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EVALUATION OF THE INFLUENCE OF ENCAPSULATED MINERAL FERTILIZERS ON PLANT GROWTH KINETICS

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Abstract. The work investigated the effect of encapsulated mineral fertilizers on the growth and development of plants for 45 days. As a mineral fertilizer, nitroammophoska was used, which was encapsulated by a shell of different compositions: sample KD1 – a mixture of polystyrene, lignin, and carbon; sample KD2 – a mixture of polystyrene, lignin, and zeolite. The bioindication method was used to determine the effect of encapsulated mineral fertilizers on plant growth kinetics. Based on the study's results, the average rate of germination of ryegrass in the experimental samples and the average rates of the main plant parameters (stem height, root length, plant weight) were determined. It was established that the highest rate of germination was in the sample with encapsulated mineral fertilizer KD1 — 100%, and the lowest in the sample GD — 85%. The highest average indicators of measurement of the main parameters of ryegrass were in samples KD1 and KD2. The highest average indicators of measurement of the main parameters of ryegrass were in samples KD1 and KD2, and the lowest in the control sample (soil). It was established that on the 45th day, the mineral fertilizer in the KD1 sample was fully absorbed by the plants.

Keywords: encapsulated mineral fertilizer, bioindication, granular fertilizer, plant parameters, biological reclamation.

1. Introduction

Plowing of agricultural land, industrial activity, and other types of human economic activity (formation of landfills and solid waste landfills) negatively affects the state of the land and surrounding ecosystems. This problem is relevant for many countries, especially for Ukraine since thousands of hectares of land have also been negatively affected due to hostilities. To reduce the negative impact on the environment and restore the natural balance, it is necessary to use a set of measures that will restore vegetation cover and soil fertility. One of these complexes is land reclamation, namely the process of biological reclamation, which is carried out after the end of technical reclamation. According to (STC, 2005), the stage of biological reclamation lasts four years and covers such works as selection of perennial grass assortment, soil preparation, sowing, and plant care. One of the key aspects of successful reclamation is using fertilizers, which can provide plants with essential nutrients and improve soil quality (Nagursky; Malovanyy, 2016). This goal can be ensured using encapsulated mineral fertilizers, the rate of release of nutrients from which is adjustable (Synelnikov et al., 2020).

At the current stage of development of agrotechnical technologies, the problem of synthesis of mineral fertilizers, and the rate of release of nutrients from which would be regulated, is becoming more and more urgent. One of the ways to solve this

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problem can be the use of encapsulated fertilizers, since in this case the loss of soluble nutrients into the environment decreases, and the efficiency of their assimilation by plants increases. In addition, the duration of action of fertilizers increases, which is an important factor not only for agricultural technologies cultivation of crops but also technologies of biological reclamation. (Grechanik et al., 2022; Vakal et al, 2021). As it is known, most fertilizers are salts, which quickly dissolve in water during a period of large amounts of precipitation and have the property of migrating in the soil, so the root system assimilates only a part of fertilizers, of which: nitrogen compounds – 50-60%, potassium – 50-60%, phosphorous – 10-25% (Hiraga et al., 2019). Atmospheric precipitation has the greatest impact on the leaching of fertilizers from the soil environment, as a result of which the concentration of nitrates in surface and underground waters increases. This leads to an increase in the process of eutrophication of water bodies. A promising method for solving this problem can be the coating of mineral fertilizer particles with capsules (encapsulated mineral fertilizers). In such fertilizers, the capsules that cover the fertilizer granules are permeable to aqueous solutions and water, thereby extending the period of release of nutrients necessary for plant growth and development into the soil environment (Nagursky, Gumnitsky, 2012). In the vast majority, the time of release is determined by the thickness and composition of the capsule. However, in the case when the capsules are impermeable, but capable of biodegradation in the soil environment, the content of the granule is released during this biodegradation. Therefore, for this option, the release of nutrients is not regulated by the intensity of dissolution of the mineral fertilizer granule, but by the beginning of the biodegradation of the capsule (Hiraga et al., 2019; Rusyn et al., 2020).

To increase the availability of encapsulated mineral fertilizers in the process of biological reclamation, the use of polymer waste and improvement of the technology of coating fertilizer granules can be a promising method (Synelnikov et al., 2020). Polymeric waste is used in many types of industrial activities, which leads to its accumulation in large quantities in solid household waste (MSW) landfills. Therefore, using them as a material for encapsulating fertilizers, on the one hand, will ensure a competitive price and wider use of encapsulated fertilizers. On the other hand, solves the problem of plastic waste disposal, since their uncontrolled accumulation creates an environmental hazard (Nagursky et al., 2022). Considering the above, the task of this study was to determine the effect of mineral fertilizers encapsulated with polystyrene on biological reclamation agroecosystems. In particular, the influence of fertilizers on the growth and development of plants (determination of mass, stem height, and root length) was investigated.

2. Materials and Methods

The research used mineral fertilizers encapsulated in polystyrene with improved solubility, which plays a crucial role in the process of creating a film-forming composition and applying a coating to mineral fertilizer granules.

The research was conducted using dark gray podzolized soil and various types of mineral fertilizer (nitroammophoska), which were carried out according to the scheme:

- soil – control (K);
- soil + granular fertilizer (GD);
- soil + encapsulated fertilizer (polystyrene + lignin + carbon) – KD1;
- soil + encapsulated fertilizer (polystyrene + lignin + zeolite) – KD2.

To determine the effect of mineral fertilizer on the growth and development of plants, the bioindication method was used (DSTU, 2004; DSTU, 2002). For this, 10 seeds of ryegrass (*Lolium perenne*) were planted in a 100 ml container filled with soil and mineral fertilizer. During the experiment, the time of emergence of sprouts, their number per day, total germination, and the length of the stem were measured. At the end, measure the length and mass of the root, and measure the height and mass of the stem. To reduce the statistical error during data processing, the experiments were carried out in fourfold repetition.

3. Results and Discussion

The results of bioindication, namely the determination of the average rate of germination of ryegrass, in experimental samples are presented in Table 1.

The results are given in the Table 1 show that the first sprouts of ryegrass appeared on the fourth day of the experiment, while the best average germination rate was observed in the control sample (soil), which was 65%, and the lowest in the KD2 sample – 20%. As for the GD and KD1 samples, the average was lower than the control sample by 38.5 and 11.5%, respectively. However, already on the 8th day, the highest average rate of germination of ryegrass was in the control sample and the

KD1 sample, which was 100%. In contrast to the GD and KD2 samples, in which this indicator was lower by 17.5 and 32.5%, respectively. On the 10th day, in the samples of GD and KD2, the average indicator was lower than the control by 15 and 12.5%, respectively. In addition, starting from the tenth day of the experiment until its completion, the average germination rate remained constant in all samples and was: for control (K) and KD1 – 100%, for GD – 85%, for KD2 – 87.5%.

Table 1

The average rate of germination of ryegrass in the studied samples, %

Variant	***Days***						
	4	***6***	***8***	***10***	***20***	***30***	***45***
K	65	97.5	100	100	100	100	100
GD	40	82.5	82.5	85	85	85	85
KD1	57.5	95	100	100	100	100	100
KD2	20	50	67.5	87.5	87.5	87.5	87.5

Fig. 1 shows the general appearance of plants on the 10th and 45th day of the experiment.

As can be seen from Fig. 1, on the 10th and 45th day of the experiment, ryegrass stalks were larger and more branched in the control sample and the KD1 sample. This indicates that the nutrients contained in the encapsulated mineral fertilizer were released gradually, feeding them to the plant as needed.

Therefore, based on the results of determining the average germination rate, it can be concluded that the use of KD1 and KD2 mineral fertilizers has a positive effect on the germination of ryegrass, in contrast to the use of ordinary granular fertilizer.

To determine the effect of encapsulated mineral fertilizers on the growth of ryegrass during the experiment, the height of the ryegrass stem was measured, the results of which are presented in Table 2 and Fig. 2.

As can be seen from the Table 2, on the 10th day, the highest indicator was observed in the control sample and was 8.92 cm, and the lowest in the sample with encapsulated fertilizer (KD2) – 8.08 cm. On the 30th day, the highest indicator was already observed in the sample with granular fertilizer (GD) – 23.04 cm, the lowest in the sample KD2 – 19.58 cm.

Fig. 2 shows how the average stem height in the test samples changed every 5 days. Growth parameters of ryegrass on the 10th day are taken as 100 %.

On the 15th day, the average stem height changed the most in sample KD2 (Fig. 2(d)), which increased by 27.84 %, the lowest indicator was in sample KD1 (Fig. 2(c)) – 17.79 %. If we compare these data with the control sample, the KD2 sample exceeded it by 6.81%, and the KD1 sample, in turn, was smaller than the control by 3.24%. On the 20th day, as in the previous case, compared to the 10th day, the average indicator changed the most in the KD2 sample – by 51.59% for the control, this indicator changed the least by only 14.48%. On the 30th day, a sharp increase in the average stem height was observed in all samples. For example, in the KD2 sample, it increased by 136.72% compared to the 20th day, in the GD sample by 102.42%, in the sample KD1 – by 122.65%, and in the control sample (K) – by 87.22%. If we compare these data with the control sample (30th day), the KD2 sample was higher by 49.5%, the GD sample by 15.2%, and the KD1 sample by 35.43%.

Thus, the samples KD1 and KD2 had the best effect on the change in the average indicator of the height of the ryegrass stem during the experiment.

Table 3 presents the average measurements of the main parameters of ryegrass in the experimental samples at the end of the experiment (45th day).

According to the results given in the Table 3 shows graphs of changes in the average indicators of the main parameters of ryegrass in experimental samples (Fig. 3, 4). Ryegrass growth parameters in the control sample (soil) are taken as 100%.

The obtained results show that the highest average value of stem height was in sample KD2 and exceeded the control sample by 6.54%. In the samples of GD and KD1, as can be seen in Fig. 3(a), the mean was also higher than the control by 2.03% and 4.34%, respectively.

As for the roots, the highest indicator was observed in sample KD1, which exceeded the control (K) by only 1.59%, in sample KD2 the average indicator exceeded the control by 1.22%. In the sample with granular fertilizer, as in the previous cases, the average indicator was also higher than the control and was 0.73%.

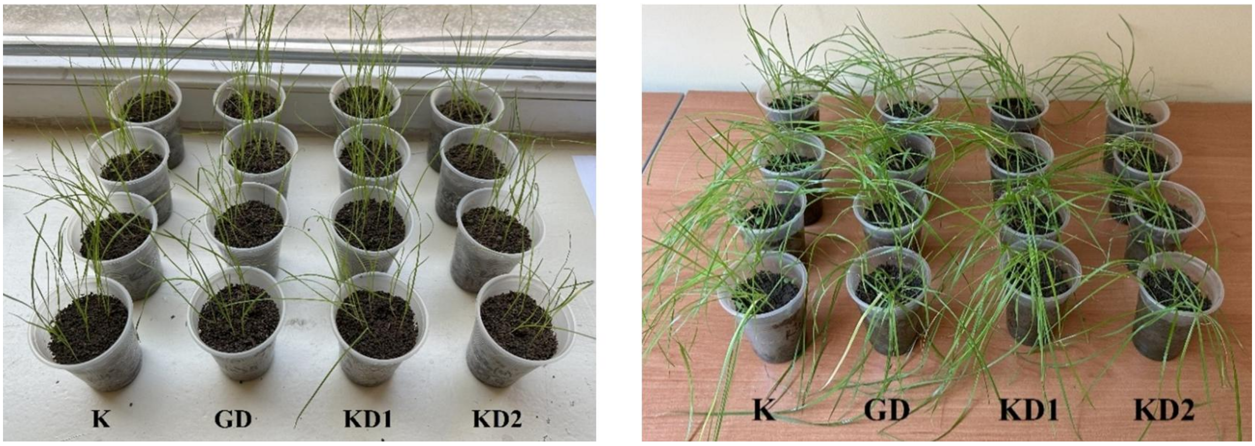

Fig. 1. General appearance of plants in the studied samples on the 10th and 45th day

Table 2

The change in the length of the ryegrass stem in the studied samples during the experiment, cm

Days	***Variant***			
	K	***GD***	***KD1***	***KD2***
10th	8.92	8.63	8.67	8.08
15th	10.79	10.88	10.21	10.33
20th	12.08	14.21	14.5	14.46
30th	21.13	23.04	25.13	25.51

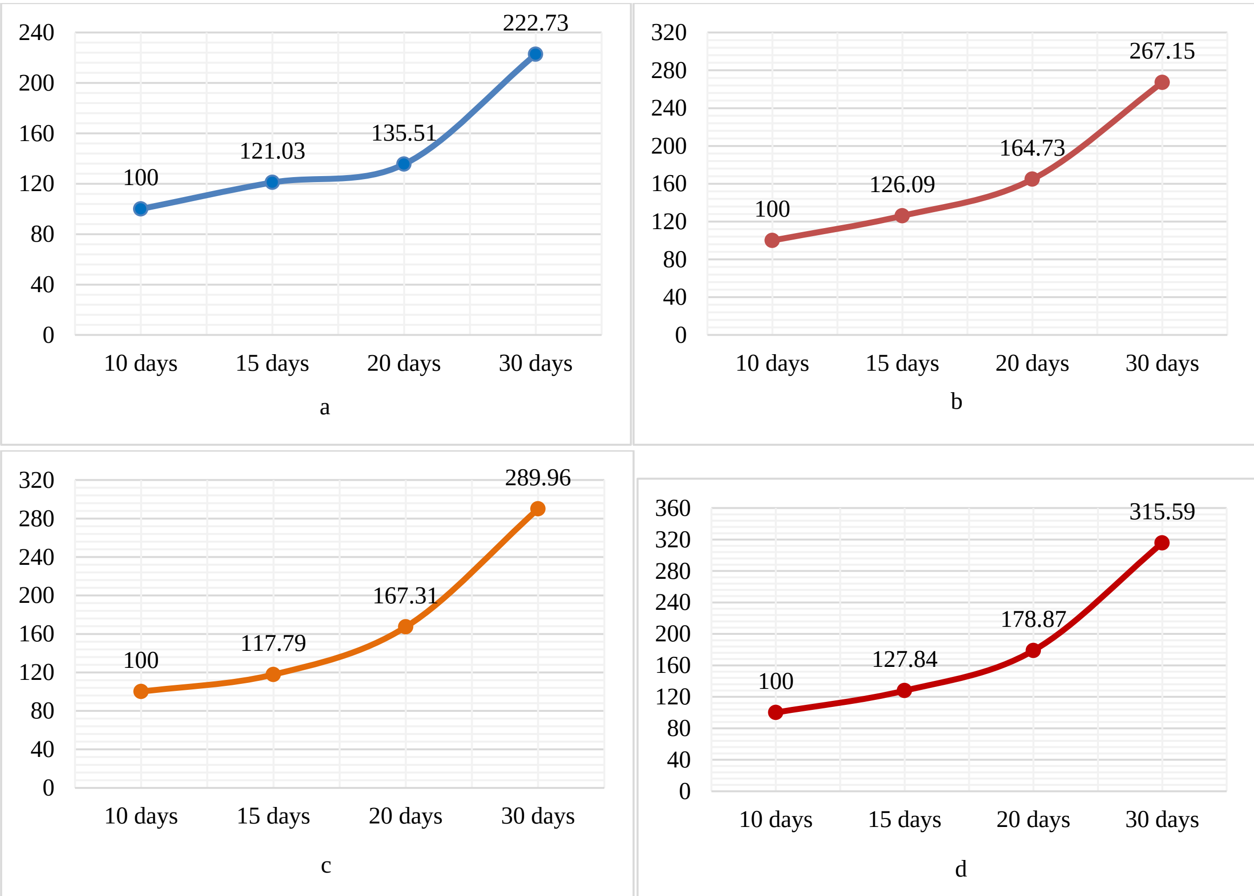

Fig. 2. Change in the average ryegrass stem height in the studied samples during the experiment, %:
a – control (K); b – GD; c – KD1; d – KD2

