IRSTI 87.21.81 https://doi.org/10.26577/EJE.2023.v74.i1.01

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CONSTRUCTION OF A GEOECOLOGICAL MAP OF DUST PARTICLES TRANSFER FROM THE SURFACE OF THE SHYMKENT LEAD (PLUMBUM) FACTORY DUMP

The study of horizontal migration of heavy metals is relevant for Shymkent city. In 1934, lead processing began, and sludge waste was stored on the territory of the lead factory. Ameliorative or other structures capable of reducing dust emissions have not been built around the lead dump, allowing lead dust to freely spread over long distances from the SPZ (sanitary protection zone). In this article, the horizontal migration of lead dust was studied based on climatic and calculated data by building a physical model; in addition, a geoecological map was built. This work has practical significance for further ecological and geochemical assessment of soils for the content of heavy metal concentrations, since it visually characterizes the spread of lead dust along the wind rose. To build a geoecological map of the transfer of impurities, we are faced with the task of determining the rate of settling of hovering particles and their distributions depending on the masses of particles and wind speed.

To determine the rate of deposition of lead particles in the atmosphere, we need to study the shape of lead, background meteorological situation, particle diameter, solid particle density, medium density and dynamic viscosity of the medium. The removal of dust particles from the surfaces of ash and slag dumps of industrial facilities into the atmosphere under the influence of wind erosion, followed by their deposition on the soil, is one of the most common ways of polluting the territories of industrial facilities. As a result of the calculations, the surface concentration of dust particles was derived and a geoecological map was compiled.

Key words: geoecological map, lead dumps, assessment of dust emissions, horizontal migration of heavy metals, physical model of transport and scattering.

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Шымкент қорғасын зауыты өндірісінен бөлінген қалдық бөлшектерінің тарау жолының геоэкологиялық картасын құру

Шымкент қорғасын зауытынан бөлінген ауыр металдардың жазықтық миграциясын зерттеу Шымкент қаласы үшін өзекті мәселе. 1934 жылдан бастап қорғасынды қайта өңдеу жұмыстары жүргізіліп, үйінді ретінде бөлінген қалдықтар зауыт аумағында орналастырылған.

Қорғасын үйіндісінің айналасында шаң шығарындыларын азайтуға арналған мелиоративтік немесе басқа нысандар салынбағандықтан, қорғасын шаңы ұзақ қашықтыққа еркін таралады. Мақалада климаттық және есептік деректер негізінде физикалық модель құру арқылы қорғасын шаңының жазықтық миграциясы зерттеліп, геоэкологиялық карта жасалды. Желжиын бағыты бойымен қорғасын шаңының таралуын көрнекі түрде сипаттайтындықтан, бұл еңбек зерттеу ауданында әрі-қарай топыраққа жүргізілетін экологиялық зерттеу мен бағалау жұмыстары үшін маңызды.

Қоспалардың тасымалдану геоэкологиялық картасын құру үшін алдымызда қалқымалы бөлшектердің шөгу жылдамдығымен қатар бөлшектердің өз массасына және жел жылдамдығына таралу байланысын анықталды. Сонымен қатар атмосферадағы қорғасын бөлшектерінің шөгу жылдамдығын анықтау үшін қорғасынның пішінін, фондық метеожағдайды, бөлшек диаметрін, бөлшек және ауа тығыздығын зерттелінді. Жел эрозиясының әсерінен өндіріс орындарындағы күл-қож үйінділері бетінен шаң бөлшектерінің атмосфера арқылы топыраққа түсу, өнеркәсіптік объектілер орналасқан аумақтарда ластанудың кең таралған түрінің бірі болып табылады. Есептеулер нәтижесінде шаң бөлшектерінің концентрациясы аңықталып, геоэкологиялық карта құрастырылды.

Түйін сөздер: геоэкологиялық карта, қорғасын үйінділері, шаң шығарындыларын бағалау, ауыр металдардың жазықтық миграциясы, бөлшектердің тасымалдану және таралуының физикалық моделі.

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Построение геоэкологической карты переноса пылевых частиц с поверхности свинцового отвала Чимкентского свинцового завода

Изучение горизонтальной миграции тяжелых металлов является актуальным для города Чимкент. В 1934 году началась переработка свинца, а шламовые отходы были складированы на территории свинцового завода. Вокруг свинцового отвала не построены мелиоративные или иные сооружения, способные уменьшить пылевые выбросы, ввиду чего свинцовая пыль свободно распространяется на длинные дистанции от СЗЗ. В данной статье была изучена горизонтальная миграция свинцовой пыли на основании климатических и расчетных данных путем построения физической модели, а также построена геоэкологическая карта. Данная работа имеет практическую значимость для дальнейшей эколого-геохимической оценки почв на содержание концентраций тяжелых металлов. Поскольку визуально характеризует распространение свинцовой пыли по розе ветров. Для построения геоэкологической карты переноса примесей были исполнены задачи по определению скорости оседания витающих частиц и их распространения в зависимости от массы частиц и скорости ветра.

