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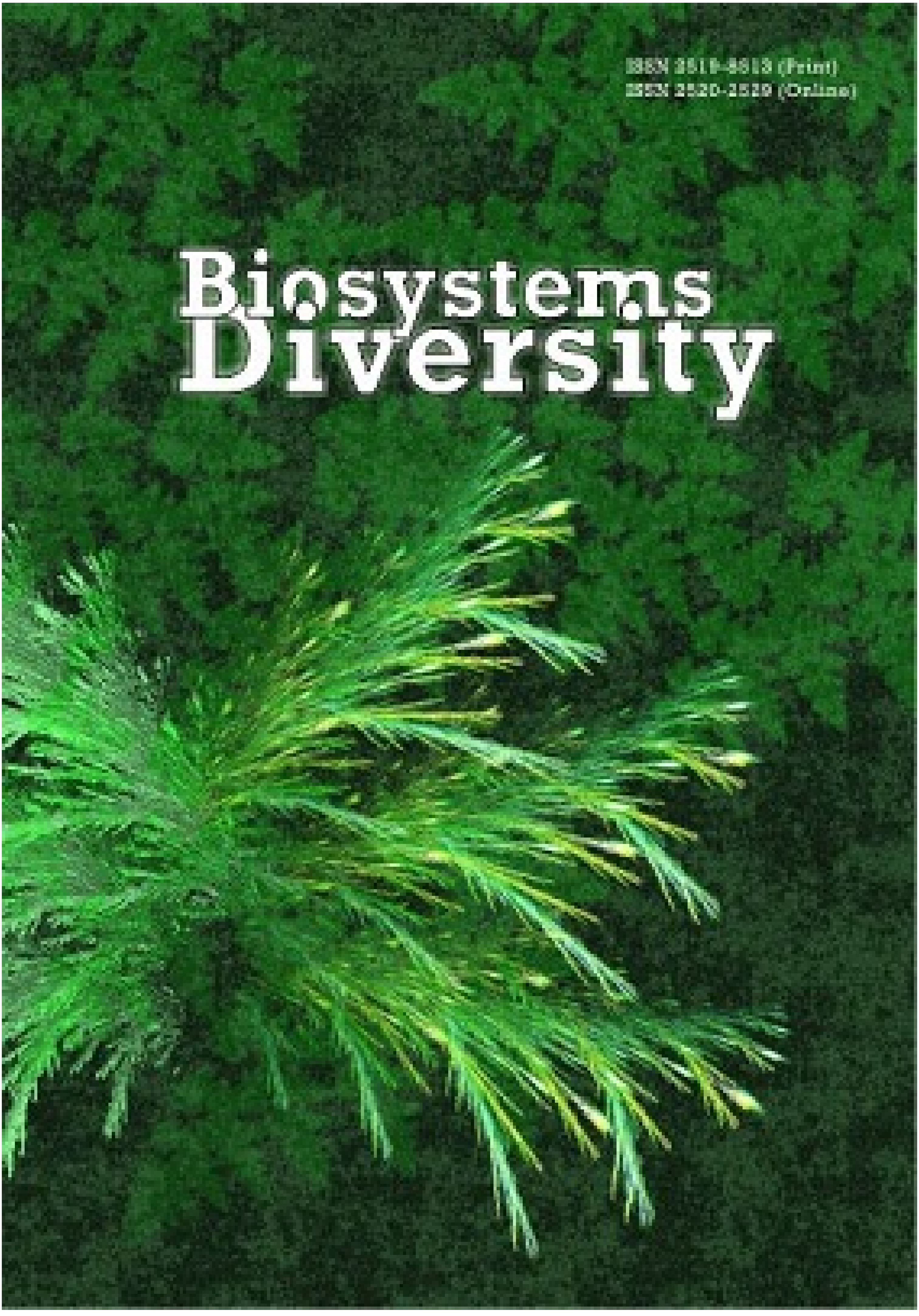

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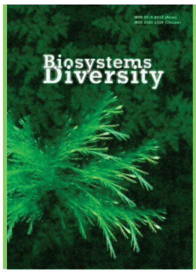

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Assessment of the state of forest vegetation of waste dumps of coal mines in Ukraine

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The aim of the work was to assess the current state of protective vegetation cover formed as a result of forest reclamation and natural overgrowth of all rock dumps of coal mines in Ukraine. The relevance of the research is conditioned by the important role of taking into account the degree of forest cover on the surface of dumps when assessing their ecological hazard to the environment. Forest plantations reduce the intensity of deflation and erosion of the surface of dumps, so the intensity of pollutants entering the adjacent territory is also sharply reduced. The main research method was the analysis of space images. The scientific novelty of the research results consists in the estimation of the average afforestation of the surface of dumps of the Lviv-Volynsky coal basin, Western and Central Donbass and in the established dependence of the afforestation of dumps slopes on their exposure and insolation coefficient proposed by the authors. Differences in afforestation of dumps of the above-mentioned basins (50.6%, 5.6% and 10.6%, respectively) testify both to the role of differences in climatic conditions and to the low level of dump reclamation in the Donetsk coal basin. Almost 1,900 ha or 79.5% of the dump surface in the north-eastern part of the Central Donbas is not forested and is a source of intensive environmental pollution. The afforestation of southern slopes in the Central Donbas is 4.7 times lower than that of northern slopes. However, a part of dumps is characterised by almost complete afforestation of southern slopes. This important fact proves the possibility of growing plantations under conditions of unstable moisture inherent in Donbas, even on such slopes. The practical significance of the work consists in the presented low-cost reclamation technology and the results of its use by the authors in forest reclamation of two rock dumps of PJSC 'Lisichanskvugillia'. The given results of the survey of forest plantations more than 30 years after their creation by the authors prove the possibility of mass afforestation of rock dumps in Ukraine and, as a consequence, the reduction of the area of agricultural lands polluted by dumps and the intensity of their pollution.

Keywords: waste dump; ecological hazard; reclamation; afforestation; insolation.

Introduction

One of the most important energy sources in the world is coal. It is mined in more than 50 countries (World Coal Institute, 2005). Coal mining results in the accumulation of waste in the form of rock dumps, which occupy many thousands of hectares worldwide and negatively affect the environment. In Ukraine there are more than 1,300 dumps occupying more than 6,000 ha and polluting almost 36,000 ha of land with deflation and erosion products of the dumps' surface (Zubov et al., 2023). Due to burning and deflation of waste rock (Smirny et al., 2006), air pollution with gases and dust occurs, which leads to deterioration of living conditions of the population (Younger, 2004; Chen et al., 2007).

The consequences of soil contamination due to leaching of heavy metals from waste rock (Ribeiro & Flores, 2020), erosion and deflation of waste dumps surface (Li et al., 2014, Rout et al., 2014; Marcisz et al., 2021) are contamination of plant products (Donggan et al., 2011; Khan et al., 2015) and reduced crop productivity (Kumar, 2013), threatening public health and food security (Lu et al., 2015).

To rehabilitate lands disturbed as a result of coal mining and to reduce the environmental hazard of waste dumps, recultivation (remediation, reclamation, rehabilitation) is applied worldwide. The main stages of recultivation are engineering and biological (Smirny et al., 2006). The first stage consists in preparing the dump and the adjacent territory for different types of use. The main types of the second stage are afforestation (Logginov, 1989; Brovko, 2012; Romana et al., 2017) or grassing of dumps (Gawor, 2014). As a result of reclamation in the EU over the last 20 years, many abandoned mines have been transformed into forests, agricultural land and even nature reserves and art installations (Sloss, 2013).

The importance of forest plantations on rock dumps is very high. They are able to fix loose rocks, reduce wind speed and prevent wind erosion (deflation) of soils and rocks not only under the canopy of plantations, but also at a considerable distance from them. In addition, as established in our previous studies (Zubova et al., 2010, 2019), the overgrowth of dumps with woody vegetation results in the attenuation of water erosion of its surface, decreases surface runoff, and stops deepening of scour holes, as evidenced by the accumulation of forest litter at their bottom. An important consequence of the reduction of runoff and erosion is the reduction of pollutant transport from the dump to the adjacent territory. As shown in our previous studies (Zubov et al., 2023), the estimated area of land potentially polluted as a result of deflation and erosion of the dump surface in the Central Donbas is 35,756 ha. As a result of afforestation of dumps, the area of these lands used mainly in agricultural production can be significantly reduced.

As noted in the many works (Korshikov & Zhukov, 2008; Popovich et al., 2011; Vacek et al., 2018; Zhukov, 2020), waste dumps have the property of gradual self-overgrowth. However, the establishment and development of natural and artificial woody vegetation is often hindered by unfavourable properties of waste rock, which contains many hazardous components and few nutrients (Logginov, 1989). Another peculiarity of waste dumps are sharply pronounced differences in insolation associated with the presence of steep slopes and their different exposures (Zubov & Zubov, 2022). These differences have a big impact on water supply to plants.

The aim of the research is to assess the current state of tree cover on waste dumps of coal mines in Ukraine. In order to achieve this aim the following was done: a) quantitative assessment of the afforestation of waste dumps in different natural-climatic zones of Ukraine; b) an assessment of the influence of slope exposure on their afforestation; c) assessment of the possibility of afforestation of excessively insolated slopes of waste dumps.

Materials and methods

Study area. Coal reserves and waste dumps of coal mines in Ukraine are concentrated in the Lviv-Volyn and Donetsk coal basins, located in the west of the country and in its eastern part (Fig. 1).

The Lviv-Volyn coal basin extends from the north (from the city of Ustilug, Volyn region) to the south (almost to the city of Velikiye Mosty, Lviv region) for 125 km, from west to east for 60 km. The total area of the basin is about 10,000 km^2. The industrial coal-bearing area is 3,200 km^2. According to (Popovych & Voloshchyshyn, 2019), in Poland the Lviv-Volyn coal basin is considered to be the eastern part of Lublin coal basin. Coal mining is carried out by two coal mining enterprises: SE "Lvivvuhillya" and SE "Volynvuhillya". They have 9 and 8 mines located respectively in the vicinity of Chervonohrad and Novovolynsk. According to different authors, the number of rock dumps in the Lviv-Volyn coal basin varies and needs to be clarified.

The area of the Donetsk coal basin (Donbas) is 60 thousand km^2. The part of Donbas located in Dnepropetrovsk region of Ukraine is called Western Donbas (let's call it WD), the part located in the Donetsk and Luhansk regions is called Central Donbas (CD). The part of Donbas located outside of Ukraine (in the Rostov region of Russia) is called Eastern Donbas (ED).