Table 3

Average indicators of measurement of the main parameters of ryegrass development in experimental samples

Variant	Average stem height, cm	Average root length, cm	The average weight of the plant, g	The average mass of the stem, g	Average root mass, g
K	24.63	8.19	0.516	0.45	0.066
GD	25.13	8.25	0.771	0.643	0.127
KD1	25.70	8.32	0.809	0.696	0.133
KD2	26.24	8.29	0.780	0.634	0.145

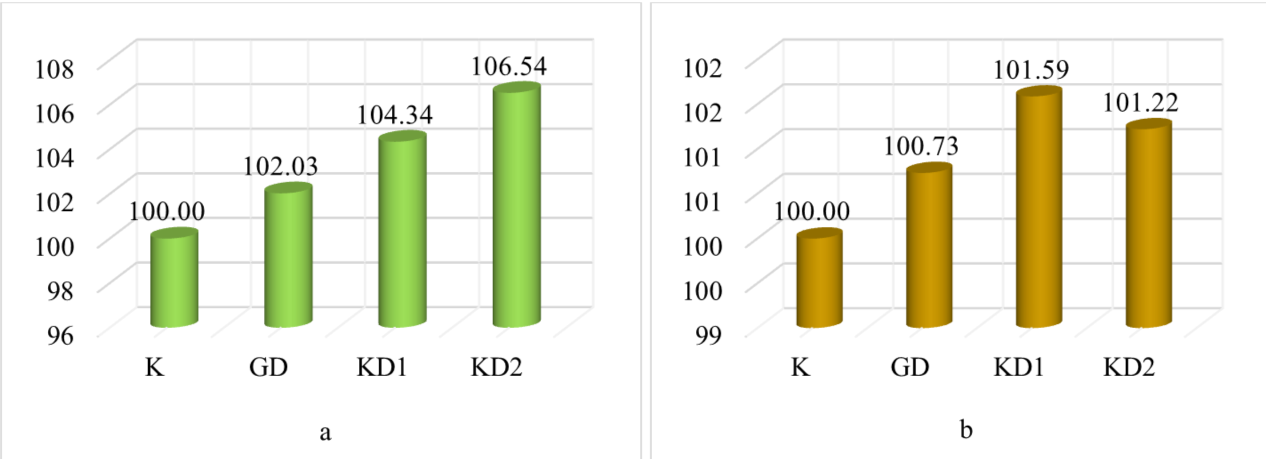

Fig. 3. Changes in growth indicators of ryegrass in experimental samples: a – stem; b – root

As can be seen, in both cases, the change in the average rate of plant stem and root growth was greater in samples with fertilizers compared to the control sample, which indicates the gradual saturation of plants with substances necessary for their growth and development.

Fig. 4 shows the change in the mass of the main plant parameters.

The average stem weight (Fig. 4(a)) in all samples with mineral fertilizer content was higher than the control. Thus, in the sample KD1, the average indicator was higher than the control by 54.67%, in the sample KD2 – by 40.89%, and in the sample GD – by 42.89%.

As in the previous case, the average value of root mass (Fig. 4(b)) was also greater than the control sample in all variants. At the same time, the highest indicator was in the KD2 sample, which was higher than the control by 119.69%, in the KD1 sample – by 101.51%, in the GD sample – by 92.42%. As you can see, when mineral fertilizers were used, the average root weight in some samples exceeded the control by more than two times.

As for the average indicator of the mass of ryegrass plants (Fig. 4(c)), the highest indicators were in samples KD1 and KD2 and were higher than the control by 56.78% and 51.16%, respectively. In the sample with granular fertilizer (GD), this indicator was also higher than the control – by 49.41%. However, if we compare it with KD1 and KD2, it was smaller by 7.36% and 1.74%, respectively.

Thus, in all three cases, sample KD1 had a positive effect on plant development. As for sample KD2, it had the best effect on the root mass of ryegrass plants.

Fig. 5 shows the appearance of the mineral fertilizer capsule in samples KD1 and KD2 on the 45th day of the experiment. As can be seen, plants absorbed nutrients from the encapsulated KD1 mineral fertilizer on the 45th day in full, as proven by the measurements of the main plant parameters, and the capsule began to decompose.

As for sample KD2, on the 45th day, there was still a significant amount of fertilizer in the capsule, i.e., the plants had not yet received all the nutrients, and the capsule itself was beginning to break down.

4. Conclusions

Therefore, the obtained results of the conducted research indicate that the use of encapsulated mineral fertilizers has a positive effect on the growth and development of plants. Thus, the highest average rate of germination was in sample KD1 – 100%, and the average indicators of the main plant parameters exceeded the control by 54.67% – when determining the weight of the stem, by 56.78% – the weight of plants, by 1.59% – the height of the stem, by 101.52% – root mass. Sample KD2, in turn, exceeded the control in terms of such parameters as average root weight (by 119.69%) and average stem height (by 6.54%). Also, according to the results of the research, it was established that on the 45th day of the experiment in sample KD1, the mineral fertilizer was fully released from the capsule, and the capsule itself began to decompose.

Thus, the use of encapsulated mineral fertilizers for biological reclamation can reduce the loss of soluble plant nutrients in the environment. It can also increase the efficiency of their absorption by plants, increase the duration of the fertilizers, and reduce the number of operations for their application. In addition, the use of biodegradable polystyrene in the process of encapsulating fertilizers can solve the problem of its accumulation in landfills.

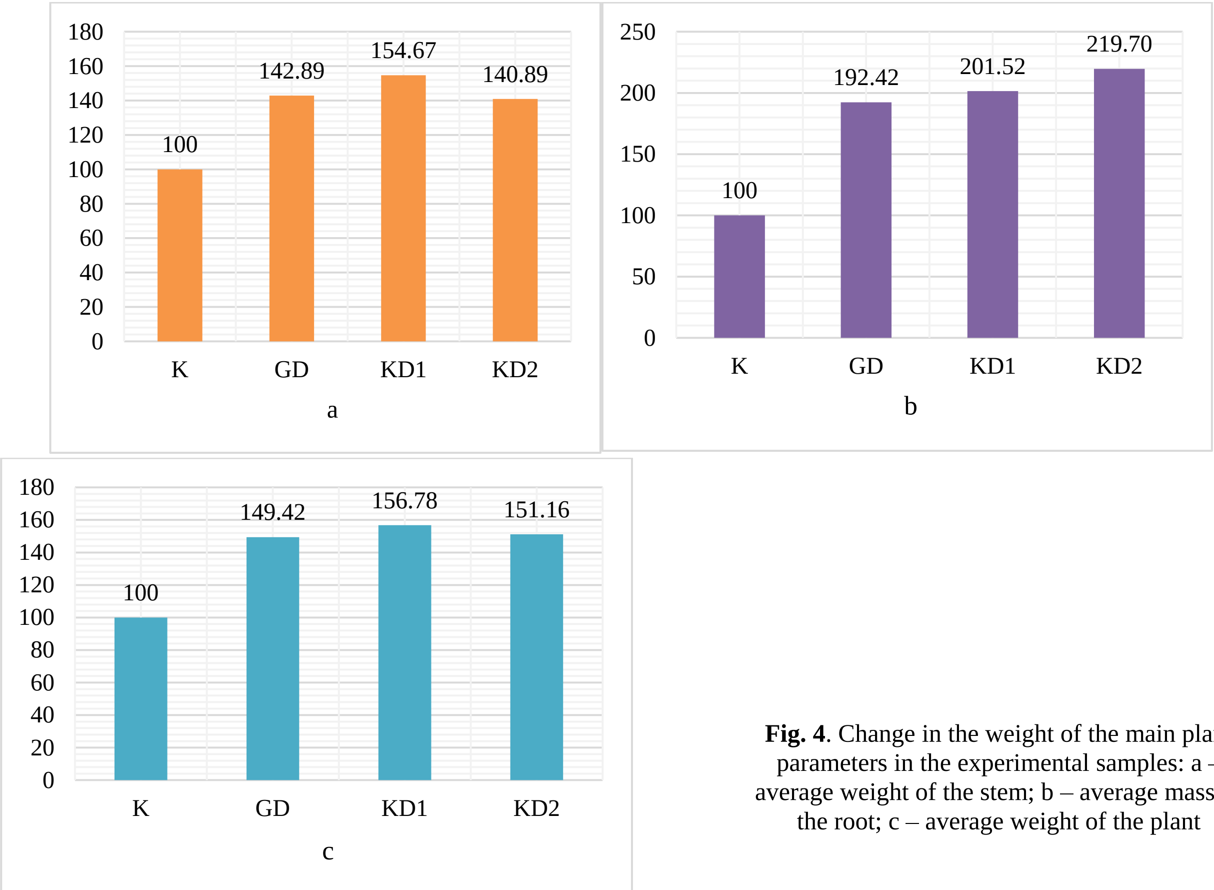

Fig. 4. Change in the weight of the main plant parameters in the experimental samples: a – average weight of the stem; b – average mass of the root; c – average weight of the plant

Fig. 5. Appearance of a mineral fertilizer capsule on the 45th day: a – KD2, b – KD1

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RESEARCH AND MODELLING KINETICS ION EXCHANGE INTERACTIONS

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Abstract. In detail, this study analysed the kinetics of ammonium ion adsorption under dynamic conditions in the "clinoptilolite -ammonium ion" system. The work includes constructing a mathematical model of this process, which allows us to estimate and predict its essential characteristics. Calculations of mass transfer coefficients revealed their dependence on the intensity of medium mixing. A significant result is that ion exchange occurs in externally diffusion and intradiffusion regions. Ion exchange rate constants were calculated for the regions of external and internal diffusion, contributing to a deeper understanding of the mechanisms of this complex process. The research results will expand our knowledge about ion exchange interactions in the " clinoptilolite -ammonium ion" system. In addition, they can be used to optimise the conditions of ammonium adsorption in similar systems, which is essential for practical applications related to water purification and other media from ammonium ions.

Keywords: wastewater, ion exchange, kinetics of adsorption, ammonium, zeolite.

1. Introduction

In modern conditions, where environmental pollution problems are becoming increasingly urgent, removing ammonium ions from wastewater is becoming necessary in many countries. Nitrogenous compounds are critical pollutants of water resources and can hurt the ecosystems of water bodies and the quality of drinking water. Various technologies are used to remove ammonium ions effectively; ion exchange methods are widely used (Wu et al., 2019). Synthetic ion exchange resins and various zeolites are considered practical materials. Special attention is paid to the possibility of using the ion exchange method for nitrogen recovery, which is essential to working with wastewater. This article is devoted to studies that reveal the potential of natural zeolites, particularly clinoptilolite, in removing ammonium ions (Muscarella et al., 2021). Considering the natural properties of these materials, their possible cost and their ecological nature, it is essential to consider them an effective and affordable resource for combating water pollution. The results of these studies can contribute to improving ammonium ion removal technologies and provide new approaches to solving water pollution problems. The main goal of this work is an in-depth study and determination of the theoretical laws governing the process of ion exchange adsorption of ammonium ions by natural zeolite. Special attention is paid to the conditions of mechanical mixing since this aspect can significantly affect the efficiency of ion exchange between zeolite and ammonium ions (de Haro Martí et al., 2020). The research aims to identify the interaction between natural zeolite and ammonium ions under the conditions of mechanical mixing, as well as reveal and formulate theoretical dependencies that determine the kinetics and efficiency of this process. Since mechanical mixing can vary in intensity, the work also aims to study these parameters' influence on the zeolite material's ion exchange properties (Lin et al., 2016).

These studies aim not only to improve our understanding of the physicochemical processes occurring during the ion-exchange absorption of ammonium by natural zeolite but also to determine the optimal conditions of mechanical mixing for the maximum efficiency of this process (Bernal, et al.,

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1993). The work results can be necessary to develop technologies for further removing ammonium ions from water environments.

2. Materials and Methods

A polyethene container with a volume of 1 dm^3 was used to study the kinetics of zeolite adsorption concerning ammonium ions. We used 0.2 dm^3 of a solution containing ammonium ions was introduced into this container. The studied solution was prepared in distilled water, with an initial ammonium concentration of 0.5 mg/dm^3, after which 5 g of zeolite was added. An installation consisting of an apparatus with a propeller-type stirrer was used to study the kinetics of ammonium adsorption. In the research process, the rotation frequency of the stirrer was adjusted in the range of 100 to 500 revolutions per minute (rpm).

The adsorption process was carried out in dynamic conditions in a stirrer. A particular rotation frequency of the stirrer was set, ensuring optimal system mixing. Samples of the solution after adsorption were analysed for the content of ammonium ions (NH_4^+) by the photometric method, using known methods (Wu et al., 2019).

It is important to note that the adsorption efficiency was determined as the change in the concentration of ammonium ions in the solution after interaction with the zeolite for a specific time. This approach allows us to establish the kinetic laws of the process and evaluate the effectiveness of zeolite as an adsorbent for removing ammonium ions under dynamic conditions.

3. Results and Discussion

The performed scientific experiments revealed that the adsorption process takes place mainly within the intradiffusion region. Type of the process was determined by finding the equilibrium of the process before reaching a constant value of the adsorption concentration of ammonium ($a\infty$)(Sabadash et al., 2020). The presentation of experimental data is illustrated in Fig. 1.

An important conclusion is that the adsorption rate reaches stability after a certain period, which indicates the completion of the intradiffusion stage of the process. The equilibrium value of ammonium adsorption concentration ($a\infty$), which was established as a result of research, can serve as a critical indicator for further analysis of adsorption efficiency based on this material.

Note that the scientific results presented in Fig. 1 determine not only the nature of the adsorption process but also indicate the possibility of optimising the experimental conditions to maximise the adsorption capacity of zeolite. Optimising the adsorption process can increase its efficiency in removing ammonium ions from solutions.