При определении скорости оседания частиц свинца в атмосфере была изучена форма свинца, фоновая метеоситуация, диаметр частицы, плотность твердой частицы, плотность среды, динамическая вязкость среды. Вынос в атмосферу пылевых частиц с поверхности золошлакоотвалов производственных объектов под воздействием ветровой эрозии с последующим их осаждением на почве является одним из наиболее распространенных путей загрязнения территорий расположения промышленных объектов. По итогу расчетов была выведена приземная концентрация пылевых частиц и составлена геоэкологическая карта.

Ключевые слова: геоэкологическая карта, свинцовые отвалы, оценка пылевых выбросов, горизонтальная миграция тяжелых металлов, физическая модель переноса и рассеяния.

Introduction

With the development of industry, humanity needs to overcome the consequences of high production growth. When natural systems began to change under human influence, uncharacteristic agents and harmful substances entered the environment. In this chain of anthropogenic impacts, one of the most dangerous and pressing issues is the impact of heavy metals on humans and the natural environment.

Due to the rapid change of industrialization and the development of urbanization, soil pollution with toxic metals is a global problem [1]. Indeed, in the era of scientific and technological progress, the negative anthropogenic impact on the environment is becoming more intense and large-scale. Soils are one of the first links in the biogeochemical food chain and the initial stage of migration of metals in the system, i.e., soil-plant-animal-food-human [2]. Local technogenic geochemical anomalies occur around metallurgical industry enterprises, which are characterized by a high content of heavy metals in the soil and unfavourable sanitary and environmental situations [3]. Being mainly in a dispersed state, heavy metals form local accumulations in the soil, where their concentration is hundreds to thousands of times higher than average planetary levels. For example, more than 40% of oil-contaminated soils contain high concentrations of heavy metals [4].

Heavy metals are predominantly in a dispersed state and thus form local accumulations in the soil, where their concentration is hundreds to thousands of times higher than the average planetary levels. For example, more than 40% of oil-contaminated soils contain high concentrations of heavy metals [4].

As past situations have shown [1, 5, 6], monitoring and correcting direct environmental impacts of the waste from abandoned industrial facilities on the soil is an urgent and key part of the environmental safety of the population. In particular, Chinese scientists [1] recreated a spatial model that characterizes the relationship between vertical and horizontal migration of heavy metals in the soil as a result of a comprehensive study on heavy metal content in soil. The spatial model showed the dependence of heavy metal concentration in the deep layers of the soil profile on the intensity of vertical migration in the surface layer.

Typically, concentrated metal contamination in soils was airborne from smelters, causing long-term contamination, especially in agricultural areas [7]. However, due to the high costs of research and soil restoration activities, many factories and contaminated areas remain abandoned [1]. Heavy metals coming from metallurgical enterprises worsen the biological and chemical parameters of the soil and disrupt its homeostasis [8].

According to the studies of Korean scientists [9], the direct impact of zinc factory emissions on the increased concentration of heavy metals in agricultural lands was proven. This indicates the danger of increased pollution not only in industrial areas, but also the dispersion of polluted dust particles in vertical space.

The Shymkent lead factory (modern name "Yuzhpolymetal") is currently not functioning. However, the volume of waste is 1.8 million m^3 and is a dump of lead sludge in the form of a mountain (folk name "Lead Mountain"), which for a long time has been and remains a source of pollution of environmental elements with lead and other heavy metals. The situation in the research area is aggravated by the fact that the stored waste is currently located near residential areas. The territory of the studied area is a steppe zone, without prominent hills and lowlands. The Badam River and non-essential green spaces are located next to the factory. Residential areas start 3 km from the plant.

Kazakhstani scientists studied the influence of the Shymkent lead factory on the health of the population, and their data showed that 66% of the surveyed children attending kindergartens in the affected area have an excess of the MPC for lead in the blood [10]. The excess of MPC was 3–4 times higher than the average for the same age group in Kazakhstan. In 45% of preschool children, there was a decrease in the number of normal epithelial cells of the upper respiratory tract. Other researchers analysed the content of heavy metals in the soil near the Shymkent lead factory. According to the results, the actual values of zinc exceeded the MPC by more than 300 times, and for lead by 40 times [11]. Previously, the area of contamination with lead and cadmium was also studied [12]. According to the data, the pollution spread 8–12 km along the radius, and in a south direction 6 km from the lead mountain. In the immediate vicinity of the lead factory, a zone of maximum contamination with a radius of 1–2 km has been allocated.