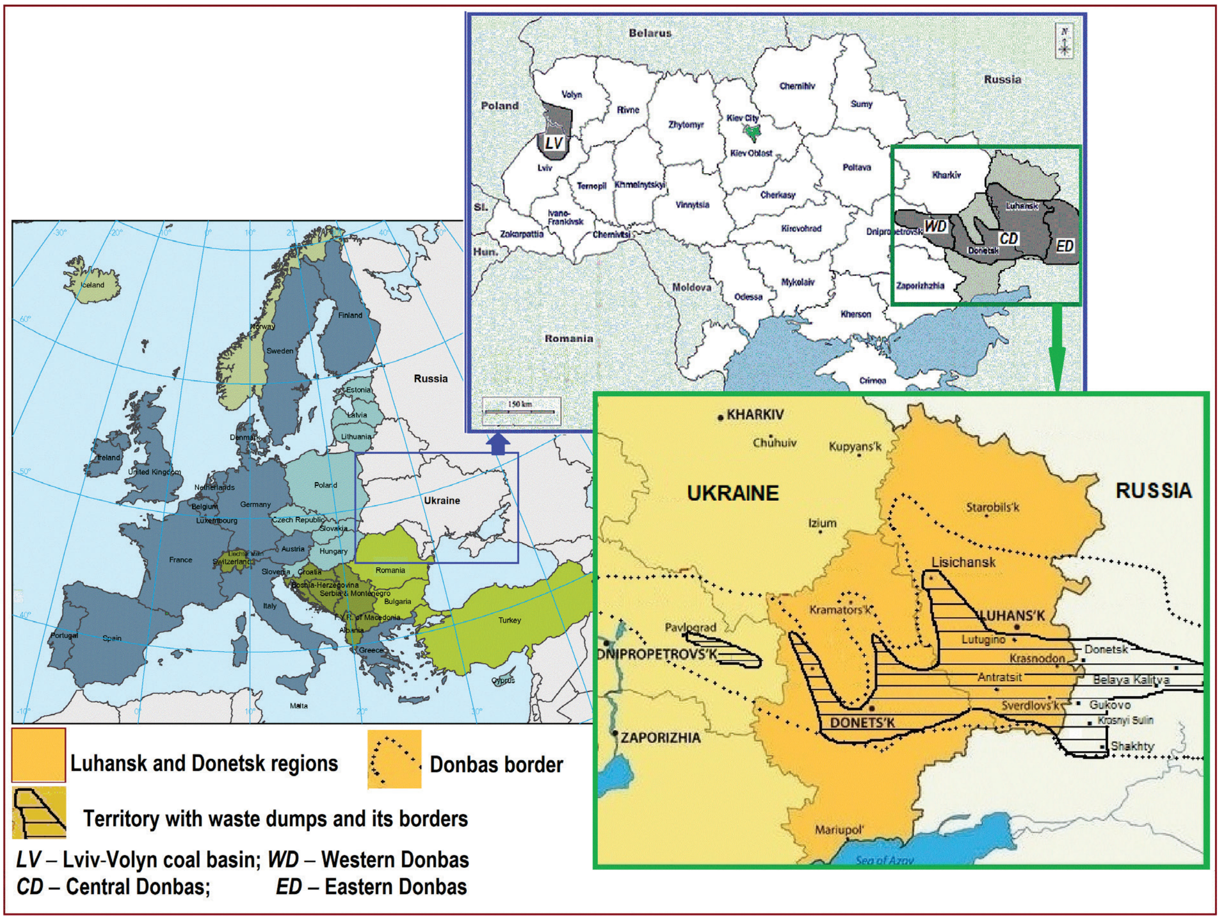

Fig. 1. Location of the Donetsk and Lviv-Volyn coal basins in Ukraine and Europe

According to Petlovanyi et al. (2023), 8 mines of PrAT "DTEC Pavlogradvuhillya" operate in Western Donbas; there are 9 dumps with almost 130 million tonnes of waste rock accumulated on an area of about 190 ha. According to our measurements, the dumps are located on a 44 km long strip between Pavlograd and Pershotravensk.

In the southwestern part of Central Donbas – in Donetsk region (let's call it CDD) there are 596 dumps. In the northeastern part – in Luhansk region (CDL), according to our calculations (Zubov et al., 2023) there are 694 dumps. Of these, 219 (31.6%) are conical including 16 paired and triplets dumps, 289 (41.6%) are truncated conical including 8 paired and triplets, 186 (26.8%) are flat dumps. The average heights of the dumps are 48.6, 44.1 and 35.9 m respectively.

Natural and climatic conditions of the territory where the rock dumps are located. The Lviv-Volyn Basin (LVB) is located within the Volyn Upland. According to (Popovych and Voloshchyshyn, 2019), its small north-western part extends into Eastern Poland. The Volhynian Upland lies between Western Bug and Korchuk rivers. It stretches for over 200 km with a width around 80 km. Average elevation is 220–250 m.

The area where the LVB dumps are located belongs to the forest-steppe zone of Ukraine, to its well moistened forest-steppe subzone and sufficiently moistened subzone. The WD and CD dumps are located in the North-Steppe Zone: in its insufficiently moistened North-steppe and moderately arid North-Central Subzones, respectively. The differences in the longitude and latitude of the basins determine significant differences in the climatic component of forest conditions on the dumps (Table 1), which we found according to (Lipinsky et al., 2003).

Characteristics of ground research objects and the history of their creation. The objects of both remote and ground surveys were waste dumps of the Chernomorka mine and the mine named after M. L. Rukhimovich of PJSC "Lysychans'kvuhillya". Let's call them dump No. 1 and dump No. 2. In 1985 and 1989, the authors carried out forest reclamation of these dumps according to the method of the Ukrainian Agricultural Academy (UAA), Kiev (Logginov & Kirichek, 1978; Logginov, 1989). The current name of the UAA is National University of Bioresources and Nature Management of Ukraine (NUBiP).

During the afforestation period, dump No.1 had a conical shape and a height of 50 m, the inclination angle of the tail part (ribs) was 19º, the slope steepness was 33–37º. It contained 690 thousand m^3 of rock, the dump base area was 1.87 ha.

Table 1
Location and climatic conditions of the coal basins of Ukraine and their parts

Coal basins	Boundaries of an area with waste dumps		Precipitation, mm		Average air temperature		Hydrothermal coefficient HTC	
	latitude	longitude	year	April–October	January	July	May–July	August–September
Lviv-Volyn	50°17.8' / 50°46.8'	24°7.3' / 24°16.3'	620	425	–4.5	17.5	1.3–1.4	1.2–1.3
Western Donbas	48°21.1' / 48°32.3'	36°2.9' / 36°25.6'	525	315	–5.5	21.5	0.8–0.9	0.6–0.7
Central Donbas (Luhansk part)	47°58.7' / 49°4.2'	38°13.5' / 39°54.2'	525	315	–7.3	21.5	0.8–0.9	0.6–0.7
Central Donbas (Donetsk part)	47°47.6' / 48°24.7'	36°59.8' / 38°50.6'	540	325	–7.1	20.5	0.8–0.9	0.6–0.7

Note: hydrothermal coefficient has been calculated by formula of G. Selyaninov: $HTC = 10 \cdot \Sigma X / \Sigma t$; where ΣX and Σt – accordingly sum of precipitations and temperatures in the period, when the temperature was not lower than 10 °C (Lipinsky et al., 2003).

Dump No. 2 is located on the north-eastern slope of the Seversky Donets River valley and occupies 5.14 ha. It has a flat top (plateau) with an area of 2.23 ha. The elevation of the plateau over the base of the dump is 35 m. Preparation of the surface of the dumps for afforestation was carried out by creating micro-terraces on their slopes by hand with a width of 30–35 cm in 2.0–2.5 m intervals (Fig. 2).

Fig. 2. Making micro-terraces on the dump No. 1 by L. H. Zubova and A. R. Zubov (1985)

On the dump No. 1 the work was carried out by L. G. Zubova together with A. R. Zubov by agreement with PJSC "Lysychans'kvuhillya". The work was carried out on unpaid basis in order to fulfil the plan of postgraduate training of L. G. Zubova. It was conducted on 30 March, 6, 7, 13 and 14 April 1985, i.e. they took 10 man-shifts of 9–10 hours each. On a slope area of 2.28 ha, 30 micro-terraces were created with total length of about 8200 m. On April 20, 27 and 28, annual nurslings of tree species were planted every 0.5–0.7 m on the micro-terraces by the authors, all bought by "Lysychans'kvuhillya" in Kreminna forestry enterprise.

The following tree species were planted on the northern half of dump No. 1 (Fig. 3–6): *Quercus robur* L., *Acer platanoides* L., *Fraxinus pennsylvanica* Marshall, *Prunus armeniaca* L., *Pinus sylvestris* L. and *Elaeagnus angustifolia* L. On unfavourable slopes of southern exposures, *Elaeagnus angustifolia* L. was planted. *Robinia pseudoacacia* L. was planted on the slope of the tail part of the dump of south-south-eastern exposure. All tree species were planted as annual seedlings in a slot formed by a bayonet spade. Before planting the roots were dipped in clay solution. *Quercus robur* acorns and *Prunus armeniaca* kernels, annual seedlings grown in the nursery planted in the vicinity of dump No. 1 were also used for planting.

Analysis of survival data obtained in 1988 showed that seedlings of *Prunus armeniaca* (92%), *Quercus robur* (75%), *Acer platanoides* L. (94%), *Fraxinus pennsylvanica* (84%), and *Elaeagnus anqustifolia* (63%) had taken good root in dump No. 1.

Afforestation of dump No. 2 was carried out in April 1989 by L. G. Zubova and A. R. Zubov together with two assistants (V. I. Tarasov and V. A. Rybin) under a contract between the Lugansk State Agrarian University and the Lysychans'k Repair and Mechanical Plant. At waste dump No. 2, the predominantly *Robinia pseudoacacia* was planted (Fig. 7).

