organic waste (wastewater, sewage sludge, crop biomass, etc.) significantly increases the possibility of protosoil formation on the rocks of dumps, quarries and tailings, organic matter helps to aggregate the soil surface and reduce the rate of water and wind erosion.

In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. It turned out that sewage sludge with an organic matter content of more than 30% can inhibit the development of vegetation, seed germination processes, growth and development of plants [14, 15]. Excess organic matter led to a significant increase in the content of nitrates in soils and their migration in the environment under the action of surface and infiltration runoff.

Analysis of the obtained results and literature data shows that the optimal content of organic matter in soils should not exceed 10–20%. Thus, in order to create optimal conditions for the restoration of disturbed land ecosystems, it is necessary to ensure the mixing of organic waste with weathered (soft) overburden and their application to the surface of the restored soil cover. Traditional means of applying organic fertilizers to the soil cannot be provided due to the lack of tools, the working bodies of which could withstand the processing of stony technical mixtures, which predominate on the lands disturbed by mining operations. The application of sewage sludge contributed to the formation of a kind of mulch on the surface of the soils, which allowed to minimize the loss of moisture through evaporation, contributed to the formation of a lumpy macrostructure. The application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. The formation of the soil absorption complex significantly improves the water and air regime of soils.

Studies of the chemical composition of overburden have shown a low content of mobile forms of heavy metals.

The content of heavy metals is shown in Tables 1-5.

The content of gross forms of heavy metals in the shales of Ingulets GZK overburden dumps is less than 0.2% for manganese, 0.02% for cadmium, 0.1% for lead, 0.2% for zinc, 0.2% for copper, 0.1% for chromium, 0.2% for nickel of their relative abundance in Earth's crust. The content of gross and mobile forms of heavy metals does not exceed threshold limit values.

The content of gross forms of heavy metals in the clays of Ingulets GZK overburden dumps is less than 0.4% for manganese, 0.02% for cadmium, 0.1% for lead, 0.002% for zinc, 0.2% for copper, 0.0001% for chromium, 0.1%

for nickel of their relative abundance in Earth's crust.

Table 1. Contents of heavy metals in the shales of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	10,0	<0,1	100,0	200,0	32,0	100	68,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

Table 2. Contents of heavy metals in the clays of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	12,0	2,8	1,0	522,0	32,0	<0,1	40,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

Table 3. Contents of heavy metals in the loams of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	13,0	<0,1	61,5	312,0	10,0	<0,1	17,0
mobile: t=25°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	5,6	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the loams of Ingulets GZK overburden dumps is less than 0.3% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 0.1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

Table 4. Contents of heavy metals in the limestons of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	12,0	<0,1	19,6	200,0	5,7	<0,1	10,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the limestones of Ingulets GZK overburden dumps is less than 0.2% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

Table 5. Contents of heavy metals in the quartzites of Ingulets GZK overburden dumps.

Form	Contents of heavy metals, hazard class, mg/kg						
	Pb (1)	Cd (1)	Zn (1)	Mn	Cu (2)	Cr (2)	Ni (2)
gross;	15,0	<0,1	8,5	112,0	4,0	<0,1	17,0
mobile: t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
water soluble t=25°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
t=40°C	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1

The content of gross forms of heavy metals in the quartzites of Ingulets GZK overburden dumps is less than 0.1% for manganese, 0.02% for cadmium, 0.1% for lead, 0.1% for zinc, 0.1% for copper, 0.1% for chromium, 0.1% for nickel of their relative abundance in Earth's crust.

In general, for overburden, the content of heavy metals is less than their relative abundance in the Earth's crust and less than the regional values established for Kryvbas. That means that waste can be applied on these rocks without endangering the environment, even if the content of heavy metals in the waste exceeds threshold limit values. According to our research, sewage sludge does not exceed threshold limit values for heavy metals, so its application will not harm secondary ecosystems due to toxic effects, but only bring them closer to the regional relative abundance.

The study of the gross chemical composition of overburden shows that the rocks have enough calcium and manganese, which are plant nutrients, to ensure the fertility potential of secondary soils. Analysis of particle size distribution was performed by screening. According to its results, the technical mixture can be attributed to the coarse clastic soils. Statistical processing of materials indicates the diversity of the particle size distribution of the technical mixture.