Pearson correlation and Principal Component Analysis (PCA) are often used to study the dispersion of heavy metals on the soil [1, 5, 13]. The Pearson correlation analysis method is used to compare correlations in pairs between several factors to determine the correlation between the studied heavy metals themselves and their shift in soil layers (depth) [1].

According to the purpose of the study, the construction of a geoecological map is based on the results of a calculated physical model of vertical scattering of heavy metals in the soil. Taking into account meteorological and landscape factors, as well as physical and chemical properties of soil and lead sludge, the method allows us to calculate the correlation of surface concentrations of heavy metals at the studied points.

Materials and methods

One of the most common ways that territories of industrial facilities become polluted is by dust particles being blown into the atmosphere from the surface of ash and slag dumps of industrial facilities under the influence of wind erosion, followed by their deposition on soil.

We focused on the soil layer around the Shymkent lead factory which was contaminated with heavy metals due to the storage technology used for production as a result of the dusting that occurred. Using empirical observational material, correlations of cases of high impurity concentrations with a certain combination of meteorological conditions were established [14].

The assessment of dust emissions from the surface of ash and slag dumps can be given by various methods, e.g., experimental, analog and calculation. This article uses a universal method for assessing the dusting properties of ash and slag dumps—a calculation method based on the reconstruction of a physical model of the process of wind erosion.

Mathematical models in modern conditions are becoming a tool for studying human relationships with the environment as they allow management of natural resources while taking into account possible anthropogenic impacts as components of the model.

Human activity poses new challenges in the visualization of anthropogenic changes in the compilation of index maps of current changes using modern means and software mapping technologies [15].

There are three components of the wind erosion process

– separation and take-off of a particle from the surface,

– moving it in a dusty stream above the surface of the ash and slag field,

– dispersion of ash eroded particles outside the ash dump after the dust cloud descends from the dam.

The effect of wind-air flow on each individual particle on the surface of the layer is associated with several simultaneously operating mechanisms: frontal aerodynamic pressure, prompting a shift in the direction of the wind along the surface, a static pressure drop that occurs when the particle flows around and creates a lifting force and turbulent diffusion in the wind flow, creating variable pulsating forces in magnitude and direction on the particle and weakening gravitational and adhesive bonds of a particle with a layer [16].

To determine the particle deposition rate and the area of the dusting surface, it is necessary to carry out several calculations based on the characteristics of the ash dump, the wind regime and the characteristics of the eroded particles.

The conditions for the formation of ash and slag particles of the Shymkent lead factory have a bulk character; the influence of the granulometric composition of deposits on the dusting properties of the layer is extreme.

To determine the granulometric composition, the following analyses are performed: sieve, sedimentation or dispersion and microscopic [17]. In the research, a sieve analysis based on mechanical separation by particle size gradation was used.

A set of sieves ranging from 7 mm to ≥ 0.25 mm was used. Two hundred grams of the sample was taken from the lead slurry, placed on the upper sieve of the kit and installed from the largest diameter of the holes to the smallest. After shaking the sieve with the contents, the material remaining on each sieve was weighed and the yield of each class in grams and as a percentage of the total mass of the sample was recorded in Table 1. The analysis was repeated twice to establish accuracy.

Table 1 – Results of the sieve analysis

No.	The size of the sieve holes, mm	Output		Total output, %
		gr	%	
1	7	2,063	1,04	1,04
2	5	15,081	7,60	8,64
3	3,75	43,127	21,73	30,36
4	3	58,952	29,70	60,06
5	2	65,953	33,22	93,28
6	1	13,165	6,63	99,92
7	0,5	0,036	0,018	99,934
8	0,25	0,056	0,028	99,962
9	under 0.25	0,075	0,038	100,000
	Initial product	198,508	100,00	

Results and discussion

The greatest deflation was observed for a layer with a predominance of 0.05–0.2 mm particles [8]. For the lead dumps of the Shymkent factory, according to Table 1, this was 0.06%. Taking into account an increase in the proportion of particles larger than 0.25–0.3 mm, the intensity of ash-slag blowing decreased sharply.

When assessing wind erosion (t/year) and the average annual current removal of particles (gr/s) from the surface of the dump, the individual characteristics of the eroded material and the wind regime were determined as follows:

1) Average wind speed at the level of the weathervane U_{avr} in the ash dump location zone was taken as a weighted average value in the range from the wind speed corresponding to the beginning of the blowing of ash particles U_{min} to the maximum wind speed U_{max}, taking into account the repeatability of speed gradations.