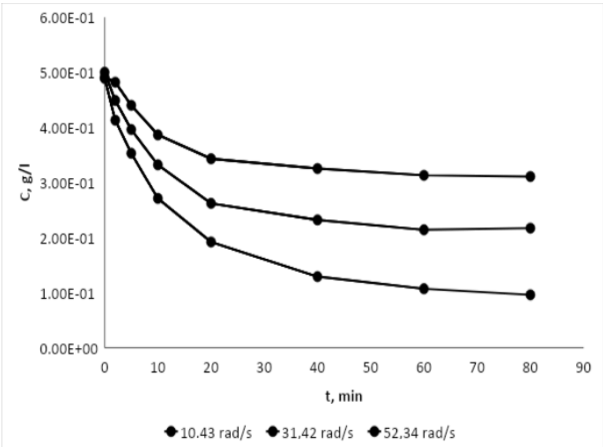

Fig.1. Kinetics of adsorption of ammonium ions of model solutions

Modelling of the adsorption process of an active component by a granular sorbent includes the analysis of non-stationary diffusion-kinetic phenomena in complex multicomponent systems. In our case, we considered the mechanisms of liquid adsorption, determining a number of stages of this process (Soudejani et al., 2019):

- Diffusion of ammonium ions to the surface of the sorbent.
- Diffusion of ammonium ions from the surface of the ion exchanger to the point of reaction.
- Ion exchange, which is accompanied by chemisorption.
- Diffusion of the exchangeable zeolite ion from the site of the reaction to the surface of the ion exchanger.
- Diffusion of the exchangeable cation of the sorbent into the solution.
- For the quantitative description of the reaction system, we use the material balance equation for ammonium ions, allowing us to consider their concentration changes at each process stage.

These stages of interaction with the sorbent can be carefully studied and optimised to increase the efficiency of ammonium adsorption and determine the optimal conditions for this process (Wang et al., 2018). The presented material balance equations are a crucial tool for quantifying the effectiveness of the studied adsorption mechanisms.

$$V_{p(NH_4^+)} \cdot C_{0(NH_4^+)} = \frac{4}{3}\pi r_0^3 \varepsilon \rho_z \overline{C}_{NH_4^+} + V_{p(NH_4^+)} \cdot C_{(NH_4^+)} . \quad (1)$$

The equation of the material balance of the ion exchange process:

$$V_{p(Kat^+)} \cdot C_{0(K^+)} = \frac{4}{3}\pi r_0^3 \varepsilon \rho_z \overline{C}_{Kat^+} + V_{p(Kat^+)} \cdot C_{(Kat^+)}, \quad (2)$$

where C_0 is the initial concentration of the corresponding cation; $\overline{C}$ is the average concentration of adsorbate in the sorbent volume; *V* is the volume of the adsorption medium; ε is the porosity of the zeolite; *ρ* is the density of the solid phase; *r* is the radius (Sabadash et al., 2018a), *t* is time.

The considered equation defines various parameters affecting the system's diffusion process of exchangeable cations. The initial concentration of the pollutant is denoted as C_0 , which is the initial amount of the substance in the solution. The average concentration of the cation in the grain reflects the concentration changes internally in the adsorbent itself. The volume of the liquid phase is denoted by *V*, and the porosity is ε, which indicates the percentage ratio of the volume of pores in the adsorbent to its total volume. The density of the sorbent is considered as ρ, and the adsorbent grain's running radius is *r*. The time of the study is denoted as t.

The process of diffusion of exchangeable cations from the solution to the ionite surface is described by the mass transfer mechanism, where the equation $j_{NH_4^+} = -D\frac{dC_{NH_4^+}}{dn}$ can determine the mass flow:

$$\frac{dM_{NH_4^+}}{dt} = -\beta F \; C_{NH_4^+} - C^0_{NH_4^+} \; , \quad (3)$$

where *β* is the mass transfer coefficient from the solution to the surface of the adsorbent, m/s; *F* is the area, m²; C_0 is the initial concentration of the corresponding cation in the solution; *C* is the average concentration of the corresponding cation in the grain (Sabadash et al., 2018b).

Table 1 shows that the value of the mass transfer coefficient β increases with an increase in the number of revolutions of the stirrer. For example, at 100 rpm, *β* equals $8.06 \cdot 10^{-5}$ m/s, and at 500 rpm, it is already $1.19 \cdot 10^{-4}$ m/s. This indicates that the mixing intensity affects the rate of diffusion of exchangeable cations in the system and may be one of the critical factors determining the mass transfer coefficient.

The mechanism of transport of the component from the solution to the site of the reaction can be determined by the equation (Sabadash et al., 2020):

$$\frac{dM_{NH_4^+}}{dt} = -\frac{D}{r}F \; \overline{C}_{NH_4^+} - C_{NH_4^+} \; , \quad (4)$$

where *C* is the concentration of ammonium in the zeolite grain; *D* is the diffusion coefficient inside the adsorbent, m²/s; *F* is the zeolite surface area, m; *r* is the running radius of adsorbent grain, m; *t* is the time, p.

Table 1

Dependence of mass transfer coefficients β on the speed of rotation of the stirrer

Rotation speed, rad/s.	Mass transfer coefficient β, $м/с$
10.43	$8.063 \cdot 10^{-5}$
31.42	$1.041 \cdot 10^{-4}$
52.34	$1.21 \cdot 10^{-4}$

The average concentration in a zeolite grain can be determined as:

$$\overline{C}_{NH_4^+} = \frac{4}{3}\frac{C_{NH_4^+} - C^0_{NH_4^+}}{2}\frac{V}{\pi r^3 \varepsilon n}, \quad (5)$$

where *V* is the pore volume of the zeolite is equal $\frac{3}{4}\pi r^3 \varepsilon$; *n* is the relative number of zeolite particles; *C* is the molar concentration (Hyvlud et al., 2019).

$$\frac{4}{3}\frac{V}{\pi r^3 \varepsilon n} = k .$$

After substituting (5) into (4), we obtain the following expression:

$$\frac{dM_{NH_4^+}}{dt} = -\frac{D}{r}F\left(k\frac{C_{NH_4^+} - C^0_{NH_4^+}}{2} - C_{NH_4^+}\right) =$$
$$= -D \cdot 4\pi d_{nop}\varepsilon \; k \; C_{NH_4^+} - C^0_{NH_4^+} \; - 2C_{NH_4^+} \; = \cdot \quad (6)$$
$$-D \cdot 4\pi d_{nop}\varepsilon \; C_{NH_4^+} \; k - 2 \; - kC^0_{NH_4^+}$$

Under the conditions of the experiment, the amount of adsorption medium significantly exceeded the amount of adsorbent. Therefore, we denote (*k−2*) as *k*, and then (6) will take the form:

$$\frac{dM_{NH_4^+}}{dt} = -4D\pi d_{nop}\varepsilon k \; C_{NH_4^+} - C^0_{NH_4^+} \; . \quad (7)$$

The resulting equation allows us to calculate the dynamics of the decrease in the concentration of the reaction mixture, taking into account the total amount of absorbed substance due to adsorption and ion exchange.

The stage of diffusion of wastewater components in the pores of the sorbent is critical in the process of adsorption of ammonium ions. During this stage, ammonium ions move deep into the sorbent, penetrating its pores, where further ion exchange and adsorption occur.

Limiting factors and parameters affecting this stage:

Porosity of the sorbent (ε): Porosity determines the volume of pores of a portion of the sorbent to its total volume. Higher porosity contributes to a larger volume of available pores for diffusion, positively affecting the diffusion rate.

Sorbent pore diameter (d): The diameter also affects the diffusion rate. Larger pores allow larger particles to penetrate deeper into the sorbent, reducing diffusion resistance.

The diffusion coefficient within the adsorbent (D) determines how fast ions can move within the sorbent material. A significant diffusion coefficient indicates a rapid diffusion process.

Sorbent grain size (r): Larger grain sizes can reduce diffusion resistance, facilitating faster penetration of ions into the sorbent.

Contact time (t): The time that wastewater components spend in contact with the sorbent affects the efficiency of diffusion and adsorption.

Positively affect the process:

High porosity and large pore diameter of the sorbent: Provide more space for the movement of ions in the pores, promoting rapid diffusion.

Large sorbent grain sizes: Reduce diffusion resistance, improving the access of ions deep into the sorbent.

High diffusion coefficient inside the adsorbent: Indicates the rapid movement of ions inside the material.

Negatively affect the process:

Low porosity and small sorbent pore diameter may limit diffusion space and reduce pore availability.

Small sorbent grain size may lead to increased diffusion resistance.

Low diffusion coefficient inside the adsorbent: Indicates the slow movement of ions inside the material.

Short contact time may limit the interaction between ammonium ions and the sorbent.

The third stage of ammonium adsorption by the ion exchange mechanism includes the actual exchange of ions between the surface of the sorbent, such as clinoptilolite, and the wastewater solution. This process of ion exchange is the crucial mechanism that leads to the retention of ammonium ions on the surface of the sorbent, replacing them with other ions that were previously on the surface of the sorbent.

The main aspects of the third stage of ammonium adsorption by the ion exchange mechanism:

Ion exchange: A sorbent like a clinoptilolite has sodium (Na^+) ions on its surface. During contact with wastewater, ammonium ions ($NH_4{}^+$) exchange with sodium ions on the surface of the sorbent. Places obtained by ammonium on the surface of the sorbent ensure its effective retention.

Selectivity: The ion exchange mechanism can be selective because different ions have different degrees of affinity for the active sites on the sorbent surface. In the case of ammonium ion exchange, the sorbent is aimed at the selective exchange of ammonium ions for sodium or other ions on its surface.

Exchange equilibrium: The ion exchange process achieves equilibrium between the amount of ammonium ions that leave the solution and the amount of other ions that join the sorbent. Various factors, such as the concentration of ions in the solution and the properties of the sorbent itself, can determine the exchange equilibrium.

Influence of parameters: Parameters such as pH of the medium, temperature and concentration of ions in the solution can affect the efficiency of ion exchange. Optimisation of these parameters allows for an increase in the efficiency of the adsorption process.

Physico-chemical properties: Properties of the sorbent itself, such as its surface charge and chemical structure, determine the possibilities of interaction with ammonium and other ions.

In general, the ion exchange mechanism is an essential step in removing ammonium ions from wastewater using sorbents, and it is represented by equation (8).

The ion exchange mechanism can be evaluated by studying the amount of exchangeable cations Kat + that leave the solution from the zeolite volume. Since we are dealing with a second-order reaction, the rate of ion exchange can be described by the following equation:

$$NH_4{}^+ + Kat(zeolite) \rightarrow Kat^+ + NH_4(zeolite), \quad (8)$$

where Kat^+ represents exchangeable cations on the zeolite's surface.

The speed of this reaction depends on the concentration of exchange cations Kat^+ and the speed of the exchange reaction. In the case of a second-order reaction, the rate (v) can be determined by the equation:

$$-\frac{dC}{dt} = kC_{NH_4^+}C_{Kat^+}\,, \qquad (9)$$

where k is the reaction rate coefficient.

However, for a more accurate assessment of the mechanism of ion exchange, experiments should be conducted. The influence of other factors, such as temperature, pH of the medium, and other parameters that may affect the nature of ion exchange in the system, should be taken into account.

During the ion exchange process lasting t, x moles reacted NH_4^+ and x moles of exchangeable cations Kat^+ were desorbed.

$$C_{NH_4^+} = \frac{m^0_{NH_4^+} - x}{V}\,;\, C_{K^+} = \frac{m^0_{z-Kat^+} - x}{V}$$

optimising the experimental conditions; →

$$\frac{dx}{dt} = k\;\; m^0_{NH_4^+} - x \;\cdot\; m^0_{z-Kat^+} - x$$

$$kdt = \frac{dx}{m^0_{z-Kat^+} - x \quad m^0_{NH_4^+} - x}\,. \qquad (10)$$

The solution of this problem is represented by equation (11):

$$k = \frac{1}{t\;\; m^0_{NH_4^+} - x \;\cdot\; m^0_{z-Kat^+} - x} \times \ln\frac{m^0_{z-Kat^+}\;\; m^0_{NH_4^+} - x \;\cdot}{m^0_{NH_4^+}\;\; m^0_{z-Kat^+} - x}\,. \qquad (11)$$

The result of logarithmic solving of (11) is represented by equation (12):

$$\ln\frac{m^0_{z-Kat^+}\;\; m^0_{NH_4^+} - x \;\cdot}{m^0_{NH_4^+}\;\; m^0_{z-Kat^+} - x} \times \;\; \times\;\; m^0_{NH_4^+} - x \;\cdot\; m^0_{z-Kat^+} - x \;= kt\,, \qquad (12)$$

where $x \equiv m_{Kat^+} \equiv a^*_{NH_4^+ обм} \cdot m_{ads} -\; a^*_{NH_4^+ обм} \cdot m_{ads}$ is the amount of ammonium that entered the reaction as a result of ion exchange, mg- equiv / g.ads m_{ads} is the mass of adsorbent.

Let us enter the notation:

$$\ln\frac{m^0_{z-Kat^+}\;\; m^0_{NH_4^+} - x \;\cdot}{m^0_{NH_4^+}\;\; m^0_{z-Kat^+} - x} \times \;\; \times\;\; m^0_{NH_4^+} - x \;\cdot\; m^0_{z-Kat^+} - x \;= A_{обм}\,.$$

We get the reaction rate equation in the classical form:

$$A_{обм==} = kt\,. \qquad (13)$$

However, the objective process of adsorption of ammonium ions in dynamic conditions is more complicated since it includes ion exchange and can also occur in external and internal diffusion regions. This equation indicates that the interaction between ammonium ions and the sorbent has various mechanisms and can be determined by various factors affecting the adsorption process in different system parts. Suppose the concentration of ammonium (a*) is expressed in terms of the mass of the absorbed ammonium ion at the moment (t). In that case, the calculated dependence will not pass through 0 because part of the ammonium can be absorbed due to physical adsorption. Therefore, we introduce into equation (13) a correction factor that takes into account the contribution of physical adsorption to the process:

$$a^* = M/m \cdot (1 + b_0),$$

where m is the mass of the absorbed ammonium ion; M is the mass of the sorbent, and b_0 is the correction factor that considers physical adsorption.

This correction factor considers the contribution of physical adsorption and allows us to model the adsorption process correctly in dynamic conditions, avoiding systematic calculation errors.

$$A_{обм==} = kt + b_0\,. \qquad (14)$$

Coefficient b_0 considers the adsorbate mass absorbed by the physical adsorption mechanism. Relative to the line plotted for adsorption in the intradiffusive region, this value reflects the amount of adsorbate and exchangeable cations involved in the first stage of the process.

After constructing equation (14) as a graph, we obtained a graphical interpretation of the experimental adsorption data, presented in Fig. 2. This graph shows the dependence of adsorbate concentration on time. It determines the influence of various physical adsorption and adsorption mechanisms in the intradiffusion region.

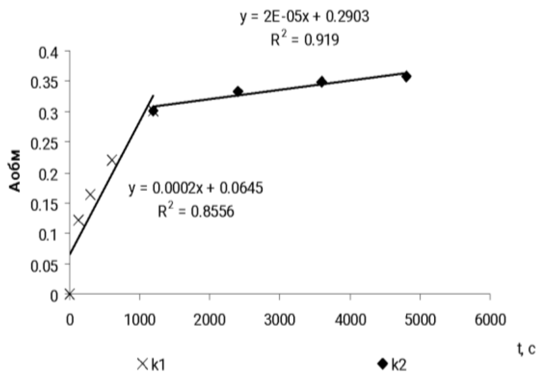

Fig.2. Interpretation of the I and II stages of ammonium adsorption under stirring conditions for n=52.34 rad/s

Graphical interpretation is an essential tool for determining the dynamics of adsorption processes and confirming theoretical models. It provides an opportunity to evaluate the role of various mechanisms and make adjustments to optimise the parameters of the adsorption system.