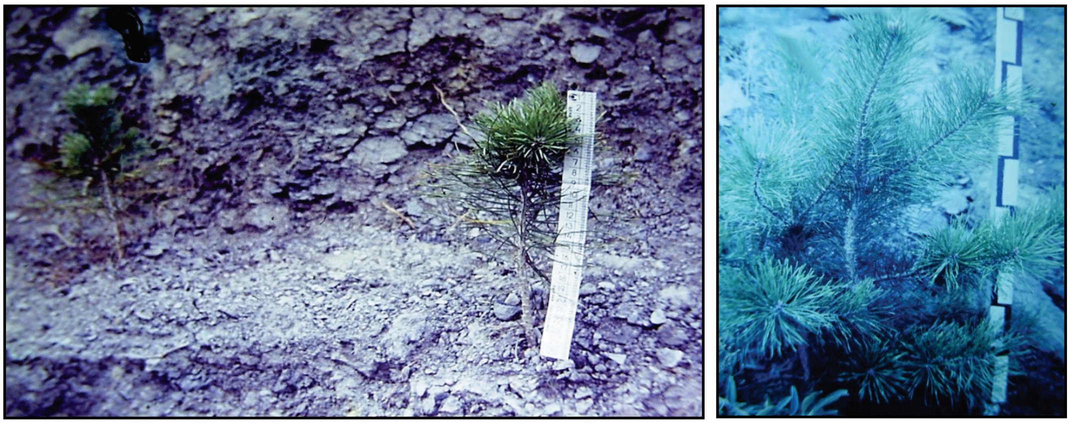

Fig. 3. Plants of *Pinus sylvestris* on microterraces in 1986 and 1989

Fig. 4. Plants grown on micro-terraces by sowing *Quercus robur* acorns, and *Prunus armeniaca* kernels in 1985

Fig. 5. Plants of *Fraxinus pennsylvanica* in 1988, *Fraxinus pennsylvanica* and *Acer platanoides* in 1995

Fig. 6. Plantations of *Elaeagnus angustifolia* on the southern half of dump No. 1 in 1989 and 1996

Fig. 7. *Robinia pseudoacacia* plantations on waste dump No. 2 in 1990 and spring of 1996

Waste rock properties characterising its suitability for dump afforestation. The properties of the waste rock are characterised in detail in Zubova (2019). Here we will limit ourselves to a brief summary.

Dump No. 1. To study rock properties, the authors dug sections up to 1 m deep. Rock samples were taken from layers 20 cm thick. The sections were placed on the top of the dump, middle and lower tiers of the slopes of northern, southern and western (frontal part of the dump) exposures. The ridge of the dump (crest of the tail section) is directed to the east, so there are no eastern slopes on this dump. The main part of the rock (75% of the mass) was coarse clastic material in the form of stones and gravel. The content of the <1 mm size fraction in the rock averaged 20%. The volumetric mass of different rock layers varied from 1.3 to 1.6 g/cm^3. The total porosity ranged from 43–50%. The pH value varied from 4.0 to 7.0. Almost all rock samples were saline. The sulphate ion content varied between 0.21–4.42%. Chlorides did not play an important role in salinisation and their content was 0.003%. Ca content was 0.046–0.493%, Mg content was 0.026–0.612% and Na content was 0.003–0.435%. The supply of mobile phosphorus was insufficient for normal plant growth. The lowest phosphorus content (0.5 mg per 100 g) was observed in the middle and lower tiers of the western exposure slope (frontal part of the spoil heap), where pH was the lowest (4). There were 4.5–60.0 mg K_2O in 100 g of dump rock, with little easily hydrolysable nitrogen.

Dump No. 2. The content of fractions larger than 10 mm in rock samples varies from 6.0% to 52.1%, of fractions smaller than 0.25 mm – from 2.34% to 6.66%. The amount of mobile aluminum in the samples ranged from 0.72 to 23.4 mg/100 g. The content of mobile phosphorus and potassium was insufficient for normal plant growth: phosphorus 0.75–3.39 and potassium 0.16–2.84 mg/100 g. The content of ammonia nitrogen in the rock was 1.5–14.5 mg, nitrate nitrogen – 1.6–2.2 mg/100 g, which is insufficient for normal growth of woody plants. The waste rock was saline. The content of water soluble salts in it exceeded 0.30%. The dry residue of the aqueous extract reached 0.73–1.76%. The sulphate ion content varied from 0.44% to 1.32%, chloride content in samples from 0.001% to 0.005%. The value of pH is 4–6.

The study of the physicochemical properties of the rock and the results of afforestation of the dumps allowed us to conclude that the rock was suitable for growing cultivated plants, subject to measures aimed at reducing excess acidity and increasing the balance of nutrients.

Research methods. The research was carried out by analyzing satellite images obtained using the Google Earth Pro application. According to (Arif et al., 2023), this 3D mapping application allows you to access satellite images with a spatial resolution of up to 15 cm. Our previous studies (Zubov et al., 2023) also proved the possibility of using the application for the assigned tasks.

Using the tools of the application, for all dumps of Lviv-Volyn basin, Western Donbas, north-eastern part of Central Donbas and dumps of Eastern Donbas we measured the base area of dumps SB, projection area of dumps surface SF', occupied by forest plantations.

More comprehensive measurements were made for a sample of 234 CDL dumps. For these dumps, we additionally measured the area of their flat top (plateau) SPL, the area of the projection surface of the slopes and the plateau occupied by forest plantations (SF'SL and SFPL). Subtracting the plateau area from the base area, we obtained the projection area of the slopes SSL'. The true area of the slopes (lateral surface of the dumps) was determined according to the formula: SSL = SSL'/cosα, where α is the angle of dump slope to the horizontal plane, taken to be 35°. The forest area on slopes was determined using the formula: SFSL. = SF'SL/cosα. Forest cover of slopes and plateaus FcSL and FcPL was determined as the ratio of forest area on these elements to their area multiplied by 100%.

In order to assess the influence of slope exposure on its forest cover, we divided the projection of the lateral surface of the dumps into 16 sectors with an internal angle of 22.5°. For this purpose, a transparent overlay divided by radial rays into such sectors was used. The axial lines of the sectors have the following rumbos and exposure azimuths: N (0.0°), NNE (22.5°), NE (45.0°), NEE (67.5°), E (90.0°), SEE (112.5°), SE (135.0°), SSE (157.5°), S (180.0°), SSW (202.5°), SW (225.0°), SWW (247.5°), W (270.0°), NW (292.5°), NNW (337.5°), N (360.0° or 0.0°). The transparent overlay was applied to the monitor so that its centre coincided with the top of the cone or the centre of the plateau. Using a "ruler" tool, the area of each sector of the lateral surface projection and the area of the forest within it were measured. Based on the ratio of these areas, the forest cover of each sector of the side surface of the dump was calculated as a percentage.

Results

Forest cover of waste dumps in Ukraine. Central Donbas. The arithmetic mean of the forest cover of all 694 waste dumps in the north-eastern part of the CD is 15.9%, without taking into account differences in their base area. The distribution of the waste dumps according to their degree of afforestation is shown in Figure 8.

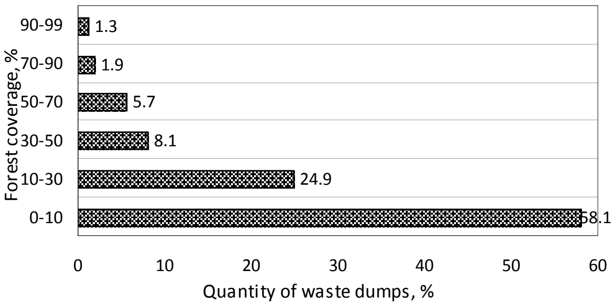

Fig. 8. Forest cover of waste dumps in the north-eastern part of the Central Donbas (CDL)

As can be seen, more than half of all waste dumps are less than 10% afforested. More than 90% of the waste dumps are forested on less than 50% of their surface area. The forest cover of dumps varies significantly across the coal mining districts of Lugansk region CD, shown in Figure 9.

Table 2 shows two indicators of afforestation: 1) Fc is the arithmetic mean, obtained without taking into account the differences in the base areas of the dumps (column 7); 2) Fc' is the weighted mean (col. 8), obtained as the ratio of the total forest area (col. 9) to the total base area of the dumps (col. 5). Due to the presence of particularly large dumps, which are usually sparsely wooded (Fig. 10), the second value is lower than the first.

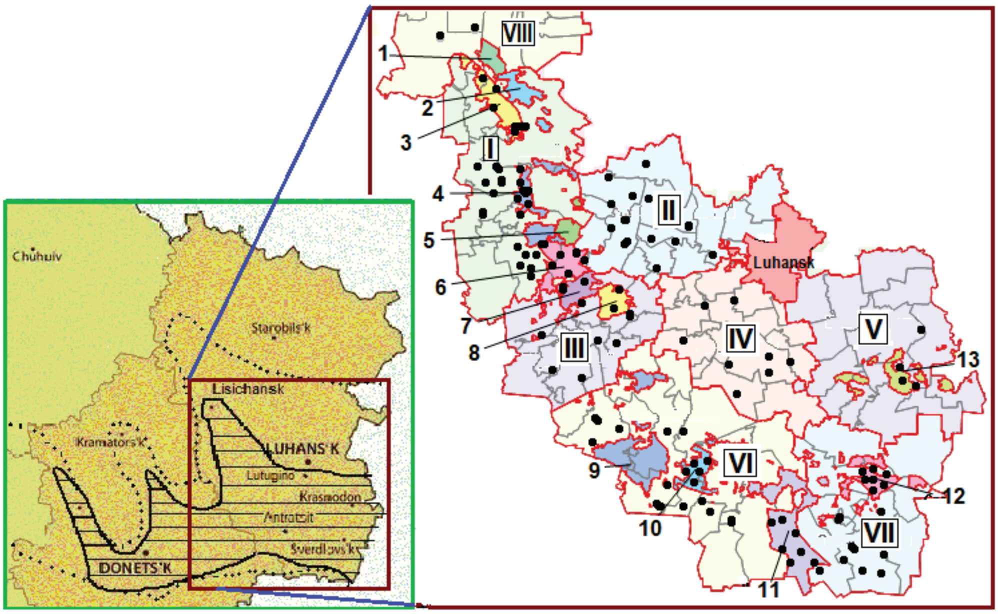

Fig. 9. Coal mining districts and towns in Luhansk region of Central Donbas: the districts: I – Popasnyanskyy; II – Slavyanoserbskyy; III – Perevalskyy; IV – Lutuhynskyy; V – Krasnodonskyy; VI – Antratsytivskyy; VII – Sverdlovskyy; VIII – Kreminskyy; district centres and other cities: 1 – Rubizhne; 2 – Severodonetsk; 3 – Lysychansk; 4 – Pervomaysk; 5 – Kyrovsk; 6 – Stakhanov; 7 – Bryanka; 8 – Alchevsk; 9 – Krasnyy Luch; 10 – Anthracyt; 11 – Rovenky; 12 – Sverdlovsk; 13 – Krasnodon; • – coal mines