2) The average size of eroded particles d_{CP} was defined as a weighted average value in the range from d_{max} to 0:

$$d_{avr} = \sum (d \cdot a)_i / \sum d_i \quad (1)$$

where: *d – i* is the fraction average particle size; *a – i* is the fraction part of particles and *i* is the eroded particles fractions number.

d_{avr} = (7 * 1.04 / 100) + (5 * 7.6 / 100) + (3.75 * 21.73 / 100) + (3 * 29.7) / 100 + (2 * 33.22) / 100 + (1 * 6.63) / 100 + (0.5 * 0,018) / 100 + (0.025 * 0.028) / 100 = 2.889 = 2.9 mm

To determine the average annual wind speed at the level of the weathervane in a dust-hazardous wind regime ($U > U_{min}$) U_{avr}, it is necessary to perform the calculation according to the following formula:

$$U_{avr}=\Sigma(UP)i/\Sigma Pi, \quad (2)$$

where: i is number of speed gradations in the range from U_{min} to U_{max}; U is average wind speed within a gradation and P is proportion of the corresponding gradation.

Necessary data: wind speed and its frequency during the year, followed by gradation (Figures 1, 2, 3; Tables 2, 3, 4) [18].

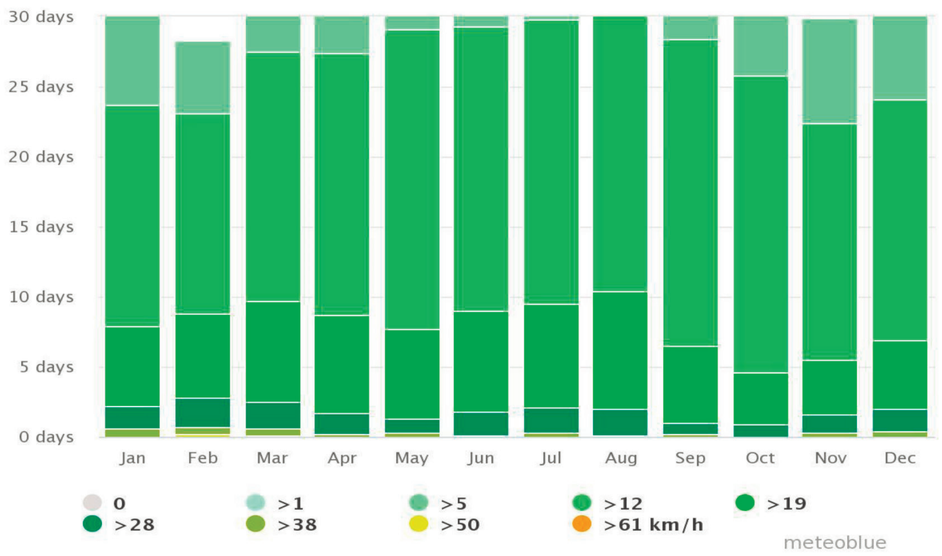

Figure 1 – Repeatability during the year of wind speed

Table 2 – Repeatability of wind speed during the year

– repeatability of wind speeds of various gradations Pui, %, throughout the year	4-5m/s – 12.7%; 12-13m/s – 60%; 18-20m/s – 21.1%, >25 m/s – 5.2%, >35m/s – 0.8%
– repeatability during the year of the wind speed in the number of times	4-5m/s – 44; 12-13m/s – 207; 18-20m/s – 73, >25m/s – 18, >35m/s – 3

Substituting this data into the formula:

U_{avr} = 4.5 * 12.7 + 12.5 * 60 + 19 * 21.1 + 28 * 5.2 + 38 * 0.8) / (12.7 + 60 + 21.1 + 5.2 + 0.8) = (57.15 + 750 + 400.9 + 145.6 + 30.4) / 99.8 = 1384 / 99.8 = 13.8 m/s.

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Table 3 – Wind rose percentage ratio

North, %	Northeast, %	East, %	Southeast, %	South,%	Southwest, %	West, %	Northwest, %
8,9	10,4	16,5	23,4	8,8	9,5	12	10,6

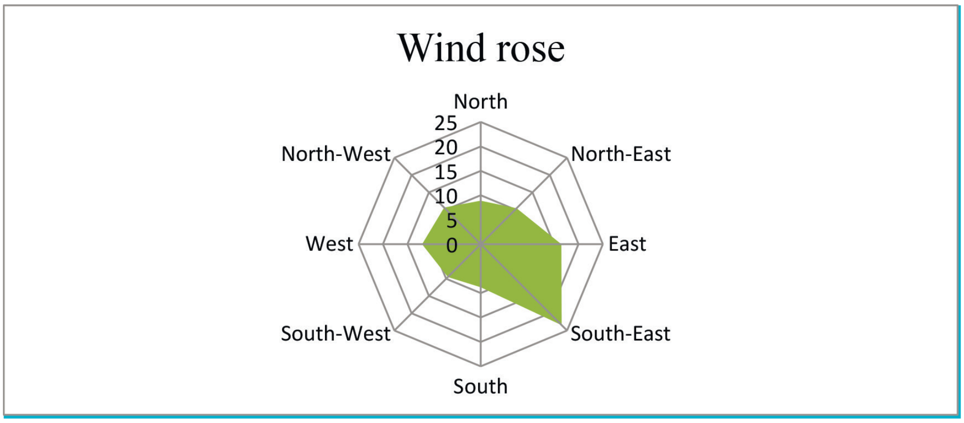

Figure 2 – Wind rose

**Wind speed (green line) and direction (purple dots). Wind direction is shown in degrees: 0° = north, 90° = east, 180° = south and 270° = west (labels on the right axis)*