In Fig. 2, the external and internal diffusion areas were graphically highlighted. The rate constants for these processes were calculated. The angular coefficient of the obtained curves corresponded to the reaction rate constant. However, none of the lines passed through the starting point (0,0) because the amount of the component that was already adsorbed from the solution at the time of the measurements was not considered. For the first stage of the process, which characterises adsorption on the outer surface of the sorbent, the rate constant was $k_1 = 2.4 \cdot 10^{-4}\ M^{-1} \cdot s^{-1}$. At the second (intradiffusion) stage of the process, the ion exchange rate constant was equal to $k_2 = 2.1 \cdot 10^{-5}\ M^{-1} \cdot s^{-1}$

4. Conclusions

In this study, we presented the results of an experiment that studied the kinetics of adsorption of ammonium ions by natural zeolite under mechanical stirring conditions using an apparatus with a stirrer. Based on the analysis of the obtained data, it was found that the adsorption process can be divided into two main stages: external and internal diffusion regions. A detailed examination of the experimental results allows us to establish that the interaction of ammonium ions with zeolite takes place in two different areas. The calculations of the rate constants of chemical reactions indicate that in the internal diffusion region, the ion exchange rate decreases by an order of magnitude compared to the external diffusion region. Thus, an important conclusion is that implementing the adsorption process in dynamic conditions is appropriate for external diffusion. In addition, it is determined that the adsorption process should be at most 20 minutes to ensure the practical nature of the ion exchange and provide optimal conditions for the reaction to proceed. These results are of practical importance for developing optimal conditions and regulating ammonium ion adsorption processes from wastewater.

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ASSESSMENT OF FOREST VEGETATION POTENTIAL OF RECLAIMED AREAS AFTER ILMENITE MINING USING THE REMOTE EARTH SENSING METHOD

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Abstract. The mining of ilmenite has irreversible negative environmental impacts on the ecosystem of the area where mining companies operate. First of all, it leads to disturbance of the soil and vegetation layer, changes in the natural landscape, formation of depression sinkholes, which causes changes in water flow and water distribution in the mining area, lowering of groundwater levels, pollution of the atmosphere, soil and water bodies, and loss of species diversity of flora and fauna. In general, the mining process lasts for decades, during which time the territory is subject to irreversible changes and disturbances and requires high-quality restoration after the completion of ilmenite mining. The article suggests a methodology for assessing the forest vegetation potential of soils in areas disturbed by ilmenite mining using remote earth sensing (RES). Based on satellite images and spectral characteristics, we determined the parameters of soil type and moisture, as well as the vegetation and moisture index of the forest vegetation layer The results of the remote earth sensing were compared with the results of laboratory analyzes of soil samples from the territory operated by the branch of the Irshansk Mining and Processing Plant of PJSC UMCC. Normalized Difference Vegetation Index, Normalized Difference Moisture Index, soil type and moisture were calculated and identified using QGIS software from data obtained from free-access satellite images. The results showed that a combination of laboratory and remote sensing methods can be quite effective for studying areas disturbed by mining activities and the state of their recovery after reclamation.

Keywords: RES, soil type, moisture, NDVI, NDMI.

1. Introduction

Reclamation of territories after mining activities is of great importance for restoring the balance of ecological systems. At present, there is a problem of environmental restoration in the mining sites, especially in the area of soil reclamation and vegetation restoration (Shao et al., 2023). The main goal of reforestation of the research plots is to return the areas to a productive capacity to interact with the ecosystem, which will function to provide a variety of economic and environmental values (Macdonald et al., 2015).

Given the state of the war in Ukraine, mastering the methods of remote sensing of various territories and objects, the ability to monitor the state of the environment and analyze the impact of important factors on individual ecosystems from a distance, is extremely relevant. The aggression of the Russian Federation has made irreparable alterations to the development of scientific research of the territories of Ukraine. Large-scale destruction, ruined cities, agricultural fields, protected territories and large productive areas of Ukraine in general, landmined forests and fertile lands – these terrible consequences make it impossible to conduct quality field research and monitoring of the territories (Dmytruk, 2023).

The analysis of the effectiveness of remote earth sensing methods will allow to improve the quality of methods for restoring disturbed areas in the future, including assessment of the state of ecosystems before conducting field studies, and predicting the possibility of using various methods of reclamation and restoration of territories, which will be a crucial stage in the development and reconstruction of the territories of Ukraine (Furdychko et al., 2019).

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The purpose of the article is to study the forest vegetation potential of soils of areas disturbed by mining activities using of the remote earth sensing method.

2. Experimental part

For this study, we have chosen the operating territory of the branch of the Irshansk Mining and Processing Plant of PJSC UMCC near the villages of Irshansk, Lisivshchyna and Desiatyny, Korosten district, Zhytomyr region. The moisture content and particle size distribution of soils in the reclaimed areas of ilmenite mining were studied using the following methods (Shomko, Davydova, 2022):

1. Cluster sampling by the envelope method according to State Standards of Ukraine DSTU 4287:2004 and DSTU ISO 10381-2:2004.

2. Measurement of soil moisture by weight method in accordance with DSTU Б В.2.1-17:2009.

3. Determination of particle size distribution by the wet method.

4. Determination of particle size distribution by the sieve method.

The source of satellite images of the study area was Landsat 8 (Roy, 2016) from the USGS platform. They have several ranges depending on the wavelength (blue, green, red, infrared, thermal, and panchromatic). Panchromatic range is used to increase data resolution. Landsat 8 data has 11 bands, only three (Red, NIR, SWIR) are used for NDVI and NDMI analysis. The Landsat 8 data bands, wavelengths and their resolution are shown in Table 1

Table 1

Landsat 8 data bands by resolution and wavelength

Landsat-8 OLI and TIRS Band (μm)		
Band 1	30 m Coastal/Aerosol	0.435-0.451
Band 2	30 m Blue	0.452-0.512
Band 3	30 m Green	0.533-0.590
Band 4	30 m Red	0.636-0.673
Band 5	30 m NIR	0.851-0.879
Band 6	30 m SWIR-1	1.566-1.651
Band 7	30 m SWIR-2	2.107-2.294
Band 8	15 m Pan	0.503-0.676
Band 9	30 m Cirrus	1.363-1.384
Band 10	100 m TIR-1	10.60-11.19
Band 11	100 m TIR-2	11.50-12.51

Normalized Difference Vegetation Index (NDVI) is a simple quantitative indicator that reflects the amount of photosynthetically active biomass, determining the level of green vegetation. The use of NDVI is widely applied for regional mapping and analysis of various landscapes, assessment of resources and areas of biosystems. Typically, the calculation of NDVI requires a series of multi-temporal images, which allows obtaining a dynamic picture of the processes of changing boundaries and characteristics of different vegetation types, such as monthly, seasonal and annual variations. One of the advantages of the NDVI is the clear color gradation of the index and the availability of this tool for free use. NDVI is calculated by the formula (1) (Kshetri, 2018):

$$\text{NDVI} = \frac{NIR - Red}{NIR + Red}, \qquad (1)$$

where *NIR* is the Near-Infrared (band 5); *RED* is the Red Light (band 4).

Normalized Difference Moisture Index (NDMI) is a commonly used indicator of water stress in plants, as it reflects the moisture level of the vegetation. It is used to determine the moisture content of vegetation and is calculated as the ratio between the values in the near infrared (NIR) and shortwave infrared (SWIR) ranges. The formula for NDMI is as follows (2) (Lastovicka, 2020):

$$\text{NDMI} = \frac{NIR - SWIR}{NIR + SWIR}, \qquad (2)$$

where *NIR* is the Near-Infrared (band 5); *SWIR* is the Short-Wavelength Infrared (band 6).

The soil type of the study areas was identified in the QGIS 3.28 Firenze program based on the FAO Digital Soil Map of the World (DSMW), as recommended by the International Union of Soil Scientists (IUSS). The vector dataset is based on the FAO-UNESCO Soil Map of the World. The digitized world soil map at a scale of 1:5,000,000 in geographic projection (latitude-longitude) intersects with a template containing water-related objects (coastlines, lakes, glaciers, and rivers with a double line). The digital map of the world soils (excluding the African continent) was overlaid on a map of country boundaries from the World Data Bank II (with country boundaries updated to January 1994 at a scale of 1:3,000,000) obtained from the US government (FAO).

Soil moisture in the study area was determined in QGIS software using the JAXA Earth API plug-in (Sobue et al.) The JAXA Earth API software component is designed to provide various types of data from JAXA Earth observation satellites in a user-friendly format that facilitates efficient and rational use. One of the important features of the API is its integration with QGIS, popular free GIS software. The API includes an interface function that allows users to directly receive and display satellite data in QGIS.

3. Results and Discussion

According to the results of the study of the territory using remote earth sensing method, 2 types of soils were identified within the Korosten district by the classification of World Reference Base (WRB): Podzoluisols eutriques (De) та Luvisols gleyiques (Lg) (Fig. 1).

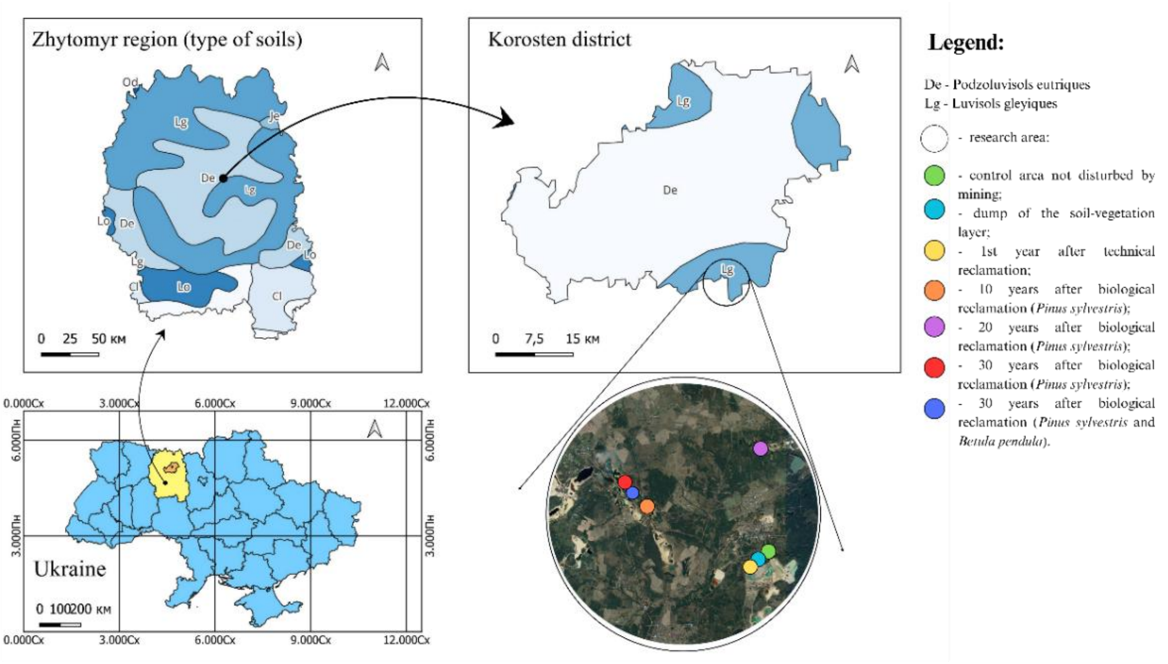

Fig 1. Soil cover of the study area according to the World Reference Base for Soil Resources (WRB) classification

According to the description of the reference groups, the WRB classification (2014), luvisols are soils that have a higher clay content in the subsoil compared to the topsoil as a result of pedogenesis processes (especially clay migration) that led to the formation of the argic subsoil horizon (Ivanuk, 2017). Gleyic Luvisols and Albic Luvisols of the WRB classification according to the Canadian soil classification (Lavkulich et al, 2011; The Canadian system) correspond to Gray Luvisols.

In publications devoted to the study of gray forest soils in Ukraine, authors use different nomenclature (Pankiv, 2017). Taking into account the hypotheses of the origin of gray forest soils and their properties, the names of these soils are quite reasonable: light gray forest, gray forest, dark gray podzolic soil. The following approximate equivalents of the WRB (2014) nomenclature were proposed for the subtypes of gray forest soils of the Ukrainian classification: light gray forest – Albic Luvisols, gray forest – Haplic Luvisols, dark gray podzolic – Luvic Greyzemic Phaeozems. The names of the gleyed analogs of these soils are preceded by the qualifier "Gleyic" (Ivanuk, 2017).

Given that the study area is located in the Zhytomyr Polissia region, which is known for its wetlands and forests, soils with gley properties are not uncommon in this region. The combination of luvisols and gley features (Luvisols gleyiques) indicates that these soils can have characteristics of both well-drained and poorly drained soils, reflecting the diversity of natural conditions found in Polissia (Pankiv, 2017; Ivanuk, 2017).

The soil moisture of the study area was identified in August 2021, during the period of sampling and soil moisture research by the laboratory method (Fig. 2). JAXA publishes data on soil moisture content around the earth's surface, etc., observed by the Global Change Observation Mission – Water "SHIZUKU" (GCOM-W). The data shows the state of preservation of moisture that has fallen as rain or the state of drying of the soil.

According to the results of this identification, the soil moisture content of the research area ranged from 7.88% to 8.26% during August 2021. The comparative characteristics of soil type and moisture content in the study area using the two research methods are shown in Table 2.

Thus, the common aspect of the two methods is the confirmation of the presence of Luvisols gleyiques (Lg) in the tested soils and the coincidence in the moisture content of the reclaimed areas. The measured soil moisture has close average values according to the remote sensing data and laboratory studies (8.07% and 8.51%, respectively).

The difference is that laboratory tests allow for more detailed results, including the identification of specific types of sand and sandy loam, and also indicate the moisture dynamics for different samples of the study area. Given the impact of mining activities in the study area, the difference in soil types between those identified by RES method and laboratory tests is understandable. This is because the digitized map of soil types had been created for 20 years using the outdated WRB database at a time when ilmenite mining activities in the Korosten district were just beginning to develop. Therefore, it is necessary to improve the identification of soil types by RES method using a modern database, which will be investigated in the process of studying the forest vegetation potential of soils of reclaimed areas after ilmenite mining.