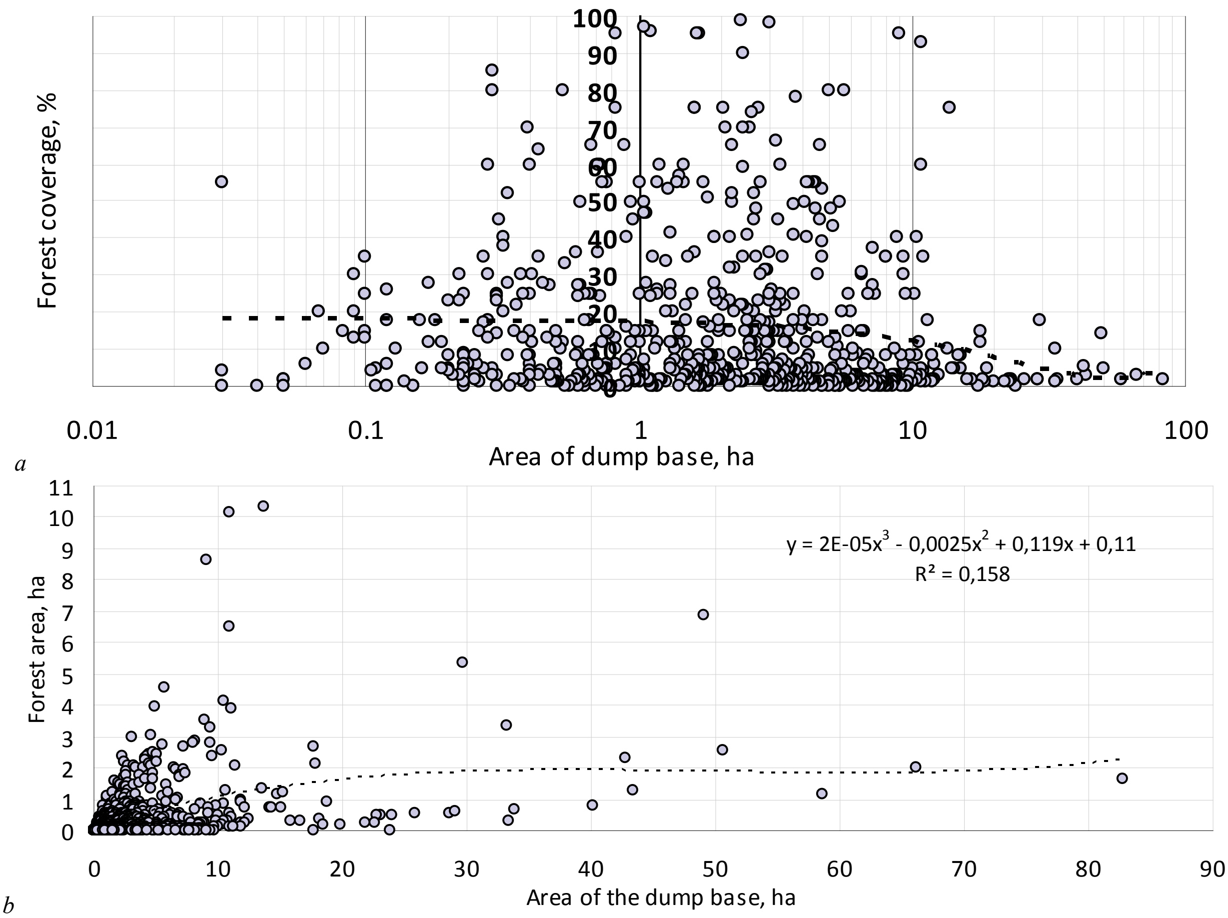

Fig. 10. Distribution of waste dumps by base area and afforestation of their surface (*a*); distribution by base area and surface forest area (*b*)

The values of Fc and Fc' differ most between the northernmost and southernmost districts (I and VII). Despite the low average forest cover of waste dumps, all districts have waste dumps with much higher than average afforestation. In five out of seven districts there are dumps with more than 90% afforestation.

Figure 11 complements Table 2 and shows not only the average value of Fc for each district marked with a cross, but also the first, second (median) and third quartiles of the series of increasing values of Fc. These quartiles correspond to the lower, inner and upper lines of the rectangles in the boxplot. Quartiles correspond to the top 25%, 50% and 75% of all values of the series under study.

An idea of the distribution of all 694 dumps by their types, the average and total area of the base of dumps SB av and SB∑, the total areas of their plateau SPL∑ and slopes SSL∑ is given by Table 3. When compiling it, we used the average indicators of a sample of 234 dumps shown in our work.

Table 2
Forest cover and other indicators of waste dumps in Luhansk part of CD

Districts		Area of the district, km²	*n*	Base area, ha		Forest cover of dumps, %		Forest area, ha
code	name			$S_{B\sum}$	S_{Bav}	*Fc*	*Fc'*	$S_{F\sum}$
I	Popasnyanskyy	1466.5	116	483.7	4.17	29.8	24.3	110.4
II	Slavyanoserbskyy	829.7	30	126.3	4.21	25.3	18.4	21.7
III	Perevalskyy	722.6	139	686.7	4.94	19.1	11.8	77.0
IV	Lutuhynskyy	1057.0	51	182.1	3.57	13.8	14.2	23.3
V	Krasnodonskyy	1400.0	82	489.5	5.97	13.5	9.1	32.2
VI	Anthracytivskyy	1700.0	177	709.8	4.01	10.6	7.2	47.1
VII	Sverdlovskyy	1132.0	99	436.6	4.41	5.5	4.4	17.7
Sum or average value			694	3115.0	4.49	15.9	10.6	329.4

Note: n is the quantity of dumps; SB∑ and SBav are the total and average area of dumps' bases; Fc is the arithmetic mean of forest cover of all dumps; Fc' is the weighted average forest cover of dumps; SF∑ is the total forest area on the dumps.

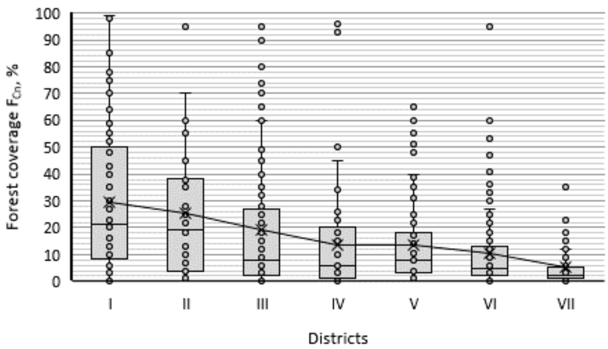

Fig. 11. Forest cover of dumps in different coal-mining districts of the CDL: I – Popasnyanskyy; II – Slavyanoserbskyy; III – Perevalskyy; IV – Lutuhynskyy; V – Krasnodonskyy; VI – Anthracytivskyy; VII – Sverdlovskyy districts

Based on the data in Table 3 and previously established data for 234 dumps, the forest areas and areas of environmentally hazardous areas without forest on these elements were calculated for all 694 dumps in the CDL (Table 4). Based on the ratio of the base areas of dumps in the CDL and CDD, equal to 3,115 ha (Table 3) and 3,533 ha, respectively, it can be assumed that in the entire CD the surface unprotected by vegetation is approximately equal to 6,200 ha.

Lviv-Volyn basin and Western Donbas. Analysis of satellite images allowed us to identify 22 rock storage areas (dumps) in the Lviv-Volyn basin, of which 12 belong to SE "Lvivvyhillya" and 10 to SE "Volynvyhillya". Two dumps of the first and four dumps of the second consist of two paired dumps each. Thus, we can also speak conventionally about the existence of 28 dumps in the LVB. The "Lvivvyhillya" dumps also include the waste dump of the Central Coal Preparation Factory (CCPF), to which the dump of the "Vizeys'ka" mine is connected. The area of the CCPF dump (95.1 ha) is very different from that of the other dumps. This dump was not taken into account when calculating the parameters of LVB waste dumps and their afforestation presented in Table 5.

Table 3
Base and surface area of all CDL dumps

Dump type	Quantity of dumps		Average and total area of dumps base, ha		The total area of the dump plateau, slopes and all surface, ha		
	Number	%	S_{Bav}	$S_{B\sum}$	$S_{PL\sum}$	$S_{SL\sum}$	$S_{all\sum}$
I	219	31.6	2.9	628.5	0.0	766.5	766.5
II	289	41.6	3.1	887.2	213.9	823.7	1037.5
III	186	26.8	8.6	1599.6	556.1	1287.1	1843.3
In total	694	100.0	4.5	3115.0	770.0	2877.3	3647.3

Notes: I – conical dumps; II – truncated conical dumps; III – flat dumps.

Table 4
Afforested and non-afforested parts of slopes and plateau of the dumps in the CDL

Waste dump types	Dump surface elements and area of their afforested and non-afforested parts								
	top			slopes			all surface		
	forest cover, %	without forest		forest cover, %	without forest		forest cover, %	without forest	
		%	ha		%	ha		%	ha
I	–	–	–	23.6	76.4	585.6	23.6	76.4	585.6
II	19.1	80.9	173.0	22.6	77.4	637.5	21.9	78.1	810.5
III	14.7	85.3	474.3	20.1	79.9	1028.4	18.8	81.5	1502.7
All types	15.9	84.1	647.3	21.8	78.3	2251.5	20.5	79.5	2898.8

Notes: see Table 3.

In Western Donbas, for the 9 dumps the base area and forest area were measured and the afforestation of the dumps was calculated (Table 5). The total base area is 191.9 ha, which is close to the value given by above authors. As can be seen from Table 5, the weighted average forest cover of the dumps Fc' in LVB is 8.6 times higher than in WD and almost 4.6 times higher than in CDL. For a more complete characterization of afforestation of waste dumps of all Donbas, the number and forest cover of waste dumps of its eastern part was estimated. As is shown in Table 6, 95.3% of all dumps of Eastern Donbas are afforested by less than half. The average forest cover of all dumps is 10.2%.

Differences in the forest cover of plateaus and slopes of waste dumps depending on their exposure. Central Donbas. The measurements and calculations were carried out for a sample of 100 dumps of CDL. Total forest cover of the sample dumps varies from 0% to 98% and is characterized by the distribution presented in Figure 12. As can be seen, the average forest cover of slopes is slightly higher, and the forest cover of the dump plateau is lower than the forest cover of the entire surface of the dumps. The median values of the forest cover are even more different. However, for different intervals of total forest cover, its relationship with the forest cover of the plateau and slopes differs. A mutual relationship between the forest cover of the slopes and the dump plateau was estimated (Fig. 13a).

As the forest cover of the dump plateaus increases, the forest cover of their slopes increases. This dependence is linear, the correlation coefficient of r = 0.40, which corresponds to a coefficient of determination of R^2 = 0.16, characterizes this relationship as satisfactory. It is more informative to compare the ratio of forest cover of slopes and plateaus FcSL/FcPL with the forest cover of the plateau FcPL (Fig. 13b). The coefficient R^2 = 0.533 characterizes the relationship as good.

Table 5
Forest cover of waste dumps in different coal basins of Ukraine

Coal basins	Quantity of dumps	Dump base area S_B, ha			Forest area S_F, ha		Forest cover F_C', %	
		min-max	average	total	total	average	min-max	average
LVB	22 /28*	3.2–29.1	12.3	270.6	131.0	6.24	1.0–100.0	48.4
WD	9	12.0–35.2	21.3	191.9	10.5	1.17	0.0–37.3	5.6
CD_L	694	0.03–82.8	4.5	3115.0	329.4	0.48	0.0–99.0	10.6

Note: * – quantity, taking into account paired dumps.