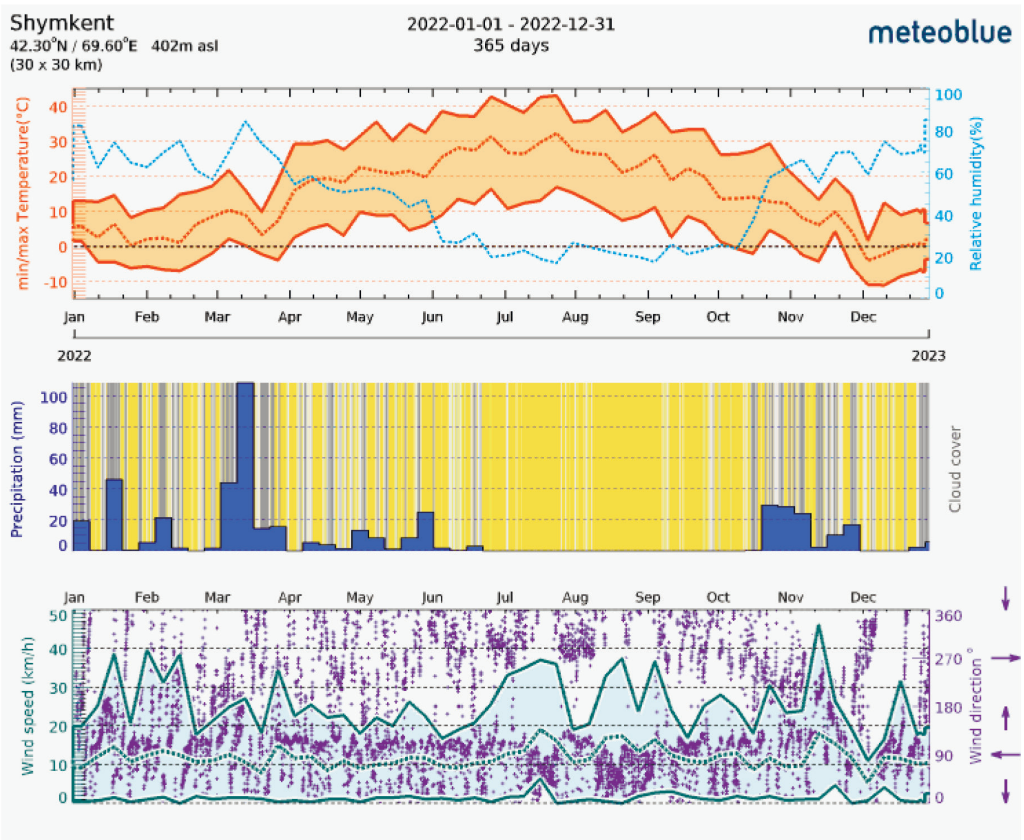

Figure 3 – Climate data

Shear or dynamic flow velocity U* is the most important parameter that characterizes the conditions of wind erosion of the surface of a pulverized material and determines the magnitude of the effort generated by the flow to separate the particle from the surface (or shear it along the surface). This parameter directly characterizes the degree of intensity of turbulent pulsating motion in the boundary layer. The value of U* is determined from the Karman-Prandtl logarithmic equation, which takes into account the altitude gradient of the velocity of a dust-free wind-air flow associated with the braking effect of the underlying surface:

$$U_Z / U_* = 1/k \cdot \mathrm{h}\left(Z/d_{\ddot{I}}\right) + 8{,}5 \qquad (3)$$

where: U_Z is wind speed at vane altitude Z, m/s; k is Karman's constant (~0,4); d_P is particle diameter in m and Z is wind vane installation height in m.

Threshold (minimum) dynamic speed in m/s, corresponding to the beginning of dusting (particle rise), is determined by the graph in Fig. 2 or by the formula:

$$U_{*_t} = A \cdot \left(\sigma \cdot g \cdot d_{\ddot{I}}\right)^{0,5}; \quad \sigma = \rho_P / \rho_v, \qquad (4)$$

where: ρ_v is air density in kg/m^3; ρ_P is aggregate density of dust particles in kg/m^3; g is acceleration of gravity in m/s^2 and A is the empirical coefficient, 0.08 ÷ 0.12.