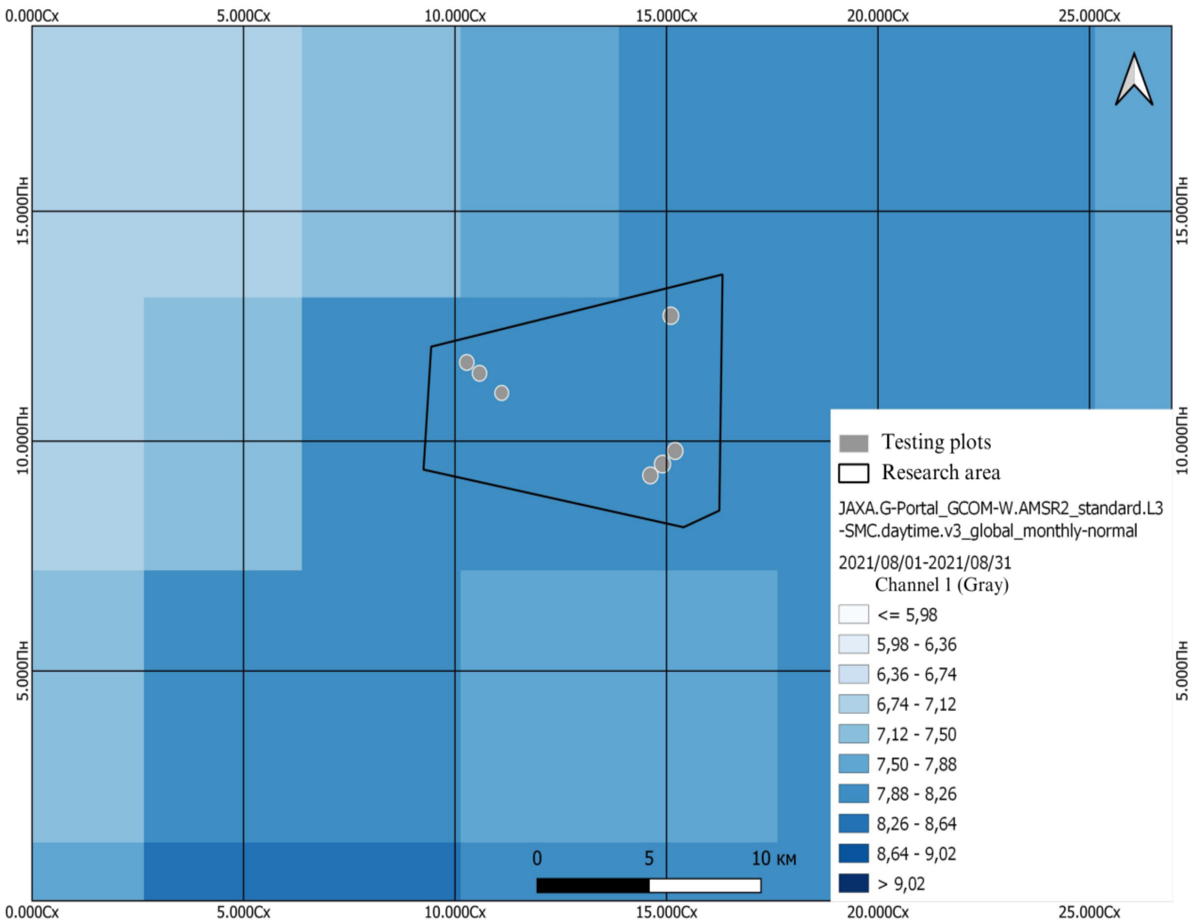

Fig. 2. Soil moisture content of the study area according to the JAXA Earth API software component

Table 2

Characterization of reclaimed areas after ilmenite mining based on remote earth sensing and laboratory studies

Number	Reclamated areas	Remote sensing data		Laboratory testing of soil samples	
		Soil type	Moisture content, %	Soil type	Moisture content, %
1	Control plot	Luvisols gleyiques (Lg)	7.88 – 8.26	Sandy-loamy sandy (heavy sands)	5
2	Dump of the soil and vegetation layer	Luvisols gleyiques (Lg)	7.88 – 8.26	Silty-loamy sandy (light loamy sands)	5
3	1-st year after technical reclamation	Luvisols gleyiques (Lg)	7.88 – 8.26	Sandy-loamy sandy (light loamy sands)	11
4	10 years after biological reclamation (*Pinus sylvestris*)	Luvisols gleyiques (Lg)	7.88 – 8.26	Silty-loamy sandy (sands)	5
5	20 years after biological reclamation (*Pinus sylvestris*)	Luvisols gleyiques (Lg)	7.88 – 8.26	Sandy-loamy sandy (light clay loam)	5
6	30 years after biological reclamation (*Pinus sylvestris*)	Luvisols gleyiques (Lg)	7.88 – 8.26	Sandy-loamy sandy (sands)	11
7	30 years after biological reclamation (*Pinus sylvestris* and *Betula pendula*)	Luvisols gleyiques (Lg)	7.88 – 8.26	Silty-loamy sandy (sands)	17.6

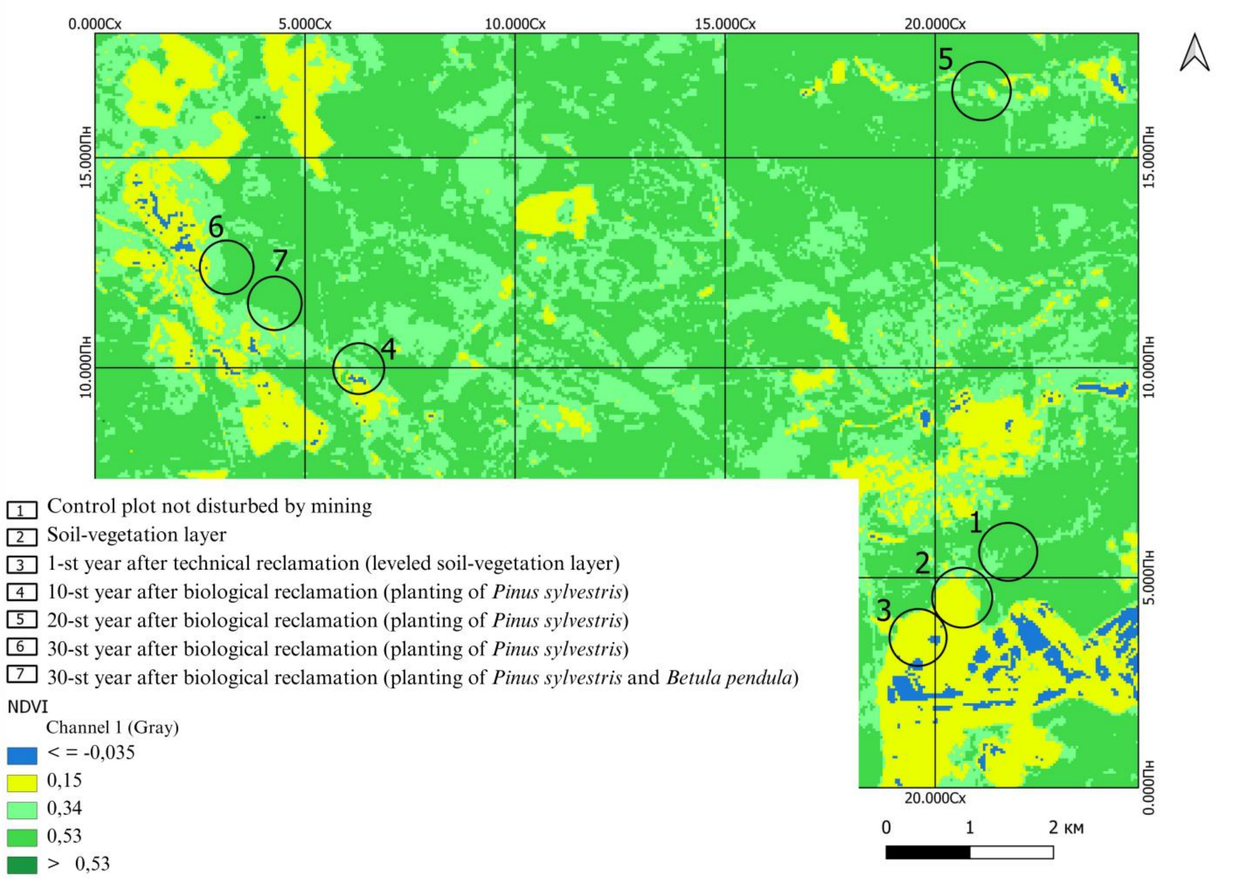

Fig. 3. Normalized Difference Vegetati

NDVI and NDMI are important indicators of the development of the forest vegetation layer of reclaimed areas, and the results of these indices of the research area are shown in Fig. 3 and 4, respectively.

The NDVI value can range from -1 to +1. A value close to +1 indicates a high activity of the forest vegetation layer, where open green vegetation reflects light well in the infrared and red spectrum. A value close to -1 may indicate water bodies or other non-vegetated areas where light is poorly reflected in the infrared spectrum. A value around 0 may indicate that there is no vegetation or that the plants are not showing vegetative activity. Thus, the most greened areas according to Landsat 8 satellite images in August 2021 were the control plot and the areas 20 and 30 years after biological reclamation. Typically, an NDVI value of 0.2 to 0.5 indicates the presence of scattered or sparse vegetation.

NDMI also varies from -1 to +1. A value close to +1 indicates a high level of moisture in the forest vegetation layer, which may indicate the presence of moisture. A value close to -1 indicates no moisture, or low moisture in the forest vegetation layer and the environment. The NDMI value indicates a low to moderate level of soil moisture in the study area. The control plot and the areas after 20 years of biological reclamation and 30 years (planting of *Pinus sylvestris* and *Betula pendula*) are the wettest of the 7 tested areas.

4. Conclusions

The article outlines the results of study the forest vegetation potential of soils of areas disturbed by mining activities using of the remote earth sensing method. Based on satellite images and spectral characteristics, we determined the parameters of soil type and moisture, as well as the vegetation and moisture index of the forest vegetation layer (Normalized Difference Vegetation Index (NDVI) and Normalized Difference Moisture Index (NDMI), respectively). According to the results of the study of the territory, 2 types of soils were identified by the classification of World Reference Base (WRB): Podzoluisols eutriques (De) та Luvisols gleyiques (Lg). The soil moisture content of the research area ranged from 7.88% to 8.26%.

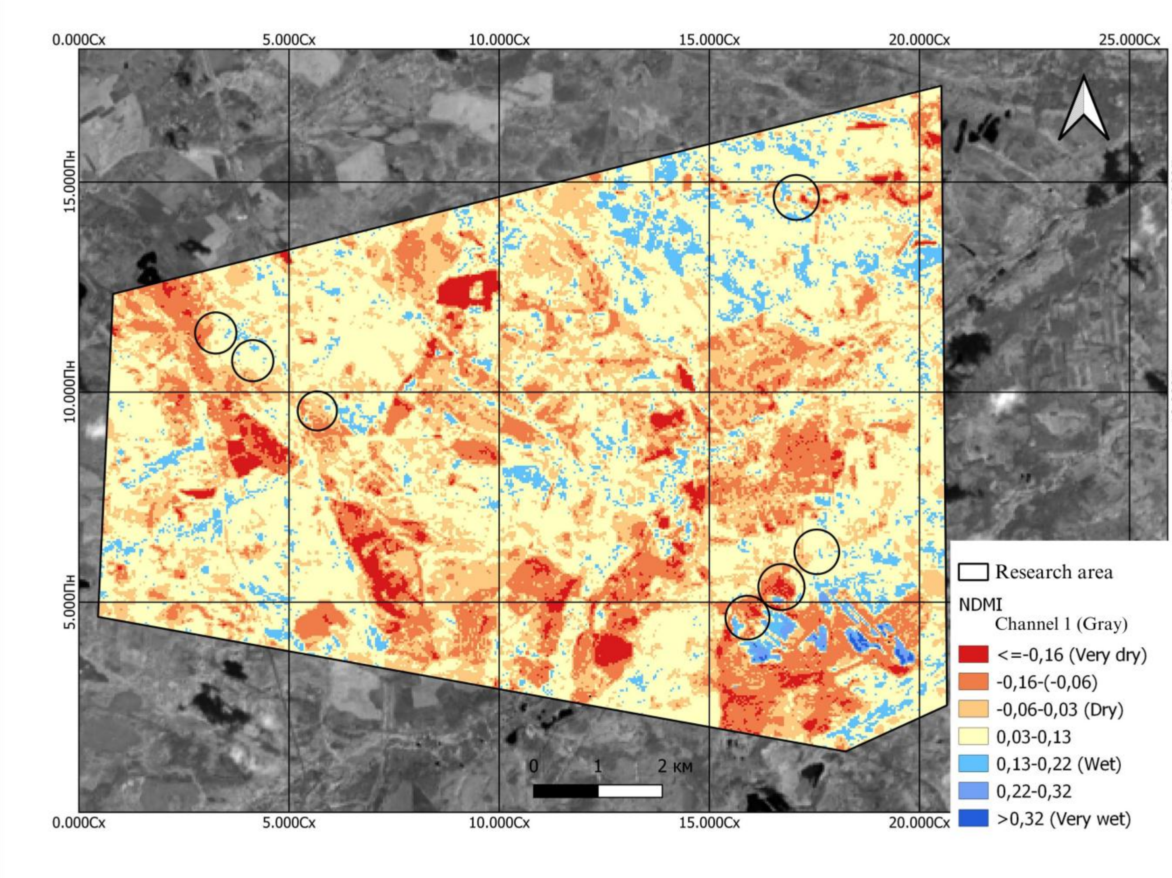

Fig. 4. Normalized Difference Moisture Index (NDMI) of the forest vegetation layer in the research area

The results of the remote earth sensing were compared with the results of laboratory analyzes of soil samples. In general, both methods complement each other. Remote sensing can provide a broader overview, and laboratory tests can provide detailed information on individual indicators. Remote sensing data is the primary source for analyzing environmental processes on a local and global scale. This data is used to identify changes over the past decades. Remote sensing data (such as Landsat, Sentinel, Spot image, etc.) is very useful for visualizing, classifying, and analyzing terrain. This data can be categorized by resolution, electromagnetic spectrum, energy source, image carrier, and number of bands. The higher the resolution of the satellite data (spatial, spectral, radiometric, temporal), the higher the degree of accuracy will be achieved during the survey.

The idea of combining remote and laboratory research of territories is relevant and effective in terms of studying ecological systems and dynamic changes that result from anthropogenic disturbances in this case.

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ENVIRONMENTAL PROBLEMS

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EDUCATION IN THE FIELD OF CLIMATE CHANGE ADAPTATION AS AN INTEGRAL PART OF ACHIEVING SUSTAINABLE DEVELOPMENT GOALS

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Abstract. Every year, the problem of globalisation of environmental challenges is becoming more and more noticeable, with climate change taking priority place among them. The lack of a sufficient number of climate-related disciplines in Ukrainian educational institutions limits the number of environmental experts who will be able to effectively implement climate change adaptation measures and implement the world's best practices in reducing greenhouse gas emissions through decarbonisation of energy, implementation of energy-saving equipment and transition from fossil fuels to renewable energy sources. It has been determined that in recent decades the number of scientific publications focused on the development of educational processes in the context of climate change has increased rapidly. It has been found that the main directions of implementing climate education in educational institutions are to provide quality school education to rethink the priorities of an environmentally friendly lifestyle and to form highly qualified specialists at universities who will be able to implement climate change adaptation projects in various sectors of the economy after obtaining a quality and holistic education at universities.

Keywords: education, students-ecologists, climate change, adaptation, mitigation.