Table 6
Number and forest cover of waste dumps in East Donbass

Waste dump types	Number	Intervals of forest cover and dump quantity, %					
		≤10	10–30	30–50	50–70	70–90	>90
I. Conical	98	73.5	14.3	5.1	2.0	3.1	2.0
II. Transcated conical	107	87.9	5.6	0.9	1.9	2.8	0.9
III. Flat	91	96.7	2.2	0.0	1.1	0.0	0.0
All waste dumps	296	85.8	7.4	2.0	1.7	2.0	1.0

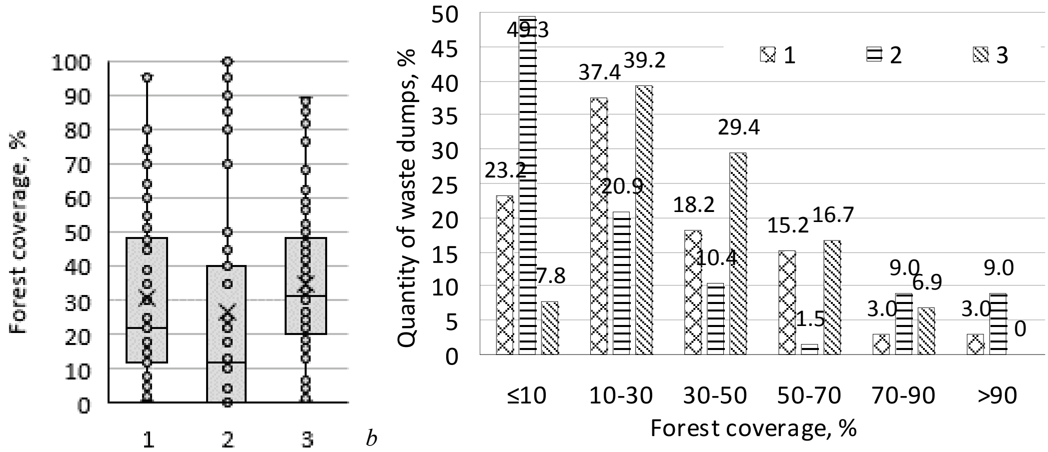

Fig. 12. Characteristics of forest cover of the plateau, slopes and the whole surface of the CDL dumps by quartiles (*a*) and by forest cover intervals (*b*): *1* – whole surface of dumps, *2* – top of dumps (plateau), *3* – slopes of dumps

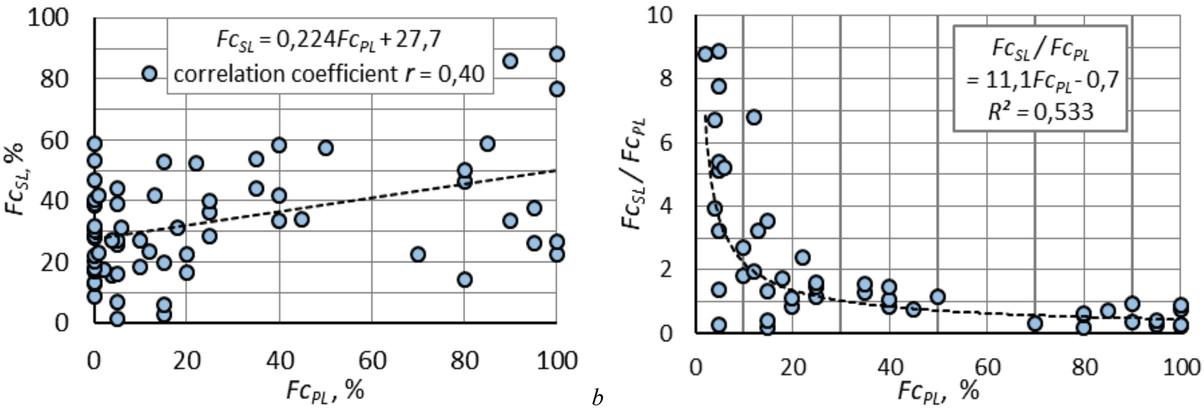

Fig. 13. Reciprocal relationship between forest cover of slopes FcSL and forest cover of plateau FcPL (*a*) and relationship between of ratios FcSL to FcPL and forest cover of plateau (*b*)

An interesting fact is that when the forest cover of the plateau FcPL ≤30%, the FCSL/FCPL ratio is > 1, i.e. the forest cover of the slopes is higher than the forest cover of the plateau. And with FcPL > 30%, the forest cover of the plateau is higher than the forest cover of the slopes. This feature suggests that the level of forest cover on the plateau and slopes depends on the same groups of factors in different ways.

The first group (endogenous factors) includes the chemical properties of the rock. With an increase in acidity, toxicity, and salinity of the rock and with a decrease in the content of nutrients in it, the forest cover theoretically decreases – both on the plateau and on the slopes of the dumps. The second group (exogenous factors) includes factors that determine the hydrothermal conditions of the rock. With the same amount of precipitation, they are determined primarily by the arrival of solar radiation – insolation. On the plateau, insolation conditions are the same as on the surrounding horizontal terrain, but on the slopes they can differ greatly from the conditions on the plateau. Therefore, the task was set to study the nature of the relationship between the forest cover of slopes and their insolation.

It was found that the forest cover of the slopes of any of the exposures varies greatly. However, the average values of the slope cover are strictly dependent on their exposure (Fig. 14).

In addition to the average values of forest cover on the slopes and plateaus of the dumps, Table 7 for each of the 8 main exposures and plateaus shows the relative number of dumps with different forest cover, expressed in 10% intervals from 0% to 100%. This makes it possible to compare the forest cover of slopes of different exposures with the forest cover of the plateau.

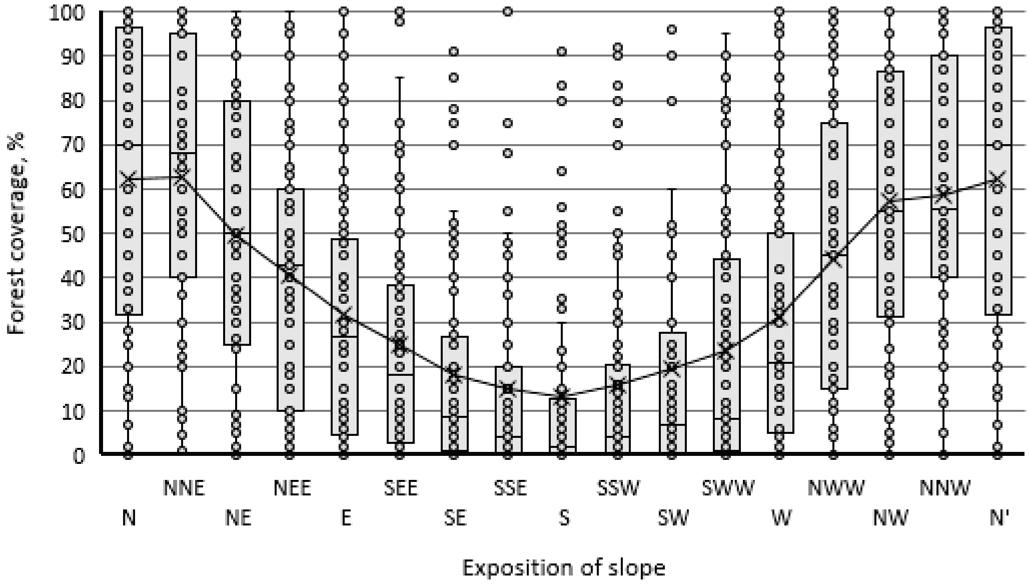

Fig. 14. Forest cover of slopes with different exposures at CDL dumps

Table 7
Forest cover of dump slopes of various exposures

Forest cover, %	Slope exposure and number of dumps, %								Plateau
	N	NE	E	SE	S	SW	W	NW	
0	4.1	4.5	16.9	22.1	34.1	25.9	12.2	2.6	26.9
0–10	9.5	19.4	31.4	54.6	73.1	55.5	31.7	11.7	49.3
10–30	14.9	10.4	24.1	24.7	9.8	21.0	30.5	13.0	20.9
30–50	10.8	22.4	22.9	7.8	7.3	13.6	14.6	18.2	10.4
50–70	16.2	14.9	10.8	6.5	4.9	2.5	9.8	18.2	1.5
70–90	20.3	22.4	7.2	3.9	3.7	6.2	6.1	19.5	9.0
90–100	28.4	10.4	3.6	2.6	1.2	1.2	7.3	19.5	9.0
Average	62.4	49.8	31.0	19.3	13.2	19.4	31.2	57.1	26.5

In Figure 15, the values of the average forest cover of slopes with different exposure azimuths Aexp are presented in the form of coefficients KFcSL, equal to the ratio of forest cover of slopes to forest cover of plateau. The Figure 15 also shows the values of average insolation for the warm season on the slopes of each exposure, expressed as the insolation coefficient KINS, equal to the ratio of insolation on the slope to insolation on the plateau.

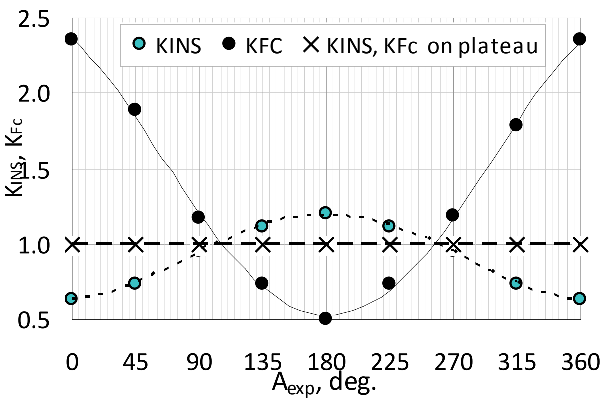

Fig. 15. Dependence of insolation coefficient and forest cover coefficient on the azimuth of slope exposure A_{exp}

As previously determined using the algorithm developed by authors, the values of insolation I on slopes with a steepness of 35° on average from April to September at a latitude of 48°, corresponding to the center of Donbas, varies from 63% to 120% of insolation on a horizontal surface.

Figure 15 shows that with the increase of slope exposure azimuth from A_{exp} = 0° (north) to 180° (south), KINS increases from 0.63 to 1.20 and the factor of afforestation of the slopes KFcSL decreases from 2.35 to 0.50, i.e. by 4.7 times. With further increase in Aexp to 360° (north), KINS decreases and KFcSL increases to initial values.