Table 4 – Calculated data for determining the speed at the beginning of dusting

$d_{avr,}$ mm	p, particle density, kg/м^3	$p_в$, air density, kg/м^3	A, empir.coefficient	g, gravity acceleration, m/s^2	U (dusting start speed), m/s
2,9	3,45	1,2754	0,6	9,8	5,84530422

Integral characteristic of the erodibility of particles is the deflation unit of the material m_O, which is determined experimentally by blowing ash samples taken at the ash dump in a wind tunnel, modelling ash alluvial conditions. An empirical dependence can serve as an approximate estimate of the order of magnitude of m_O

$$m_O = c \cdot U_*^2 \cdot \left(U_*^2 - U_{*_t}^2\right), \text{ gr/m}^2\text{s}, \quad (5)$$

where is universal constant c =100; m_o=100*(0.18)^2*(0.18^2-0.17^2)=0.0037 gr/m^{2}s

There are three forms of movement of eroded dust particles under the action of an air flow: saltation (bouncing movement), in a suspended state, by continuous movement of particles along the surface (drag, rolling). The ash blown off the surface of the ash dump and carried outside it is polydisperse, includes dust particles from submicron to 500 microns (hovering, up to 40 microns in size, and gravitating, which participate in the saltation movement, up to 500 microns in size). Large particles more than 500 microns can move along the surface under the action of the frontal air flow force continuously. These particles are practically not carried outside the ash and slag field. Hovering particles follow the wind flow and disperse at a considerable distance from the ash and slag dump. The movement of a particle in a suspended state occurs when the final velocity of the particle falling (determined by the particle size, shape, density) is less than the threshold dynamic velocity for this particle.

During saltation, the air flow sets the initial lifting pulse to the particle, then the particle moves down under the influence of gravity and the force of friction against the air.

The criterion for separating the processes of solvation and suspension transfer is the ratio of the dynamic velocity U_{*t} to the rate of gravitational settling of particles V_t. The boundary size of the dust particle d_{BS} (the minimum size of the saltation particle) separating the hovering and saltation particles corresponds to the value of the complex

$$U_{*t} / V_t = 1{,}0. \qquad (6)$$

The value d_{BS} can be determined by the graph in Figure 4.

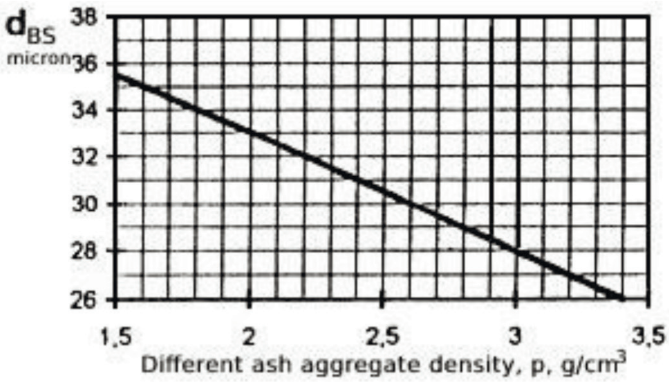

Figure 4 – The value of the boundary particle size d_{BS} at different ash aggregate density

According to the graph in Figure 4, the d_{BS} value corresponds to 26 microns.

Each value of the wind speed at the height of the weather vane U_Z corresponds to the limit (maximum) size of the eroded particle $d_{\max}$, determined from the ratio $U_* = U_{*t}$ according to the graph in Figure 5.

1 – P_{Π}=3.0 gr/cm^3, 2 – P_{Π} = = 2.65 gr/cm^3, 3 – P_{Π}=2.0 gr/cm^3

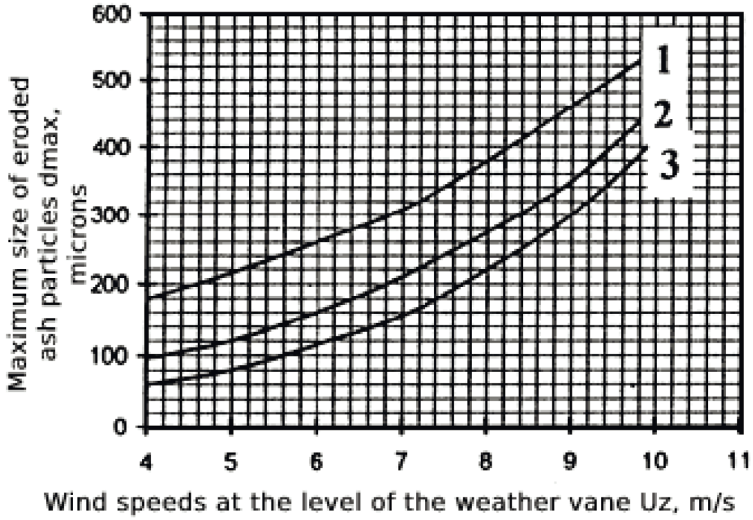

Figure 5 – The value of the maximum size of eroded ash particles at different wind speeds at the level of the weather vane