Soil formation can be carried out only under the condition of vegetation formation. The development of the latter is constrained by a shortage of diaspore stocks (seeds). The state of the phytocenosis was managed by introducing seeds of tree and shrub species. Pioneer plant colonies had spatial and relief peculiarities. A knotgrass colony with explerent species was formed on flat areas. There were dominated by common knotgrass, or doorweed (*Polygonum aviculare L*). Species that implement the life strategy of explerents have low competitive power, but quickly capture the ecological niches of dump territory. Late annuals predominate among them. In the wet year, yellow sweet clover (*Melilotus officinalle L*) and honey clover (*Melilotus album L*), whose height reached 150 cm, prevailed on flat areas. On the slopes coltsfoot grows, which can occupy up to 5% of the area. Ecological features of the coltsfoot species (*Tussilaga farfara L*) allow to withstand lack of moisture, soil erosion, poor nutrient content of substrates. On the slope there were seedlings of ash-leaved maple, field elm and walnut due to self-restoration processes. In the first year after the implementation of technological actions, seedlings of tree and shrub species were obtained. Formed pioneering communities show a balance between ecological, economic and botanical groups and families. Legumes, represented by several species, have the ability to initiate nitrogen fixation and promote the accumulation of nitrogen of biological origin. The terrace was dominated by an annual plant (common knotgrass), and the stability of such a colony remained low. The slope was dominated by a rhizomatous perennial (coltsfoot) and ash-leaved maple. The development of the root system, the possibility of both seed and vegetative means of plant reproduction determine the prospects for stabilization of emerging ecosystems. The development of vegetation during the application of wastewater has led to the formation of colonies of Chenopodioideae plants on the terrace and on the slope: their biodiversity (52 flora species) and productivity increased. The development of populations of tree and shrub species indicates that the plants have developed and successfully overcome harsh living conditions. Analysis of morphometric parameters shows that the best vitality is still demonstrated by the silver berry (wild olive), apricot and walnut.

Treatment of rocks with organic matter of domestic wastewater has led to a positive dynamics of soils, which is reflected in the enhanced development of vegetation of secondary ecosystems. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs.

Morphometric parameters of plants that grow on soils treated with organic matter exceed the control values: by 29% for average height, by 5.9% for mean increment, by 22% for average diameter of the root collar. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity and total biomass of colonies increases; seed germination is enhanced. The application of organic matter on the surface of the dump allows to provide ecosystems with nutrients, to create a valuable soil structure, to promote the formation of moisture reserves for the scarce summer months.

But the application of sewage sludge promotes the restoration of ecosystems only when they are transferred to a state where the parameters of chemical composition, physical and biological properties are in the optimal range for plants and soils.

When sewage sludge is applited to disturbed lands, they are exposed to natural agents (surface runoff, wind, etc.), which promote the migration of sludge substances in the environment. In order to avoid negative impact on the environment, it is necessary to achieve the safety of sludge during application, or to apply special measures that would exclude the possibility of migration of hazardous substances after application (disinfection, preservation, remediation).

Obviously, the main problem that hinders the use of sewage sludge as organic fertilizers is their contamination with heavy metals. Even with an average content of heavy metals below the threshold limit values, the risk of uneven sedimentation and local pollution, contamination by re-introduction as a result of the accumulative effect, volley pollution of wastewater and sludge, which is not detected by means of control, is not excluded. Under such conditions, the use of sewage sludge as fertilizer on chernozems is associated with the risks of contamination of fertile soils and irreversible changes in their use. Practice shows that the owner prefers to lose the ability to use additional nutrients than to risk losing everything. The urgency of this problem persists with the use of sludge in green construction, when hazardous substances can get into the immediate environment of population of cities and villages.

Sanitary and hygienic problem is one of the key problems. It lies in the content of pathogens (microorganisms, helminths, etc.) in the sludge. Despite various safety measures, it is known that in Japan, a country that has long used municipal waste as fertilizer, infectious diseases, especially ascariasis, are very common. Sludges are very diverse in condition and properties, penetration of substances that carry out disinfection is uneven, the formation of areas in which disinfection does not work is possible. Artificial disinfection methods (infrared and ultraviolet radiation, chlorination, ozonation, etc.) require significant energy consumption and can only be effective for a short period of time. The most effective methods are those that are formed naturally and last for a long period of time. They are achieved by the creation of uniform conditions in which the pathogens die from dehydration, by the formation of an alkaline or acid reaction, and so on.

The problem is the ability to move sludge and substances contained in them. Sewage sludge enters natural ecosystems from the technosphere, has no place in the ecosystem, is not integrated into the natural cycle of matter and energy, and is not a stable element. Sewage sludge, or the substances that make it up, can migrate in space, not appearing where it was applied. Migrations occur under the action of gravity, convection effects, laminar and turbulent flows. Thus, the positive effect of ecosystem restoration can be offset, and in some cases become negative (pollution of surface and groundwater, the spread of infectious diseases).