At exposure azimuth values of 115° and 255°, both coefficients are equal to 1. This means equality of insolation and forest cover of such slopes and plateaus. Thus, decrease of insolation below its level on the plateau and related increase of forest cover of dump slopes in the Central Donbas occurs on slopes with Aexp in the interval from 255° to 115°. This interval corresponds to the slopes of the northern and partly southern parts of the dump with exposure from SW to N and further to SE. Increase of insolation over its level on the plateau and, accordingly, decrease of forest cover takes place on slopes of the southern part of the dump with exposure from SE to SE, i.e. on a smaller part of the lateral surface of the dumps.

The average KFcSL on all slopes is 1.33. This means that, despite the decrease in forest cover on the slopes of the southern part of the dump, the forest cover of its lateral surface as a whole, due to the increase in forest cover on the slopes of the northern part of the dumps, is 33% higher than the forest coverage of the plateau.

Let us consider forest cover of the most contrasting slopes – northern and southern. As shown in Table 7, the number of dumps with forest cover on the southern slope Fc ≤ 10% and, including the complete absence of trees, is 8.1 and 8.3 times higher than the number of dumps with the same forest cover on the northern slope. And the number of dumps with forest cover on the northern slope Fc > 90% is 23.7 times higher than the number of dumps with the same forest cover on the southern slope. However, the fact of the existence of dumps with afforestation of the southern slope above 50%, 75% and even 90% indicates the possibility of afforestation of the entire surface of these and other dumps.

The relationship between the forest cover of the northern and southern slopes with each other and with the average forest cover of slopes of all exposures (the average forest cover of the side surface of the dumps) is characterized in more detail in Figure 16. As can be seen, there is a connection between the forest cover of the southern and northern slopes of the dumps (Fig. 16a). This is explained by the fact that as conditions improve, the forest cover on both exposures increases, which means that the forest cover of the slopes as a whole also increases. With an increase in the forest cover of the side surface of the dumps FcSL from 0% to 90%, the ratio of forest cover of the northern slope FcN to FcSL decreases from 2.5 to 1.0, and the ratio of forest cover of the southern slope FcS to FcSL increases, but remains below 1 (Fig. 16b). The decrease in the difference between the forest cover of the southern and northern slopes FcS and FcN with an increase in the average forest cover of the slopes of the FcSL dumps is evidenced by the increase in the FcS/FcN ratio with an increase in FcSL from 0% to 90% (Fig. 17a) and with an increase in the forest cover of the plateau FcPL from 25% to 100% (Fig. 17b).

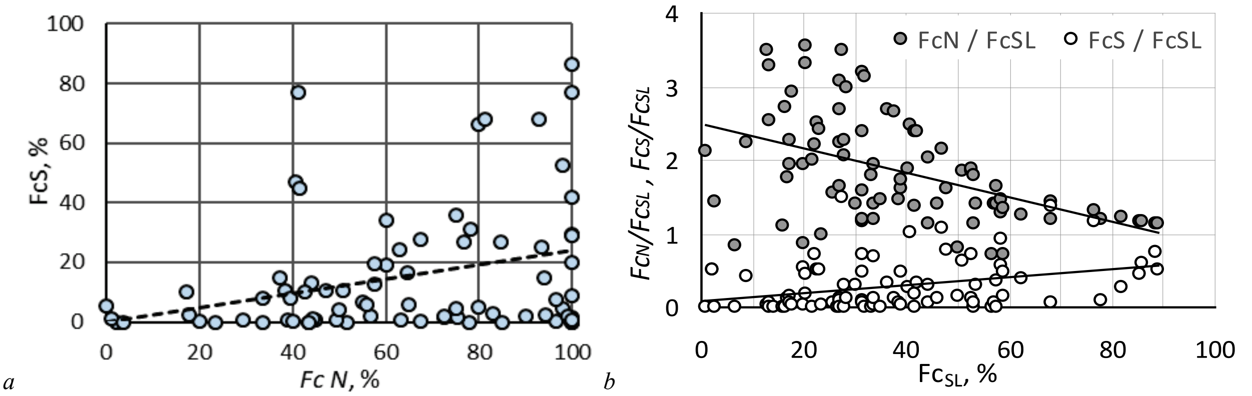

Fig. 16. Relationship between the forest cover of the southern and northern slopes FcS and FcN (*a*) and the relationship between the ratio of FcN and FcS to average forest cover of all slopes FcSL and FcSL (*b*)

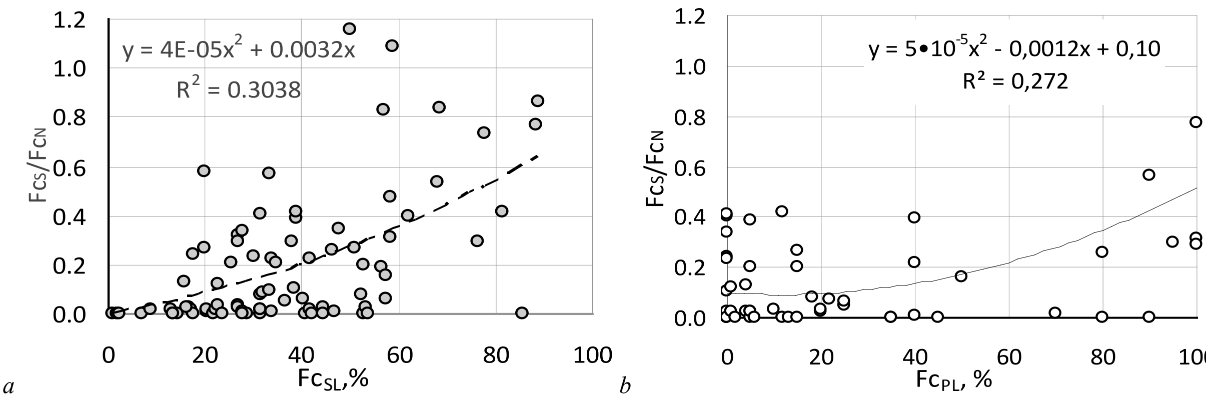

Fig. 17. Relation of the ratio FcS/FcN and forest cover of slopes FcSL (*a*); relation of the ratio FcS/FcN and forest cover of plateau FcPL (*b*)

If we consider the degree of forest cover of the plateau as an indirect criterion for the degree of well-being of the forest growth conditions of the dump, determined by the properties of the rock, then the tendency for the forest cover of the northern and southern slopes to converge (Fig. 17b) can be explained, in our opinion, by the decreasing role of differences in insolation when improving the properties of the rock.

Lviv-Volyn coal basin and Western Donbas. The indicators of forest cover of the slopes of the dumps of these basins (Table 8) differ markedly from CD. Average forest cover of slopes in WD is lower and in LVB higher than in CD. The FcN / FcS ratio in the WD is 2 times higher, and in the LVB it is 3.3 times lower than in the CDL. We attribute these differences to better wetting of the dumps in the LVB and differences in insolation associated with higher latitude and less steep slopes of the dumps in this basin. The lower forest cover of the WD dumps is probably due to the fact that all dumps in this basin are active, unlike those in the Central Donbas.

Table 8
Forest cover of dump slopes of different exposures in LVB, WD and CDL

Forest cover, %	Slope exposures and quantity of waste dumps, %								Fc_{SL}	$\frac{FcN}{FcS}$
	N	NE	E	SE	S	SW	W	NW		
LVD	77.5	65.1	58.3	45.1	54.0	53.7	57.8	69.2	60.1	1.44
WD	22.0	13.6	9.7	2.4	2.4	1.9	13.6	19.1	10.6	9.20
CD_L	62.4	49.8	31.0	19.3	13.2	19.4	31.2	57.1	35.4	4.70

The state of artificial forest plantations on reclaimed dumps after a long period. Over the years since afforestation, the dump No. 1 has undergone serious changes. In 2006, the State Enterprise "United Company "UkrCoalRestructurisation" reduced the height of the dump from 50 to 30 m by cutting off its top with a bulldozer (Fig. 18).

The cut rock was poured on to slopes with southern to western exposures. We have no knowledge of the state of the *Elaeagnus anqustifolia* L. plantations planted in 1985 at this time, but when we inspected the waste dump in October 2019, we saw that they had almost completely disappeared as a result of the backfilling of the rock. Only a few of the backfilled trees were able to recover. The results of statistical processing of the preserved trees *E. angustifolia* and other species are presented in Table 5.

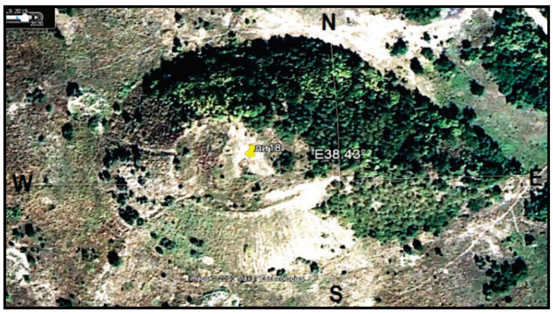

Fig. 18. Forest plantations at waste dump No. 1 (satellite image, September 2019)

The slopes of the northern half of the dump No. 1 are distinguished by better preservation of forest plantations (Fig. 18, 19). The *Quercus robur* plantations here are characterized by completely closed crowns, with a height of 7–8 and up to 9 m.

Despite harsh insolation conditions, the *R. pseudoacacia* trees at the tail part of the dump (south-south-eastern exposure) were in satisfactory state. However, the diameter of the tree trunks does not correspond to what they would have reached in 35 years of life if they had not been subjected to deforestation by the population and periodic thermal exposure when burning dry grass at the base of the dump and under the canopy of trees. This is evidenced by the stumps of trees up to 25 cm in diameter, cut down as early as 15 years old, judging by the annual rings. However, the plantations have almost complete crown closure. This suggests the viability of *R. pseudoacacia* plantings even on southern slopes and their ability to self-heal. This ability of *R. pseudoacacia* is also evidenced by a repeated survey carried out in 2020.

Table 9
Statistical indicators of the diameters of 34- and 30-year-old tree species growing on dumps No. 1 and No. 2 (autumn 2019)

Indicators	Tree species			
	Q. robur, dump No. 1	*R. pseudoacacia*		*E. angustifolia*, dump No. 1
		dump No. 1	dump No. 2	
Arithmetic mean, cm	13.5	8.0	10.6	10.8
Dispersion	24.3	3.7	21.9	28.2
Standard deviation, cm	4.9	1.9	4.7	5.3
Coefficient of variation, %	36.4	6.2	45.2	39.3
Arithmetic mean error, %	7.2	4.9	90.0	9.8
Confidence interval, cm	13.5 ± 2.0	8.0 ± 0.7	10.6 ± 1.7	10.8 ± 2.2
Asymmetry	0.41	–0.37	0.87	0.62
Excess	–1.43	–0.54	–0.46	–0.33

The survey showed active regeneration of *R. pseudoacacia* trees damaged by grass burning at the foot of the dump No. 1 in 2019. Many of the burnt trees gave root growth. There is also the emergence of self-seeding *R. pseudoacacia* plants. Over the years since the re-forming, the plateau has been partially overgrown with woody vegetation and completely overgrown with grass.