According to the graph in Figure 5, the d_{max} value is 560 microns. The height of the eroded particle h (excluding the possible impact of ascending air flows and turbulent large-scale vortex formations) is determined by the formula:

$$h = \frac{U_{eff}^2}{g} \cdot \frac{1}{a} \cdot \left[\left(1 + \frac{1}{a} \right) \cdot \mathrm{h}\,(1 + a) - 1 \right], \text{ m} \quad (7)$$

$$a = 0{,}0383 \cdot \frac{U_* \cdot U_{eff}}{\sigma \cdot d_P}, \quad (8)$$

where: U_{eff} is wind speed at the level of the dust cloud axis, taken equal to

$$0.8 \cdot U_Z. \quad (9)$$

$U_{eff} = 0.8 * 5.8\ m/s^2 = 4.64\ m/s^2$
$a = 0.0383 * (0.181 * 4.64) / 2.7 * 0.12 = = 0.099 = 0.1$
$h = (4.64)^2 / 9.8*1 / 0.1 * ((1+1/0,1) * * \ln(1+0,1)-1) = 1.06m$

Flight of the salding particle over the ash – slag field is determined by the dependence:

$$L_{\text{р}} = \frac{h}{V_t} \cdot U_{eff}\ , \text{m}. \quad (10)$$

L= 1.06 / 1.189 * 4.64 = 4.13
Dust cloud height on the dam h_0

$$h_0 = 2h \quad (11)$$

$h_0=2*1.06=2.12m$

Initial concentration of dust particles at the exit from the dam μ_0, mg/m^3

$$\mu_0 = M_{rem.} / L_{\Pi} \times h_0 \times U_{eff} \quad (12)$$

$\mu_0=146.9/4.13*2.12*4.64=146.9/40.62=3,6\ mg/m^3$

Current removal of ash particles $M^{T}_{removal}$, gr/s

$$M^{T}_{rem.} = m_0^{cur.} \times (n_{hov.} \times S + n_{salt.} \times S_{eff.} \times K_1) \times K_{2\text{-}4} \quad (13)$$

M = 0.0037*(0,28*39760+1,07*39760)*1*0,74= =(11132,8+42543,2)*(0,0037)*0,74=146,9 gr/s

Proportion of hovering and saltation particle particles in the total mass of eroded ash material ($d<d_{MAX}$)

$$n_{hov} = \sum a_{dBS\text{-}0} / (1 - a_{\geq dmax}) \quad (14)$$

$n_{hov}=\sum 0,26-0/1-(0,01)=0,28$

$$n_{salt.} = \sum a_{dBS\text{-}dmax} / (1 - a_{\geq dmax}) \quad (15)$$

$n_{salt.} = \sum(0.076+0.21+0.29+0.33+ +0.06+0.00018+0.00028)/1-0.01=1.07$

a = value of the percentage yield of the fractional composition is more/less than d_{max} (560 microns) [8].

Since the slag is not dusty, the calculations estimate the wind erosion of the storage area of the working map S_{map} = 39760m^2 (according to Figure 6).

$S_{eff}=S_{map}=39760m^2$

Figure 6 – Satellite image of a lead dump with automatic area calculation

Accounting for structural, planning and natural-climatic factors is ensured by introducing a number of correction factors K1–K4 to the calculated blow-off value. These ratios reflect:

K1 – dedusting of the dust flow due to the deposition of ash particles during the flow around the dam. K1 is taken depending on the excess of the dam crest relative to the surface level of the ash and slag field according to Figure 7;

K2 – the state of the surface layer (crust formation, aggregation of ash particles in the layer as a result of chemical interaction) depending on the content of calcium oxide in the ash:

$K_2 = 1{,}0$ at $CaO < 10\%$;

K3 – protection of the object from wind impact (influence of high-altitude relief elements, special windproof structures, forest plantations) and surface fixing of the ash beach, according to Table 5. When exposed to several security factors, the K3 coefficient is determined by multiplying the corresponding coefficients. Under the influence of several security factors, the coefficient K3 is determined by multiplying the corresponding coefficients. K4 – application of operational methods of dust suppression (irrigation of a dusty surface with water, etc.) is determined according to Table 6.