1. Introduction

The challenges we are facing today make the problem of climate change and the consequences that result from it very acute. Insufficient understanding of the problem and ignoring the impending threat leads to a loss of time and the opportunity to implement projects that will reduce the rate of climate change, mitigate the impacts and adapt society to climate change within the framework of sustainable development (IPCC, 2021). At the same time, sustainable development of society involves the synergy of society, ecology and economy, which cannot be achieved without proper education and a deep understanding of the processes taking place in the environment. The harmonious and mutually beneficial combination of all three components of modern society is the key to preserving life and ensuring the well-being of humanity for future generations (UNESCO, 2017). Therefore, an essential stage in ensuring high-quality of education is to raise awareness of the sustainable development goals and the importance of their proper implementation, which is a prerequisite for understanding the responsibility for the future of all categories of the population without exception (Fuso Nerini et al., 2019, Liu et al., 2021). Realizing that future generations will play a crucial role in the economy of the 21st century, Ukraine, like the European Union, focuses on raising awareness of this issue among a wide range of pupils, students and society. Indeed, currently, the main problem in implementing many energy-saving, climate or environmental projects is not only the lack of a sufficient number of qualified employees, but also the inadequate level of public support. Particular attention should be paid to sustainable development issues and to broadening the awareness of people, from

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secondary school students to qualified professionals and ordinary citizens, to determine the right priorities for further development. Starting from primary education, children should be aware of the main environmental, social, cultural and economic impacts of climate change at all levels, about prevention, mitigation and adaptation strategies at different levels, and be able to identify their individual environmental impact. Gaining such basic knowledge about climate change in schools can increase the number of informed people who will implement and promote the use of environmentally friendly technologies and reduce greenhouse gas emissions (Dawson et al., 2022, Cordero et al., 2020).

A detailed assessment of the environment and climate change in Ukraine is reflected in the European Commission's 2023 Country Report on Ukraine (Ukraine report 2023, 2023) The European Commission noted a "certain" level of "readiness" of Ukraine in the environmental and climate sectors, highlighting "good" progress on environmental issues (adoption of horizontal legislation, water quality, waste management, chemicals and noise legislation) and limited progress on climate issues.

The Report's significance lies in the fact that the European Commission has identified key reforms in this sector that are expected from Ukraine in 2024:

✓ Cross-cutting reforms:

– ensure cross-sectoral integration of environmental and climate measures into the country's reconstruction plans;

– define green reconstruction strategies for key sectors of the economy;

– prioritise EU standards and legislation to which priority adaptation measures will be implemented in the National Programme for the Adaptation of Ukrainian Legislation to EU Law.

✓ Environmental reforms:

– adopt primary and secondary legislation to continue the reforms initiated in water management and waste management;

– adopt a law on environmental control and legislation to harmonise with industrial emissions legislation.

✓ Reforms in the climate area:

– adopt a climate law;

– initiate an update of the long-term low-carbon development strategy in line with the EU's 2030 climate and energy policy.

Reforms in the environmental and climate areas should focus not only on the adoption of relevant legislation, but also on its implementation and strengthening the administrative, financial, supervisory and human resources capacity of public authorities and local governments to implement the necessary reforms and attract investments. According to the European Commission, Ukraine's weak administrative capacity in the field of environment and climate is a major challenge.

In the climate area, the European Commission has highlighted efforts to be focused on:

– developing a strategy and action plan for the implementation of the updated Nationally Determined Contribution (NDC)

– developing a National Energy and Climate Plan; accelerating the implementation of the Decarbonisation Roadmap for the Energy Community Contracting Parties, in particular, the introduction of an emissions trading system;

– alignment of the future national climate strategy and climate law with the EU legislation adopted as part of the Fit for 55 package.

That is why only deepening people's understanding of the need to urgently solve this problem, expanding priorities and forming awareness of mutual responsibility of all categories of the population for the environment and the future of humanity will help to determine the main vector of efforts to promote sustainable development of society. It should be remembered that climate change is a global challenge that has no national borders or boundaries and affects all of humanity. Understanding this, most countries are open to cooperation in the field of climate change, implementation of common ideas and practical solutions through the transition to a green economy, use of alternative energy sources, decarbonisation of the economy etc.

Implementation of any initiatives requires the involvement of specialised experts and professionals, and this, accordingly, requires ensuring high-quality education of students in higher education institutions. However, the number of climate-oriented disciplines taught in Ukrainian universities is quite low. On the other hand, young people are the driving force and future of society. Therefore, it is very important to increase the number of educational programmes focused on deepening students' knowledge of climate change and sustainable development, climate change mitigation and adaptation. An increase in the number of climate-oriented specialists will help to create a basis for researching the impact of climate change on economic sectors and developing effective strategies for economic development under the new conditions.

2. Theoretical part

Every year, the problem of globalisation of environmental challenges is becoming more and more noticeable, with climate change taking the priority place among them. Until recently, this problem was mainly raised at the level of the scientific community and specialised experts in this field. However, the threatening rate of change in global temperature, rapid climate change, and the increasing number of abnormal events and natural disasters indicate that the solution to this problem must be brought to a higher, global level. It is already well established that this problem requires a comprehensive solution involving scientists, specialised professionals, educators and humanity as a whole.

The global nature of this problem makes it impossible to take separate decisions by different states, and requires a synchronised, harmonious and balanced decision on the actions of each individual state or humanity as a whole. This can only be realised through the introduction of the latest technologies and the transition of the economy to a new environmentally friendly level of functioning, which can be ensured by obtaining high-quality comprehensive and holistic education to broaden people's understanding of this problem and increase the number of specialised professionals in this area, as well as by engaging specialists in climate-dependent industries and the public to create conditions and support for best European practices in this area.

According to the results of research, the number of scientific publications focusing on the development of educational processes in the context of climate change has significantly increased in recent decades (Fig. 1).

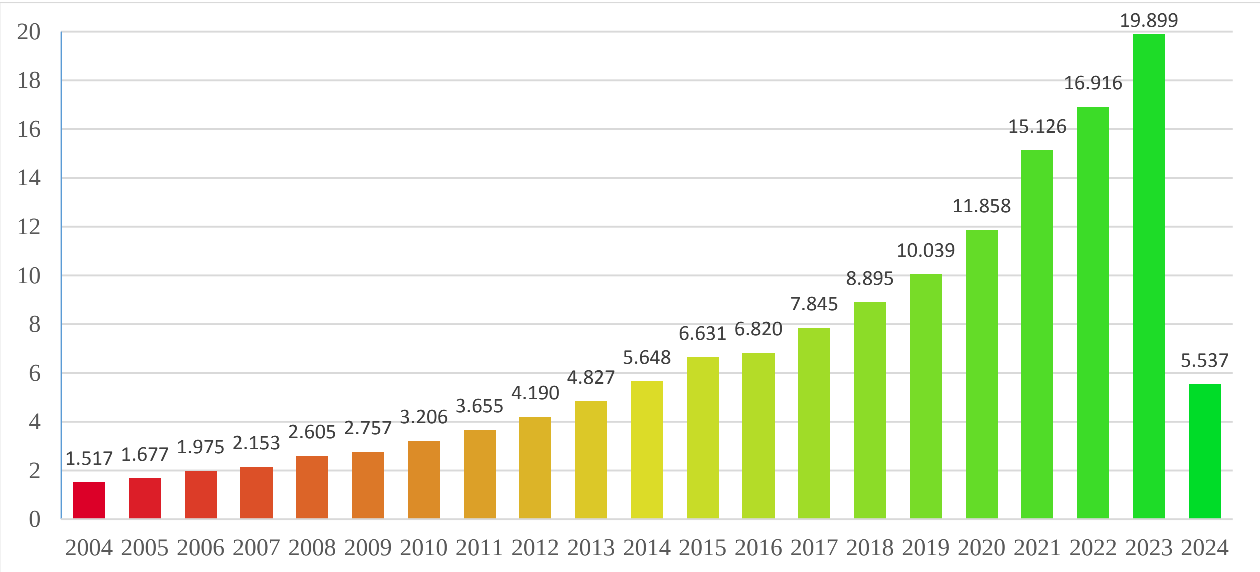

Fig. 1. The number of scientific publications on the request "climate change education" in the online platform for scientific publications ScienceDirect over the last 20 years (in thousands per year)

The obtained education should encourage people to re-evaluate their own values and live their own lives in accordance with the goals of sustainable development and climate change mitigation (Tolppanen, 2022).

Therefore, an important direction in the development of modern education should be a vector focused on raising public awareness of climate change and its main impacts. The main attention should be paid to reviewing the knowledge of school and university students, as well as scientists and environmentalists, to broaden their outlook on the use of the latest technologies in climate change adaptation and mitigation for both the population and the economy as a whole. After all, deepening the knowledge of students, scientists and society as a whole contributes to the achievement of sustainable development goals, their content, ways of implementing them in the framework of climate change adaptation and preserving an environmentally friendly environment for future generations. This area is especially relevant and important to implement today. It promotes the use of renewable energy sources, responsible consumption and adherence to the principles of a green economy, which is in line with the main vector of societal development in the European Union and the whole world. This, in turn, will enable the full and comprehensive implementation of environmentally friendly technologies for climate change adaptation in Ukraine in the future, based on the best international practices.

The lack of a sufficient number of climate-related disciplines in educational institutions limits the number of environmental experts who will be able to effectively implement climate change adaptation measures and implement advanced European policies to reduce greenhouse gas emissions through energy decarbonisation, the implementation of energy-saving equipment and the transition from fossil fuels to renewable energy sources. Providing quality education with the best European practices will allow Ukrainian specialists to fully contribute to solve the common problem of climate change and create safe living conditions on the planet in the future.

In addition, it is important to engage participants in the educational process to deepen their knowledge of the possibilities of using digital technologies and their application in education. Today, we have enormous opportunities to work in the world of digital technologies. Databases on climate change and its impacts, computer applications, digital maps, and real-time online monitoring of the environment are just a small part of what modern digital technologies provide us with. This approach ensures access to education for all people, including people with disabilities, and expands the scope of receiving, searching for and transferring information between user groups. There is no longer a need to travel thousands of kilometres to meet colleagues or share information. With computer technologies, you can reach a large audience of listeners almost anywhere in the world. Computer technologies make it possible to engage scientists from other European countries in cooperation and communicate easily with them. An important aspect of the digitalisation of the educational process is its environmental friendliness and the ability to follow the 12th Sustainable Development Goal, namely responsible consumption, as it minimizes the need to use paper booklets, leaflets, manuals, notebooks, and organize the whole process using computer technologies. In this way, we preserve forests and the environment, reduce the burden on the economy, and make a small contribution to the Green Economy of Europe and the world.

Ensuring ecological education for the general population, equal access to education for all people without exception to raise their awareness of ecological problems of society and broaden their understanding of the sustainable development goals, their respective roles and the need to implement these goals in everyday life is the key to their support in implementing environmental initiatives and projects, which in turn is an important step towards successful implementation of changes and transition to climate neutrality by 2050.

In addition, it is equally important to provide ongoing education on climate change issues, starting at school. Deepening children's awareness, identifying priorities for preserving environmental quality, understanding the processes and effects that occur, create environmentally responsible students who are ready to work and implement their ideas in climate change adaptation. Students who choose to continue their education and become experts in the implementation of climate change adaptation and mitigation technologies have more opportunities to become highly qualified professionals in this field.

Having analysed the state of educational programmes, a conclusion could be made that there are not enough educational programmes on climate change and sustainable development in Ukraine, which consequently limits the integration of the issues of climate change, sustainable development and European climate policy into existing curricula. Therefore, students often lack a holistic understanding of the scientific basis of climate change and its consequences, ways to implement the European approach to climate policy to adapt all sectors of life to these changes, and the main criteria for environmentally safe and socially oriented development of society. Insufficient technological training in climate change adaptation caused by insufficient knowledge reduces the professional qualities of future professionals and decision-makers in dealing with climate change issues in the application of advanced technological solutions to adapt various sectors of the economy to climate change and reduce greenhouse gas emissions. Studentsts-ecologists and specialists in climate-dependent industries lack specialised training in the selection of specific technological solutions for adapting various sectors of the economy to climate change, mitigating its effects, ensuring the use of green technologies and sustainable development of society.

Limited public engagement, lack of informed public discourse reduces public support for the implementation of energy-saving and climate-friendly technologies and minimises public participation in dealing with climate change issues, etc.

That is why increasing the number of disciplines focused on deepening knowledge of climate change and ways to adapt to climate change through the exchange of best practices with EU countries, especially for students-ecologists, is important and a priority task for the further development of education in Ukraine. It is impossible to underestimate the enormous contribution to dealing with climate change made by educational institutions, such as those in the European Union. Many leading universities in Europe and around the world are developing their own strategies to engage students in measures to reduce greenhouse gas emissions, transition to innovative technologies and achieve sustainable development goals. This only shows once again how important it is to understand the value of each individual, organisation and state in this process.

3. Results and Discussion

Integration of Ukraine into the EU in the field of environment involves the implementation of national and international programmes focused on ensuring social justice in the area of climate change. Such programmes should include the adaptation of regulatory legislation to EU standards, the development of digital technologies, the creation of a national system for the purchase of CO_2 emission quotas, and the promotion of ongoing education and a high level of professionalism among environmentalists, which should be implemented within the framework of existing training programmes for climate change specialists. Therefore, it is very important to ensure the formation of qualified environmental specialists who meet the European labour market demand and to raise public awareness of European and global experience in the field of climate change.

The special role of universities is to develop environmentally aware, qualified climate change professionals who are prepared to deal with scientific, social, environmental and economic challenges on the path to climate change adaptation and mitigation (Molthan-Hill et al., 2019, Leal Filho et al., 2023). Ensuring ongoing education and an interdisciplinary approach will ensure the formation of highly qualified professionals who will be able to implement projects in various sectors of the economy, based on the principles of sustainable development and improving the quality of the environment through the rational use of natural resources and mitigation of climate change.

In the short term, by engaging a large number of students in interdisciplinary education on climate change adaptation, we will get professionals who are able to implement projects in various climate-dependent sectors of the economy. In the long term, we get aware citizens who will share and implement their experience in reducing greenhouse gas emissions and living an environmentally friendly lifestyle.