Organic matter in sewage sludge is in raw form, and at the initial stage of formation is poisonous to most living organisms. To convert to a state suitable for use by soil and plants, it is necessary to carry out the transformation when the raw organic matter is either mineralized or converted into humic and similar substances that are able to form a soil absorbing complex, quickly give nutrients in mobile forms (anions and cations) to the soil solution. The problem of organic matter conversion stems from the need to adapt the artificial element to the needs of the ecosystem.

Wastewater sludge has a concentration of organic matter that is almost non-existent in nature. To include this organic substance in natural cycles, it is necessary to dilute it with inert materials. This dilution when applying organic fertilizers is achieved by scattering on the surface of the field and mixing with the soil in the process of tillage (plowing, cultivation, harrowing). When composting sludge using earthworms, sludge is mixed with waste paper, rags, soil, etc. Dilution of organic matter can be achieved in the process of natural migration under the action of natural agents with surface runoff, wind. The use of natural distribution processes can significantly reduce costs and make recycling processes attractive from an economic point of view.

All these problems of sewage sludge application also occur when it is used to activate ecosystem restoration. In various conditions of disturbed lands, these problems are exacerbated or weakened under the influence of natural factors.

The basic principles of technology should determine the methodological basis of their development, which allows to solve the problems of their application.

Studies of overburden have shown a generally low content of heavy metals compared to modern soils. The content of only some of them exceeds threshold limit values set for soils. This generally coincides with the theoretical generalizations about the biogenic origin of anomalies in the content of heavy metals observed on the earth's surface. According to this hypothesis, plants “pump” heavy metals to the surface, where they are distributed by natural agents (surface runoff and wind). In deep layers of the earth there is no high content of heavy metals, especially in layers that correspond to epochs deprived of the organic world (plants and animals). Based on this, the use of sewage sludge on overburden is environmentally justified. The application of excess heavy metals on the overburden in the general case will help the soils to reach the regional relative abundance.

Thus, for most heavy metals the following is true:

$$C_r = F + B + T \tag{2}$$

$$S < B + T \rightarrow F + S < C_r$$

where C_r is the regional relative abundance of heavy metals in the Earth's crust (regional clarke); F is the content of heavy metals in the soil-forming rock; B is the content of heavy metals of biogenic origin; T is the content of heavy metals of technogenic origin; S is the content of heavy metals in sewage sludge.

If there is a high content of certain heavy metals in the overburden, the genesis of this anomaly has its origins in the special conditions that developed on Earth during their formation in ancient times. This anomaly cannot coincide in time or space with the content of heavy metals in sewage sludge. Therefore, sewage sludge cannot contain the amount of heavy metals that would significantly increase their content in secondary soils.

In natural conditions, pathogens are present in the environment in certain quantities. It is impossible to achieve the complete absence of pathogens. The environment cannot be completely sterile. Sewage sludge after disinfection and pasteurization procedures contains a minimum number of pathogens that does not exceed natural levels. Thus, when overburden that has no biological contamination, almost sterile, comes to the surface of the earth, it is inhabited by either the microflora of sludge or the microflora of the environment. It is obvious that biological pollution from sewage sludge poses the least danger to humans on dumps and tailings in comparison with agricultural, recreational, urban lands, where contact with humans is direct (through the respiratory system, food). Sewage treatment plants are usually located on the terriroty near the industrial site and cannot be completely isolated from the facility employees. Pathogens move with the dust under the action of wind, posing a threat to employees. Dumps, quarries and tailings are located at a considerable distance from the places of concentration of the population (settlements, industrial facilities). They are guarded, which prevents people from accessing them. Therefore, the probability of disease spread when applying sewage sludge to them is the minimum of all possible ways of usage. Contamination of overburden can occur in two ways: by invasion, that is the reproduction of pathogens to the natural level, or contamination, i.e. the application of sludge that already has a natural level of contamination (the presence of invasive pathogens in the environment). Thus the following equation holds:

$$k_p = k_d \times k_0 = k_r \times I \tag{3}$$

where k_p is the value of contamination of overburden and technical mixtures (the number of pathogens per unit volume of sludge — microbes per liter); k_d is the disinfection rate; k_0 is the value of contamination in fresh sludge (number of pathogens of each species per unit volume of fresh sludge — microbes per liter); k_r is the reproduction rate; I is the value of the initial invasion (the number of pathogens at the beginning of the invasion per unit volume — microbes per liter).