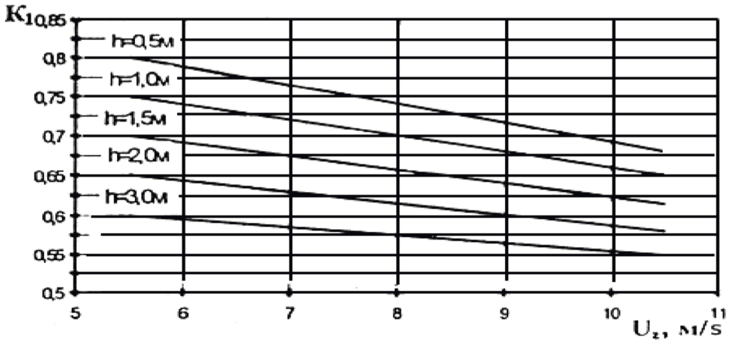

Figure 7 – Dependence of the transfer coefficient of ash particles when flowing around a dam

K1 on wind speed UZ at different heights of the dam crest above the ash beach h. The coefficient K1 according to Figure 7 and previously calculated data is 0.74.

Table 5 – The value of the correction factor K_3

Factors of protection of the dump from dusting	K_3
1. Covering the dump with high-rise relief elements: - one side - on both sides - from three sides	 0,6 0,3 0,15
2. Construction of solid barriers along the perimeter of the dump dams (lattice fences, laying of pulp pipelines along the dam crest, forest belts along the dump boundaries)	0,7
3. Relative increase in dam height downwind of prevailing winds	0,85
4. Fixing the ash beach surface with astringents (crust formation)	0,1
5. Fixing the ash beach surface with slag	0,05
6. Fixing the ash beach surface with a protective layer of cohesive soil (loam, clay)	0,02

Table 6 – Value of the correction factor K_4

Operational dust suppression method	K_4
1. Raising the water level in the clarifier pond above the level of the golden beach	0-0,2
2. Periodic irrigation of dry beaches with stationary sprinklers or irrigation machines	0,1-0,5
3. Wetting of dry beaches with clean water supplied via the backup pulp of the distribution network	0,2-0,3
4. Increased switching of releases in the warm season	0,7

Due to the absence of any protective structures around the dump, coefficients K3 and K4 are equal to 0 (Figure 8) [2].

Surface concentration of dust particles μ_x mg/m^3 at a distance x (m) from the dam:

$$\mu_x = \mu_0 \cdot e^{-ax} \tag{16}$$

Where: a – dispersion coefficient equal to $6{,}2 \cdot 10^{-3}$

x=300м (distance from dump)

x=500м (distance from dump)

x=800м (distance from dump)

μ_{x200}=3,6 mg/m^3*e$^{-6,2*0,001*300}$= =3,6*0,289=1,04 mg/m^3

μ_{x500}=3,6 mg/m^3*e$^{-6,2*0,001*500}$= =3,6*0,04=0,1 mg/m^3

μ_{x800}=3,6 mg/m^3*e$^{-6,2*0,001*800}$= =3,6*0,007=0,02 mg/m^3

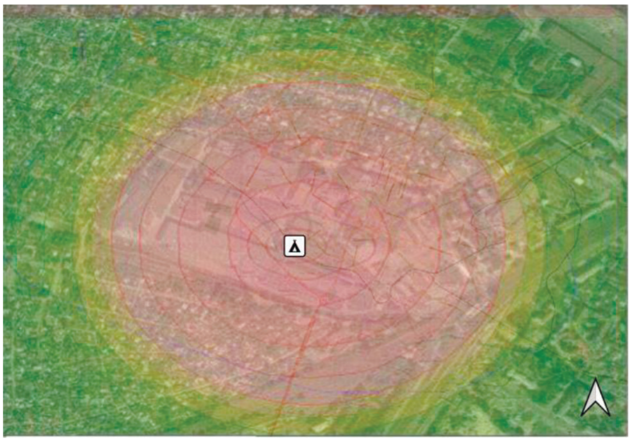

Figure 8 – Map of heavy metal dispersion

Conclusion

Analyzing the data obtained, it should be noted the importance of constructing a geoecological map based on physical modeling as a tool for further ecological and geochemical assessment of soil pollution in the studied area. In particular provides more systematic and detailed information on the dispersion of harmful substances, which in the course of further work will allow mark the most important places for soil sampling. In this aspect, study showed that the physical modeling of the horizontal migration of heavy metals is an actual area of research, since the study of the deposition of hovering particles and saltation process of heavy metals in the composition of a dust cloud is extremely rare.

Acknowledgment

The work was carried out within the framework of the project AP09259945 "Potential of sweetpotatoes (*Ipomoea batatas* L.) for phytoremediation of plumbum in contaminated areas of southern Kazakhstan", funded by the Ministry of Science and Higher Education of the Republic of Kazakhstan.

Conflict of interest

Authors of the article confirm the absence of a conflict of interest.

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