Checking the homogeneity of the data using the Student's t-test according to the method led to the conclusion that they do not correspond to the normal distribution law. The values of the coefficient of variation, asymmetry and kurtosis (Table 9) also allow us to put forward a hypothesis about the absence of subordination of tree diameter to the normal distribution law. This is confirmed by the calculation performed by the method of straightened diagrams, presented in our work.

The best state is found in the *R. pseudoacacia* plantations on the slopes of dump No. 2 (Fig. 20). Clockwise slope exposure varies from west to south-east. Forest cover is not lower than 88.8%, stand density is not lower than 95.0%. A comparison of the forest cover of slopes of different exposures of dumps No. 1 and 2 is made in Table 10.

Statistical parameters of 30-year-old *R. pseudoacacia* plantations grown on the slopes of the dump No. 2 (Table 9) allow us to put forward a hypothesis that the diameter of trees does not obey the normal distribution law. With an average diameter of 30-year-old *R. pseudoacacia* plantations equal to 10.6 cm, the standard deviation is 4.7 cm, that is, there is a significant number of trees with a trunk diameter both significantly less and more than 10.6 cm. Individual specimens have a much larger diameter – up to 25 cm. Considering the high growth rate of *R. pseudoacacia*, which we observed in the first 2–3 years, we can assume that a significantly larger number of trees should have had such a diameter. This is evidenced by the large number of stumps of cut down trees. That is, the existing stands, which are quite dense, are largely the result of self-healing of the cut down part of the stands.

Fig. 19. View of the north-eastern side of waste dump No. 1 in October 2019

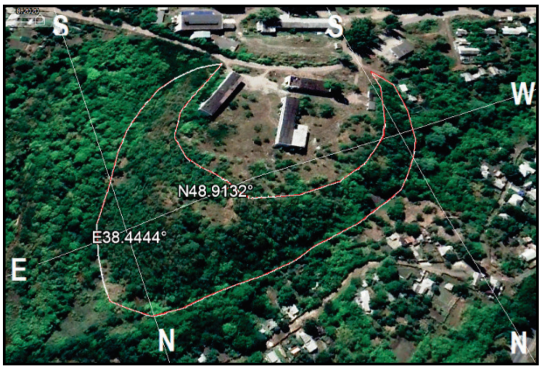

Fig. 20. *Robinia pseudoacacia* on the slopes of dump No. 2 as of 2019

Table 10
Characteristics of forest cover of slopes and plateau of dumps No. 1 and 2

Dumps	Slope exposure and forest cover, %									Fc_{SL}, %	Fc_{PL}, %
	N	NE	E	SE	SSE	S	SW	W	NW		
No. 1	100	100	*	*	90.0	3	11.6	29.3	57.5	55.9	26.9
No. 2	94.0	88.8	92.5	97.3	97.3	*	*	*	94.3	93.4	19.7

Note: * – there is no slope with such exposition.

Discussion

A large number of scientific works all over the world is devoted to the problem of forest reclamation of waste dumps. A characteristic feature of these works in Ukraine is an in-depth study of vegetation cover, but on individual dumps or their groups. The forest cover in the context of basins, administrative districts and slopes of different exposures in Ukraine has not been studied before. The peculiarity of this paper is the coverage of all coal basins of Ukraine, the study of the degree of afforestation of absolutely every dump of LWB, WD and Luhansk part of CD. This was the result of analyzing space images of each dump, i.e. the application of remote sensing. This method has proven to be effective both in solving agroecological monitoring tasks (Tarariko et al., 2019) and in studying waste dumps (Vambol, 2019).

Currently, in many parts of Donbas, remote sensing is the only possible method of landscape surveys. Since 2014, field work has become dangerous due to the risk of contact with unexploded ordnance. This risk has significantly limited the authors' ability to study woody vegetation in

2019 and 2020. Since March 2022, this risk has increased manifold and travel to the non-Ukraine-controlled part of Donbas has become impossible. The study showed the possibility of aerospace monitoring of the state of protective forest plantations on rock dumps of any mining enterprises in order to determine the impact of dumps on the ecological condition of adjacent agricultural lands and the quality of plant products grown on them.

Quantitative assessment of actual afforestation of rock dumps in different coal basins of Ukraine, performed in the article, allows us to estimate the degree of realization of reclamation of dumps, carried out in the country since the last century, and its efficiency.

The revealed differences in the afforestation of waste dumps in the Lviv-Volyn basin, in Western and Central Donbas, as well as differences in the afforestation of waste dumps in the section of separate administrative districts of Central Donbas testify to the great influence of climatic differences on the condition of tree plantations on rock dumps.

The fact that in the Lviv-Volyn basin low forested dumps are found proves that even in more favorable climatic conditions one should not count on rapid self-overgrowth of dumps. In order to obtain ecologically safe, fully afforested dumps, their reclamation is necessary.

The obtained data on the area of waste dump slopes and their plateaus in combination with the data on their afforestation allow us to estimate the available resources of non-forested areas and the required amount of reclamation works. Knowledge of the resources of the non-forested area is also important for the implementation of various proposals for the use of the dump surface presented in the scientific and patent literature. Among them is the proposal to use the dump surface to create carbon-depositing ("Kyoto") forests and as cores of local ecological networks (Zubov et al., 2012). Knowledge of the area of the unforested part of the slopes and plateau of the dumps is also important for estimating the mass of pollutants carried off the dumps as a result of deflation and erosion. As previously defined, 35,765 ha of land in the Donbas is potentially contaminated by these processes (Zubov et al., 2023). Reducing the surface area of dumps exposed to erosion and deflation through afforestation will reduce the area of land exposed to pollution and its intensity.

It is known from the scientific literature that vegetation composition differs on slopes of different exposures. A review (Sokolova, 2016) and a study Nienartowicz et al. (2010) described in detail the influence of exposure and slope steepness of natural landforms on the spatial distribution of plant species composition. In development of the results of these and other papers describing the qualitative condition of forests on natural and anthropogenic sites, our paper is the first to quantify the dependence of differences in the degree of forest cover of slopes of waste dumps and flat tops on the conditions of their insolation.

The revealed differences in afforestation of dump slopes of different exposures and their relation to the slope insolation coefficient KINS proposed by the authors have both theoretical and practical significance. In combination with the previously developed methodology for estimating insolation of slopes of different steepness and exposure at different latitudes (Zubov, 2022), the obtained dependencies can be used to predict the afforestation of slopes of any steepness and latitudes.

The revealed facts of presence of dumps with afforestation of the southern slope above 75% and even 90%, firstly, confirm the possibility of growing plantations in the Northern Steppe even on the southern slopes of the dumps; secondly, they testify that the conditions of afforestation of the slopes of dumps depend not only on insolation, but also on other factors. Therefore, the difference of actual values of slope afforestation from the expected ones can be considered as an indirect indicator of other more or less favorable forest conditions of the slope: water-physical properties of the rock, its salinity, presence of toxic substances and plant nutrition elements. This suggests the need for careful selection of tree crops for their successful cultivation on slopes of different exposures.

The facts of high safety of artificial plantations of black locust on two waste dumps afforested by the authors in 1985 and 1989, as well as the revealed ability of the black locust to self-restoration even on the slope of unfavorable exposure, close to the southern slope, allow us to recommend this culture for afforestation of southern slopes along with other drought- and salt-tolerant crops, such as *Prunus armeniaca* and *Elaeagnus anqustifolia*.

In our opinion, the reason for the unsatisfactory condition of afforestation of the Donbas dumps is the high cost of the existing reclamation technology. According to the method of reclamation of conical dumps, officially adopted in Ukraine in the 1970s, before afforestation the dumps are lowered by cutting off their tops. In addition, wide terraces are formed on the dumped slopes by bulldozer. At the same time, as noted by Logginov (1989), the burned-out, weathered, loose rock, which has partially lost its toxicity, is poured down, and the trees are planted in dense, unburned rock. Studies have shown the advantages of the method of reclamation without cutting the conical top of dumps, known as the UAA method, developed by Prof. Logginov and his colleagues. According to the calculations of its developers, the cost of afforestation using this method is 40–100 times less than the official method known as the method of the Donetsk Botanical Garden (Logginov, 1989).

Successful afforestation of two dumps of PJSC "Lysychans'kvuhillya", carried out by the authors using the UAA method, allows us to recommend it as a method that does not require special expenditures of time and finances. The data on the labor costs of those who carried this work out given in the article allow us to express them in monetary equivalent. It is possible to reduce costs by using alternative methods proposed by the authors and protected by patents of Ukraine for a useful model No. 25148, No. 25149 (2007) and by patents of Ukraine for a invention No. 123518 (Tarariko & Zubov, 2021). Manual labor can be mechanized using a micro-terracer protected by patents of Ukraine No. 34829A (Omelchenko et al., 2001) developed with the participation of L.G. Zubova and described in Smirnyi et al. (2006).

Conclusion

The total area occupied by rock dumps in the Lviv-Volyn Basin (LVB) is 366 ha, in the Western Donbas (WD) – 193 ha, in the Central Donbas (CD) – 6,648 ha, respectively. In aggregate, all the dumps occupy 7,207 hectares. The area of environmentally hazardous unforested surface of dumps subject to erosion and deflation in the Luhansk part of the CD is 79.5% of the surface of dumps and equals 2,899 ha. Based on the assumptions made in the article, the unforested environmentally hazardous surface in the entire Central Donbas is about 6,200 ha.

Despite the legal obligation of mining companies in Ukraine to reclaim abandoned mine dumps, more than half of the dumps in the northeastern Central Donbas are less than 10% afforested. The low average afforestation of the dumps in general indicates that reclamation of most of the reclamation was not carried out, since the fact of the presence of dumps that are more than 90% forested proves that the dumps can be completely afforested even in conditions of unstable moisture characteristic of the steppe zone.

Forest cover of dumps is characterized by a number of features:

– in different natural-climatic zones with different hydrothermal conditions, it differs sharply: in LWB (forest-steppe zone) it is equal to 50.6%; in WD and CD (North-steppe zone) it is equal to 5.6% and 10.6%;

– the forest cover of dumps in the coal-mining areas of the Lugansk part of the CD decreases from the foot of the Donetsk Ridge to its top (from north to south) from 24.3% to 3.5–7.2%;

– the forest cover of dump slopes of various exposures depends on the ratio of the average insolation of the slope for the warm period of the year to the insolation of the horizontal surface (plateau).