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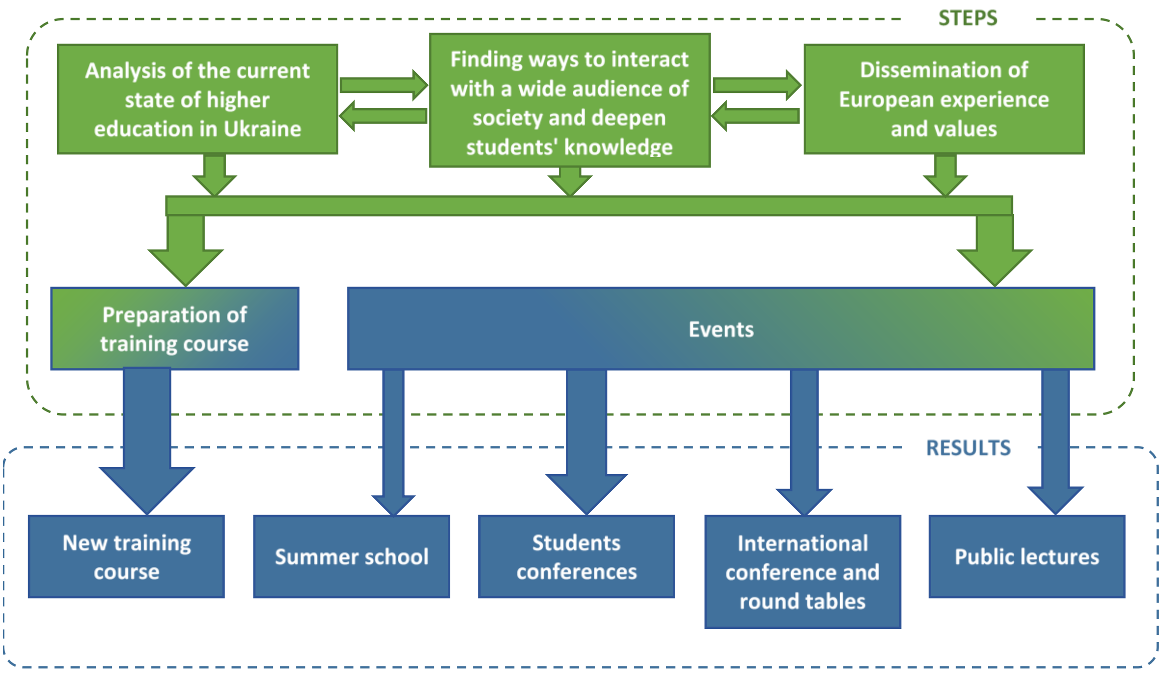

Fig. 2. Possible ways to engage students in active study of climate change issues with the involvement of the wide public

It is important to increase the number of representatives of government and business, as well as NGOs, participating in roundtables and conferences, which will draw attention to the global problem of climate change and raise awareness of the target audience about climate change issues and possible ways to adapt to climate change and mitigate the effects of climate change. This will create conditions for supporting and implementing climate change projects and expanding cooperation between different sectors of the economy. After all, sustainable development of society is only possible with the interaction of all spheres of life, without exception.

Only at the university level students can be fully engaged in the study of climate change through a combination of theoretical learning and practical skills, which contributes to better learning and the development of professional skills of students-ecologists. On the other hand, an interdisciplinary approach and the involvement of students in various events with scientists, stakeholders and environmental NGOs allows to obtain a holistic picture of the level of knowledge required for future professionals (fig. 2).

4. Conclusions

Considering the urgency of the climate change problem and the low awareness of people, an important stage in the development of education in Ukraine is the introduction of disciplines into educational programmes that will ensure an interdisciplinary approach to learning and deepen students' knowledge of climate change, adaptation of all spheres of life to climate change and promote adherence to the principles of sustainable development of society. Taking into account that the main forecasts of both climate change and sustainable development goals have a long-term perspective, the creation of educational programmes is a mandatory step for the full development of all areas of education. Over time, almost all climate-dependent sectors of the economy will require specialists who are not just experts in their field, but also have the skills and can be useful in dealing with issues related to climate change and industry adaptation to these changes.

On the other hand, it is also very important to increase the number of climate-related courses for students-ecologists. After all, climate change problems are based on environmental issues, namely the emission of pollutants into the environment as a result of anthropogenic activities. And the implementation of new academic disciplines in educational programmes will eventually ensure a sufficient level of training for students-ecologists to implement measures to mitigate climate change and adapt economic sectors to climate change.

The organisation of annual student conferences, roundtables and public lectures on climate change and the involvement of a large number of participants will create conditions for the exchange of experience between representatives of various professions, NGOs, students, scientists and international partners. The invaluable European experience and the opportunity to implement advanced European technologies in Ukraine are the basis for further development of this area in Ukraine.

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ENVIRONMENTAL PROBLEMS

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ASSESSMENT OF THE ECOLOGICAL STATE OF RURAL SETTLEMENTS BY INDICATORS OF DRINKING WATER QUALITY IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

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Abstract. The purpose of the study was to assess the state of ecological development of rural rural areas of the amalgamated territorial communities of Zhytomyr district based on drinking water quality indicators of non-centralised water supply sources to ensure their sustainable development. It was found that the average pH value was within the current standard, which indicates an excellent environmental condition for this indicator. The average content of nitrates in drinking water, which in all the studied communities exceeded the standard by 1.4 to 3.5 times, was assessed at only one point. The average concentration of total iron exceeded the current standard by 1.9 times only in the rural settlements of the Liubar community. Satisfactory water quality, in terms of total iron content, was recorded in 50 per cent of the surveyed communities. In 70 per cent of the studied communities, the average value of total hardness was recorded at a level higher than 7.0 mmol/dm^3, which indicates, according to European legislation, a poor condition of drinking water. Thus, having assessed the ecological state of rural areas in terms of drinking water quality, it was found that most of the studied communities have a satisfactory state of the territories, as the total number of points varied between 2.25-3.3 points. And the greatest contribution to the decline in the level of environmental development of rural settlements is made by the indicators of nitrate content in drinking water and its hardness.

Keywords: rural urban areas, drinking water, pH, nitrates, total iron, hardness.

1. Introduction

According to the main provisions of the Sustainable Development Strategy of Ukraine for the period up to 2030, ensuring the environmental safety of rural areas through the development of a balanced system of nature management and timely prevention of the negative impact of anthropogenic processes on the environment is a prerequisite for their sustainable development (Sustainable Development Strategy, 2023). One of the main tasks for ensuring the sustainable development of rural settlements is to achieve Global Goal 6 "Clean water and adequate sanitation". The danger of this situation can be seen from different angles. Firstly, drinking water from private shaft and tube wells, private capitals and even natural springs often does not meet regulatory requirements for the content of substances harmful to health, and secondly, the lack of sewage can lead to contamination of drinking water. Therefore, assessing the environmental status of rural areas in terms of drinking water quality should become a priority task for municipal authorities in amalgamated communities to achieve sustainable development goals.

2. Experimental part

The state of drinking water supply in rural areas is of concern to many scientists around the world. Assessments of the quality of drinking water from non-centralised sources and its pollution within rural settlements have been carried out in Ukraine (Huschuk et al., 2018; Zufiaurre et al., 2020), European

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countries (Moldovan et al., 2020; Zufiaurre et al., 2020), the USA (Wheeler et al., 2015) and China (Yu et al., 2020). A significant number of studies have focused on the impact of poor-quality drinking water on public health (Moldovan et al., 2020; Pustovit, 2013; Stehney, 2015). However, research on assessing sustainable rural development is mainly focused on comprehensive assessments (Tymoshenko, 2018), with little attention paid to environmental factors (Stehney, 2015). Therefore, we believe that the assessment of the environmental development of rural settlements in terms of drinking water quality is insufficiently studied (Herasymchuk et al., 2022).

Therefore, the purpose of this study is to assess the state of environmental development of rural settlements by drinking water quality indicators to ensure sustainable development of rural settlements in Zhytomyr Oblast.

The study was carried out within the framework of the topic on the territory of amalgamated territorial communities of the expanded Zhytomyr region. Drinking water samples were collected from nonconcentrated water sources (public and private wells, boreholes and natural springs) in the following cities, towns and rural settlements amalgamated into a rural ATC: Zhytomyr, Liubar, Novohuyvynske, Pulyny, Cherniakhiv, Berezivka, Vilshanka, Volytsia, Hlybochytsia, Oliyivka, Stanyshivka and Teterivka. Drinking water quality was analysed according to generally accepted methods, including pH, nitrates, total iron and total hardness. The results show that the standards in force in Ukraine, namely DSanPiN 2.2.4-171-10 "Hygienic requirements for the quality of water intended for human consumption" (DSanPiN 2.2.4-171-10, 2010) are mandatory and DSTU 7525:2014 "Drinking water. requirements and methods of quality control" reflects the requirements of Council Directive 98/83/EC on the quality of water intended for human consumption and is mainly advisory in nature (DSTU 17525: 2014).

To calculate the ecological state of rural settlements, the methodology presented in the work of Pustovit I. M. was chosen, according to which the traditional five-point scale and the standards presented in Table 2 were used (Lototska et al., 2018).

Since the criteria in Table 2 are in line with DSTU 7525:2014, the ranking by total hardness is also based on this document. This document defines the recommended values of total hardness as an indicator of the physiological adequacy of drinking water, which range from 1.5 to 7.0 mmol/dm^3.

The graphical representation of the study results was prepared using ArcGIS Pro software.

Table 1

Drinking water quality standards for non-centralised water supply sources

Number	Indicator	Unit of measurement	Standard according to Sanitary and Epidemiological Norms 2.2.4-171-10 (Zufiaurre et al., 2020).	Standard according to DSTU 7525:2014 (Kotsiuba et al., 2022).
1.	Hydrogen index (pH)	units pH	6.5-8.5	6.5-8.5
2.	Nitrates	mg/dm^3	50.0	5.0
3.	Total iron	mg/dm^3	1.0	none
4.	Total hardness	mmol/dm^3	10.0	1.5-7.0

Table 2

Reference table for determining the ecological status of rural areas by drinking water quality indicators (Pustovit et al., 2013)

Indicator	Environmental condition of a rural settlement				
	1 Very poor	2 Not good free	3 Advanced	4 Good	5 Excellent good
pH	>8.5 <6.0	6.0-8,5	6.0-8.0	6.5-8.5	6.5-7.0
Nitrate content, mg/dm^3	>50.0	10.0-50.0	7.1-10.0	5.0-7.0	<5.0
Total iron content, mg/dm^3	>2.0	1.0-2.0	0.3-1.0	0.2-0.3	<0.2
Total hardness*, mmol/dm^3	>7.0	5.1-7.0	3.1-5.0	1.5-3.0	<1.5

Note: * the introduction of this indicator was proposed by the authors of the study.

3. Results and Discussion

The results of the analytical survey showed that, on average, none of the surveyed districts had any inconsistencies with the pH standard. However, in almost all settlements, with the exception of Liubarska, Vilshanska and Volytska, there are isolated cases of pH decreasing to 5.45, and in the Oliyivska community, a pH increase to 12.5 units was recorded (Fig. 1)

The average content of nitrates in drinking water in all study areas exceeded the reference value (50 mg/dm^3), ranging from 1.4 times in Novohuyvynske community to 3.5 times in Volytsia community (Fig. 2)

The average content of total iron in drinking water in rural settlements exceeded the standard (1 mg/dm^3) set by the Sanitary and Epidemiological Norms by 1.9 times only in the village of Lyubar. Compared to European legislation, which sets a safe level of iron at 0.2 mg/dm^3, the average iron content in drinking water in all settlements, except for Vilshanka and Volytsia, exceeded the standard by 1.15-2.7 times (Fig. 3).

Depending on the region, the average values of total hardness ranged from 4.2 to 11.3 mmol/dm^3 Only the drinking water of the Vilshanka community exceeds the standards set by the Sanitary and Epidemiological Norms, and taking into account the recommendations of DSTU 7525:2014, the water of good quality is provided by the Berezivka, Hlybochytsia and Teterivka communities (Fig. 4).

As for the pH of well water, 75% of the surveyed communities received a score of 5, with almost all communities having excellent environmental conditions. The average nitrate content in drinking water in all cases exceeds the norm, so each community received only one point, which indicates a very poor environmental condition. Only in Vilshanka and Volytsia communities the average content of total iron was less than 0.2 mg/dm^3, which corresponds to five points. The communities of Zhytomyr, Chernyakhiv and Stanyshivka, where the average iron content ranged from 0.2 to 0.3 mg/dm^3, received 4 points; 50% of the communities received 3 points for satisfactory drinking water quality in terms of iron content, and only in the community of Rybar the average iron content was higher than 1.0 mg/dm^3, which corresponds to a score of 2. The average water hardness value was above 7.0 mmol/dm^3 in 70% of the surveyed communities, which corresponds to a score of 1; only Hlybochytsia community received a score of 2, while Berezivka and Teterivka communities received a score of 3 (Table 3).