The main agents that move sludge and substances are surface runoff and wind. To prevent the movement of sludge, it is necessary to block access of these agents or to minimize their activity. In the first case, a radical solution is achieved; in the second case the solution is partial.

A modified universal equation of water erosion can be used to describe the processes of soil movement under the action of surface runoff:

$$A = R \times L \times S \times C \times P, \tag{4}$$

where A is the loss of the substance; R is the factor of erosion force of precipitation; L is the indicator of slope length; S is the surface slope index; C is the indicator of the surface factor; P is the indicator of technological impact on overburden.

It is obvious that the values of L, S, C, P can be adjusted at the mining stage of dump formation. Access of agents can be blocked by creating an insulating layer between them and the sludge. One can use film, layer of soil, mulch, etc. At present, innovative methods of creating artificial soil, the properties of which can be predicted, are already used. Artificial soils can cover sewage sludge, achieving conservation and isolation.

The conversion of organic matter must be achieved naturally. It takes from 1 to 3 years for raw sludge to ferment under the influence of local microflora. This process can be sped up by the application of active strains of microorganisms, animals that process organic matter in nature (millipedes, worms, etc.).

Dilution of organic matter is very difficult to achieve on stony technical mixtures of disturbed lands. Only surface treatment can be carried out on them. The application of mulch or artificial soil looks much more promising. Artificial soil is formed in the process of mixing weathered overburden with dry ground sewage sludge.

The main methods of application of sludge:

1. Application of small volumes of fermented sewage sludge (0.5 dm^3) into holes during planting of tree and shrub seeds. Such discrete application of organic matter in the norms of 150 mg/dm^2 does not require large amounts of waste (up to 5 m^3/ha). The use of this technique allowed to stimulate the germination of common oak seeds. This technique is difficult to apply on the slope of the dump, where the steepness can reach 45°. Any movement of people and mechanisms on this slope is a threat to occupational safety.

2. Application of a mixture of seeds and fermented sewage sludge on the soil surface in the norms of 100 m^3/ha. After application in the autumn, organic matter has time to penetrate into the soil and to begin its action in the spring to increase nutrient content, soil aggregation and accumulation of moisture. The use of such huge amounts of sludge simultaneously solves the problem of their disposal.

3. Raw sewage sludge with a moisture content of 80% requires surface disinfection with chemicals, such as 10% ammonia solution after loading on a PTS-4 tractor trailer. After transportation to the dump, the sludge is unloaded into the holding pond. After unloading, the surface is disinfected again. Raw sludge with a moisture content of 80% must be kept in holding pond for 3 years to disinfect and ferment the raw organic matter. After holding, the sludge is used by applying in the norms of 100 m^3/ha with a coating by vegetable mulch. Steppe plant sod, rolled lawn, etc. can be used to fix organic matter. Application of sewage sludge from food enterprises to intensify restoration of ecosystems is the most promising area for their disposal.

4. Macroencapsulation is a new way of growing forest zoochories and their crops. Sewage sludge treatment allows the production of multilayer capsules that contain nutrients, micronutrient elements, biologically active substances that stimulate plant development, and biosorbents that allow the transfer of heavy metals to a safe state. Seeds (acorns, drupes) are placed in the capsule and covered with soil.

The effectiveness of such macroencapsulated seeds in agriculture is due to: increased seed germination, accelerated sprout growth and higher plant yields, as well as a significant reduction in the total consumption of organo-mineral fertilizers in field crops, especially on poor soils.

Conclusion

1. Application of sewage sludge significantly increases the absorption capacity of overburden. A secondary soil absorbing complex is formed, which is able to accumulate and retain mineral nutrients of plants, especially calcium and magnesium cations. The formation of the soil absorption complex significantly improves the water, nutrient and air regime of soils.

2. Studies of the chemical composition of overburden have shown a low content of mobile forms of heavy metals.

3. Treatment of rocks with organic matter of domestic wastewater has led to a positive dynamics of soils, which is reflected in the enhanced development of vegetation of secondary ecosystems.

4. In the conditions of field research the influence of treatment of rocks with organic matter of sewage with introduction of seeds of perspective species was studied. Comparative analysis of vegetation shows a positive effect of the treatment of overburden with organic matter on productivity and morphometric performance of trees and shrubs. A comparison of the average condition of plant objects after treatment with organic matter and control studies shows the following: the vitality of herbaceous and tree species increases; the total projective cover and average height of plants increases; biodiversity and total biomass of colonies increases; seed germination is enhanced.

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