On southern and northern slopes this ratio (insolation coefficient) at latitude 48° is equal to 0.63 and 1.20, and average afforestation of the southern slopes of dumps in CDL is 4.7 times lower than northern slopes. On the slopes of the northern half of the dumps with exposure from western to eastern, on which the insolation coefficient is higher than 1, the forest cover is higher than on the plateau, and on the southern half, vice versa. In LVB and WS, the ratio of forest cover between the northern and southern slopes is 1.4 and 9.2 times, respectively.

Despite the low average forest cover of the southern slopes, on 8% of dumps it exceeds 50% and even 90%. This fact confirms the possibility of afforestation even on such slopes with the proper selection of forest crops most adapted to arid conditions.

The authors' experience of afforestation of two waste dumps of PJSC "Lysychans'kvuhillya", highlighted in the paper, confirms the low cost of the method, developed in the Ukrainian Agricultural Academy. And the good condition of forest plantations after more than 30 years confirms the effectiveness of this method. Taking into account this possibility and the great ecological danger of the dumps, the works on their biological recultivation should be renewed. The result of afforestation of dumps will be a reduction in the intensity of pollutants from their surface to the adjacent territory and a reduction in the area of polluted agricultural land.

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References

Arif, H., Kausar, A., Afzal, A., Ahmed, S. R., Afsar, S., Lahori, A. H., Vambol, S., & Vambol, V. (2023). Geospatial techniques for comparative case study of spatio-temporal changes in New Karachi and North Karachi parks. Ecological Questions, 34(4), 1–9.

Brovko, F. M. (2012). Suchasni problemy ta dosyahnennya lisovoyi rekul'tyvatsiyi pustyrs'kykh landshaftiv Ukrayiny [Modern problems and achievements of forest reclamation of wasteland landscapes in Ukraine]. Forestry and Horticulture, 1, 4 (in Ukrainian).

Chen, Y., Jiang, Y., Wang, H., & Li, D. (2007). Assessment of ambient air quality in coal mine waste areas – a case study in Fuxin, China. New Zealand Journal of Agricultural Research, 50(5), 1187–1194.

Donggan, G., Zhongke, B., Tieliang, S., Hongbo, S., & Wen, Q. (2011). Impacts of coal mining on the aboveground vegetation and soil quality: A case study of Qinxin coal mine in Shanxi Province, China. Clean – Soil, Air, Water, 39(3), 219–225.

Gawor, Ł. (2014). Coal mining waste dumps as secondary deposits – examples from the Upper Silesian Coal Basin and the Lublin Coal Basin. Geology, Geophysics and Environment, 40(3), 285.

Khan, A., Khan, S., Khan, M. A., Qamar, Z., & Waqas, M. (2015). The uptake and bioaccumulation of heavy metals by food plants, their effects on plants nutrients, and associated health risk: A review. Environmental Science and Pollution Research, 22(18), 13772–13799.

Korshikov, I. I., & Zhukov, S. P. (2008). Samovidnovlennia derevnykh roslyn na vidvalakh vuhil'nykh shakht Donbasu [Self-renewal of woody plants on dumps of Donbass coal mines]. Industrial Botany, 8, 17–23 (in Ukrainian).

Kumar, B. M. (2013). Mining waste contaminated lands: An uphill battle for improving crop productivity. Journal of Degraded and Mining Lands Management, 1(1), 43–50.

Li, Z., Ma, Z., van der Kuijp, T. J., Yuan, Z., & Huang, L. (2014). A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. Science of the Total Environment, 468–469, 843–853.

Lipinsky, V. M., Dyachuk, V. A., & Babichenko, V. M. (Eds.). (2003). Klimat Ukrayiny [Climate of Ukraine]. Raevsky Publishing House, Kyiv (in Ukrainian).

Logginov, B. I. (1989). Osobennosti rekul'tivatsii terrikonov ugol'nykh shakht Donbassa [Peculiarities of reclamation of waste heaps of coal mines in Donbass]. Forest Journal, 6, 33–37 (in Russian).

Logginov, B. I., & Kirichek, L. S. (1978). Metodicheskie rekomendatstii po zashchitno-dekorativnomu obleseniyu terrikonikov i ugol'nykh shakht Donbassa [Guidelines for protective and decorative afforestation of heaps of coal mines in Donbass]. Izdatel'stvo USHA, Kiev (in Russian).

Lu, Y., Song, S., Wang, R., Liu, Z., Meng, J., Sweetman, A. J., Jenkins, A., Ferrier, R. C., Li, H., Luo, W., & Wang, T. (2015). Impacts of soil and water pollution on food safety and health risks in China. Environment International, 77, 5–15.

Marcisz, M., Adamczyk, Z., Gawor, L., & Nowińska, K. (2021). The impact of depositing waste from coal mining and power engineering on soils on the example of a central mining waste dump. Gospodarka Surowcami Mineralnymi – Mineral Resources Management, 37(2), 179–192.

Marcisz, M., Probierz, K., & Gawor, L. (2020). Possibilities of reclamation and using of large-surface coal mining dumping grounds in Poland. Gospodarka Surowcami Mineralnymi, 36(1), 105–122.

Nienartowicz, A., Deptuła, M., Kunz, M., Adamska, E., Boińska, U., Gugnacka-Fiedor, W., Kamiński, D., & Rutkowski, L. (2010). Relief and changes in the vegetation cover and the flora of the Zadroże Dune near the city of Toruń: Comparison of the conditions in 1948 and 2009. Ecological Questions, 12, 17–50.

Omelchenko, A. V., Kharkovsky, B. T., & Zubova, L. G. (2001). Prystriy dlia pidhotovky poverkhni terykonu pered ozelenenniam [Device for preparing the surface of terikon before greening]. Patent of Ukraine, IKI A01B35/00, No. 34829A, Bul. No. 2 (in Ukrainian).

Petlovanyi, M., Sai, K., & Stoliarska, O. (2022). Problems of waste rock formation during mining of Western Donbass coal reserves: State-of-the-art and solutions. Collection of Research Papers of the National Mining University, 71, 79–90.

Pietrzykowski, M., Pająk, M., & Krzaklewski, W. (2011). Application of soil quality indexes for the habitat conditions variability assessment in the forestry rehabilitated former mining spoil banks. Folia Forestalia Polonica, 53(1), 17–24.

Popovich, V. V., Misiak, R. I., & Brunets, K. S. (2011). Pryrodna fitomelioratsiya vuhil'nykh vidvaliv [Natural phytomelioration of coal waste dumps]. Scientific Bulletin of NLTU of Ukraine, 21(4), 127–131 (in Ukrainian).

Popovych, V. V., & Voloshchyshyn, A. I. (2019). Environmental impact of devastated landscapes of Volhynian Upland and Male Polisya (Ukraine). Environmental Research, Engineering and Management, 75(3), 33–45.

Ribeiro, J., & Flores, D. (2021). Occurrence, leaching, and mobility of major and trace elements in a coal mining waste dump: The case of Douro Coalfield, Portugal. Energy Geoscience, 2(2), 121–128.

Romana, P., Michal, Š., Ota, R., & Pavel, K. (2017). Trees as ecosystem engineers driving vegetational restoration/retrogradation of industrial deposits in cultural landscape. Journal of Landscape Ecology, 10(2), 122–131.

Rout, T. K., Masto, R. E., Padhy, P. K., George, J., Ram, L. C., & Maity, S. (2014). Dust fall and elemental flux in a coal mining area. Journal of Geochemical Exploration, 144, 443–455.

Sloss, L. (2013). Coal mine site reclamation. IEA Clean Coal Centre, Paris.

Smirny, M. F., Zubova, L. G., & Zubov, A. R. (2006). Ekologicheskaya bezopasnost' terrikonovykh landshaftov Donbassa [Ecological safety of slag heap landscapes of Donbas]. Volodymyr Dahl East Ukrainian National University, Lugansk (in Russian).

Sokolova, G. G. (2016). Vliyanie vysoty mestnosti, ekspozitsii i ugla uklona na prostranstvennoe raspredelenie rasteniy [The influence of terrain altitude, slope exposure and slope degree on plant spatial distiribution]. Acta Biologica Sibirica, 2(3), 34–45 (in Russian).

Tarariko, O. H., & Zubov, A. O. (2021). Sposib fitomelioratsiyi terykoniv [The method of phytomelioration of slag heaps]. Patent of Ukraine for invention. No. 123518. Bul. No. 15 (in Ukrainian).

Tarariko, O., Ilienko, T., Kuchma, T., & Novakovska, I. (2019). Satellite agroecological monitoring within the system of sustainable environmental management. Agricultural Science and Practice, 6(1), 18–27.

Vacek, Z., Cukor, J., Vacek, S., Podrázský, V., Linda, R., & Kovařík, J. (2018). Forest biodiversity and production potential of post-mining landscape: Opting for afforestation or leaving it to spontaneous development? Central European Forestry Journal, 64(2), 116–126.

Vambol, S., Vambol, V., Sundararajan, M., & Ansari, I. (2019). The nature and detection of unauthorized waste dump sites using remote sensing. Ecological Questions, 30(3), 43–55.

World Coal Institute (2005). The coal resource: A comprehensive overview of coal. World Coal Institute, London.

Younger, P. L. (2004). Environmental impacts of coal mining and associated wastes: A geochemical perspective. Geological Society, London, Special Publications, 236(1), 169–209.

Zhukov, S. P. (2020). Woody plants on rock dumps of the Donetsk-Makeevka urban agglomeration. Èkobioteh, 3(3), 412–417.

Zubov, A., Zubov, A., & Zubova, L. (2023). Ecological hazard, typology, morphometry and quantity of waste dumps of coal mines in Ukraine. Ecological Questions, 34(4), 1–19.

Zubov, O. R., & Zubov, A. O. (2022). Osoblyvosti radiatsiynoho balansu na skhylakh orodnykh vidvaliv i v systemi lisovykh smuh [Features of radiation balance on the slopes of waste heaps and in the system of forest belts]. Taurian Scientific Herald, 126, 258–269 (in Ukrainian).

Zubov, A. R., Zubova, L. G., Vorobiev, S. G., Zubov, A. A., & Kharlamova, A. V. (2012). Povyshenie ekologicheskoy bezopasnosti ugol'nykh shakhtnykh otvalov [Improving of environmental safety of coal mine stockpiles]. Volodymyr Dahl East Ukrainian National University, Lugansk (in Russian).

Zubova, L. G., Zubov, O. R., & Zubov, A. O. (2019). Analiz sostoyaniya lesnykh nasazhdeniy na terrikonakh [The analysis of the state of forest plants on the terricons]. Taurian Scientific Herald, 110, 141–151 (in Ukrainian).