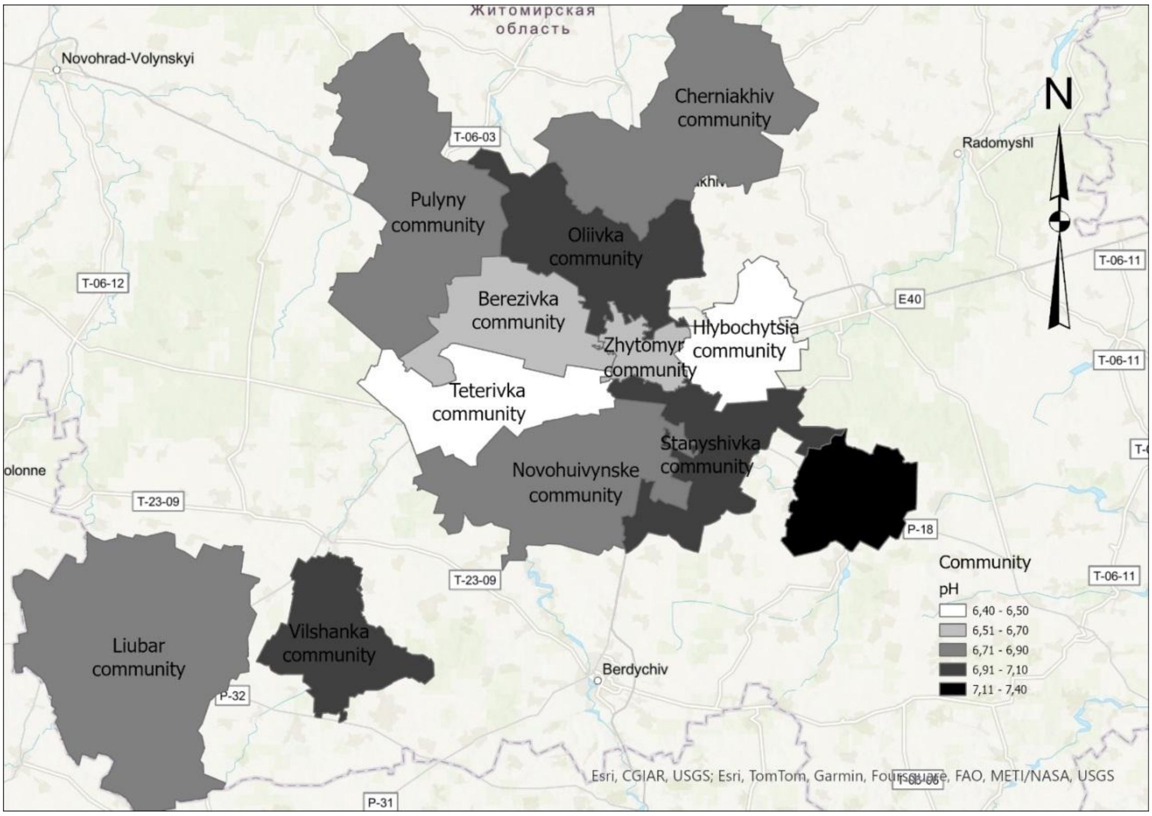

Fig. 1. Average pH values of drinking water in ATCs

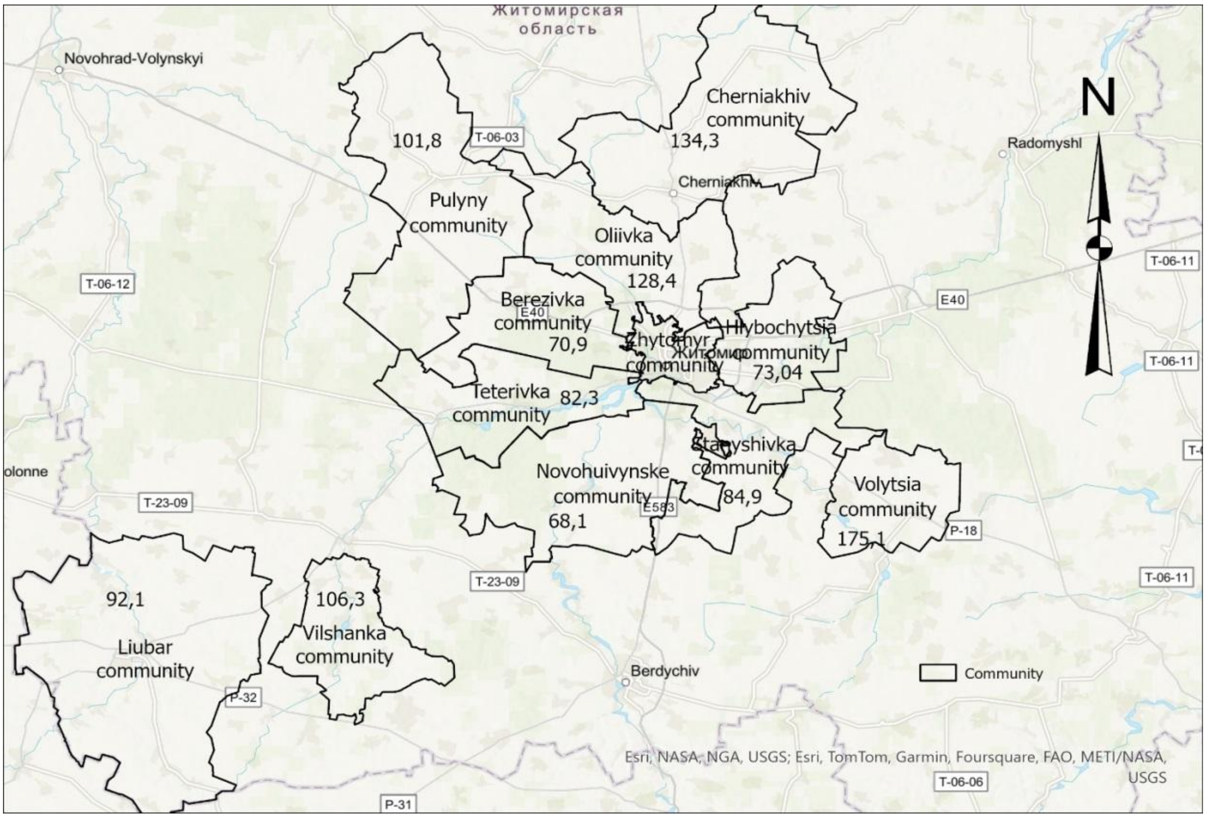

Fig. 2. Nitrate content in drinking water in ATCs

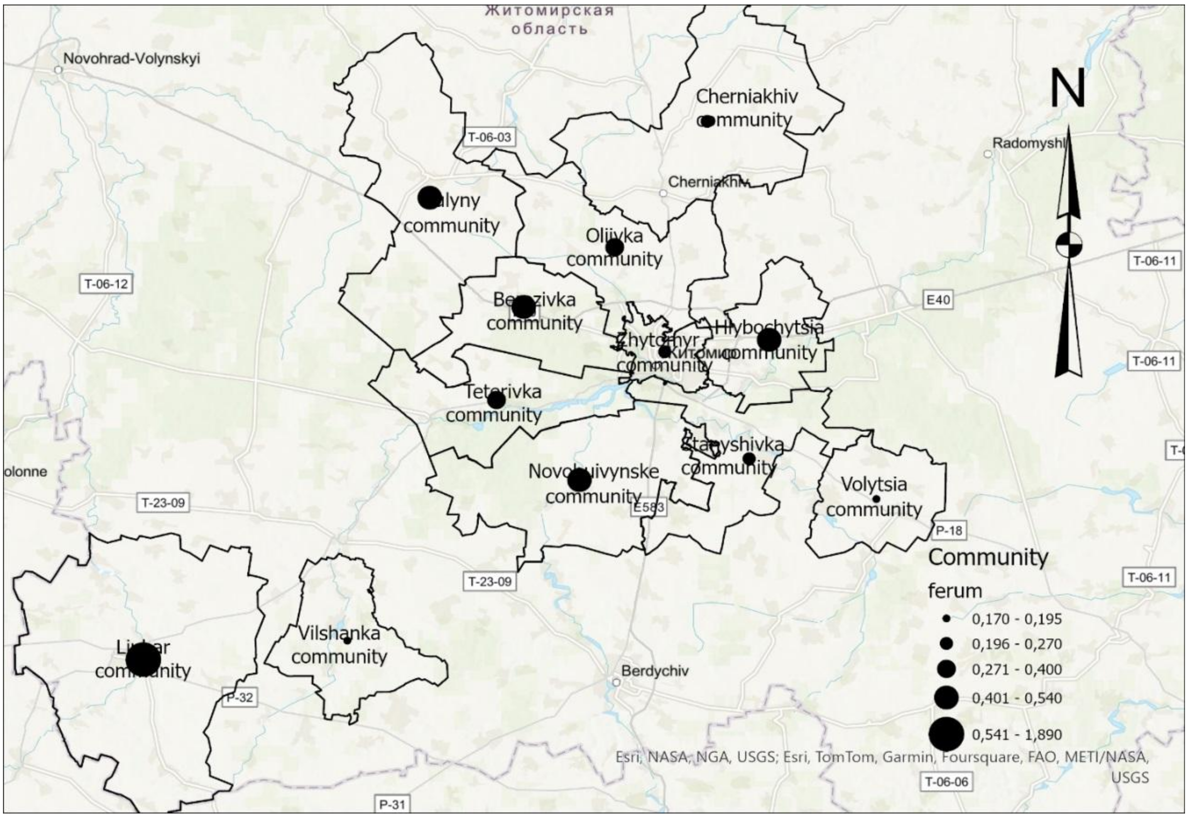

Fig. 3. Total iron content in drinking water in amalgamated territorial communities, mg/dm^3

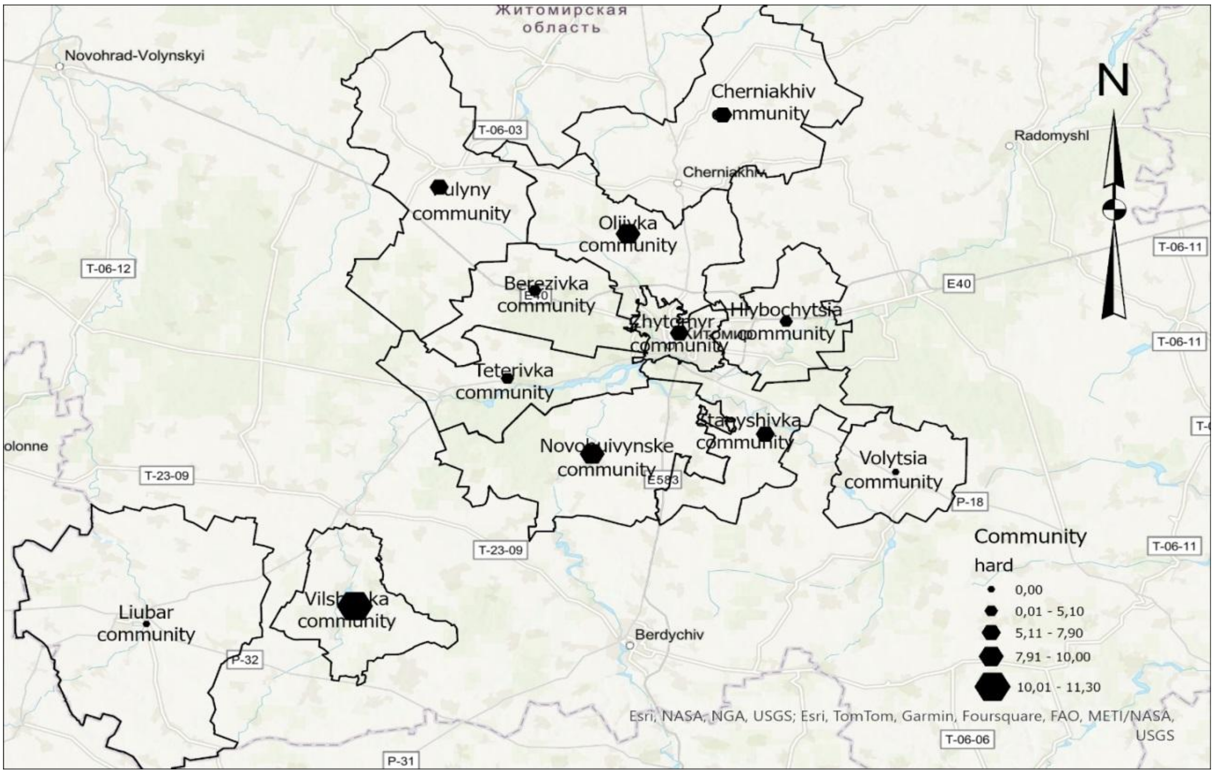

Fig. 4. Total hardness of drinking water in ATCs (mmol/dm^3)

Table 3

Number of points assigned to communities for drinking water quality indicators

Community	Number of points for the relevant indicators				
	pH	nitrates	iron	hardness total	number of points
Zhytomyr	5	1	4	1	2.75
Lyubar	5	1	2	-	2.7
Novohuyvynske	5	1	3	1	2.5
Pulyny	5	1	3	1	2.5
Chernyakhiv	5	1	4	1	2.75
Berezivka	5	1	3	3	3
Vilshanka	5	1	5	1	3
Volytsia	4	1	5	-	3.3
Hlybochytsia	5	1	3	2	2.75
Oliyivka	4	1	3	1	2.25
Stanyshivka	5	1	4	1	2.75
Teterivka	3	1	3	3	2.5

Thus, having assessed the ecological state of rural areas in terms of drinking water quality, it was found that the total number of points varied between 2.25 and 3.3 points. Most of the communities studied have a satisfactory state of the territories and require attention, and Volytsia has a good state that needs to be improved (Fig. 5)

Thus, it has been established that it is the content of nitrates in drinking water and its hardness that most contribute to the reduction of the level of environmental development of rural settlements.

4. Conclusions

The results of the study indicate that the hardness indicator has a significant impact on water quality and should therefore be included in the list of drinking water quality indicators for calculating the environmental status of rural areas, and the ranking of hardness indicators was carried out on the basis of DSTU 7525:2014 "Drinking Water. Requirements and methods of quality management", which reflects the requirements of the European Directive. The ecological condition of all the surveyed areas was assessed as satisfactory, and the good ecological condition of rural settlements was found in Volytsia village. The worst environmental condition of rural settlements in terms of the quality of drinking water from non-centralised sources was found in Oliyivka village.

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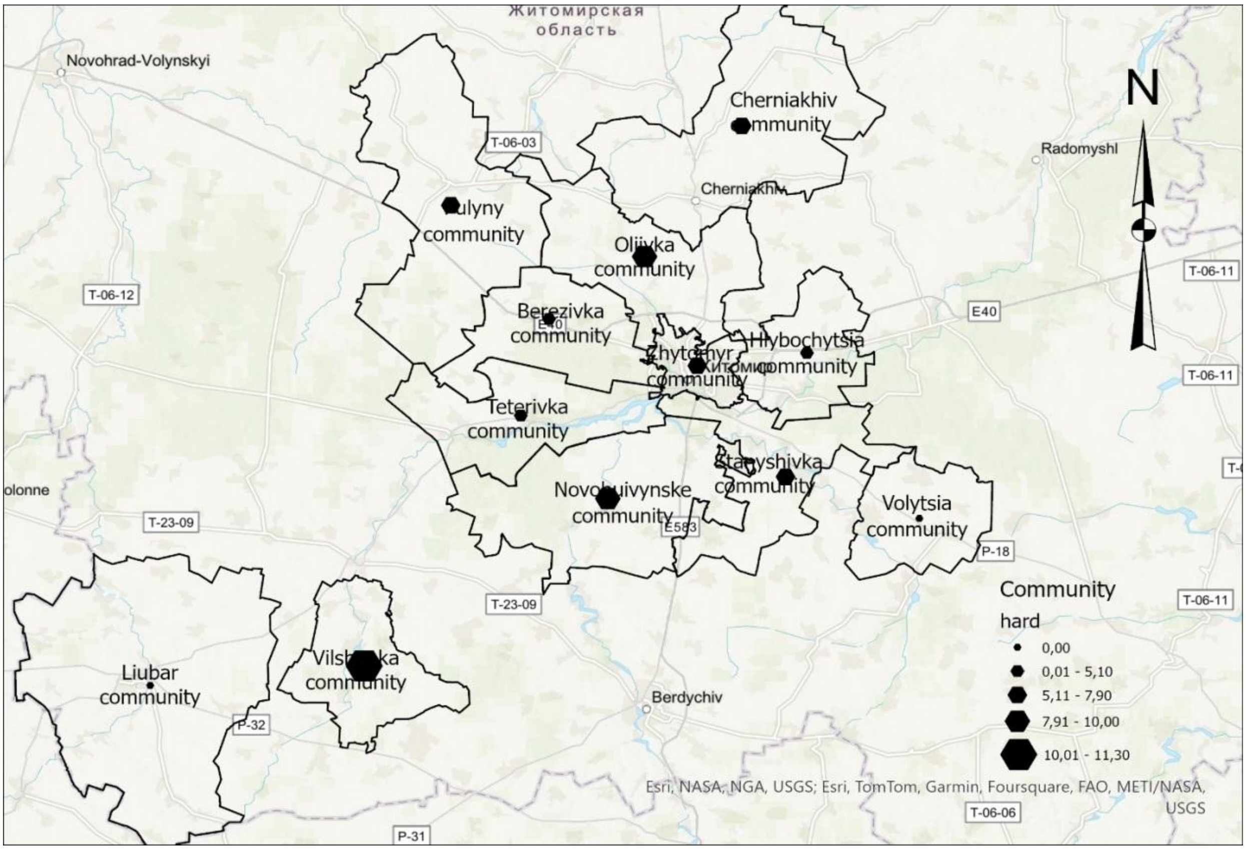

Fig. 5. Environmental status of the community by drinking water quality indicators, points

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ENVIRONMENTAL PROBLEMS

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INFLUENCE OF THE SMALL HYDROPOWER STATIONS ON THE HYDROLOGIC PROCESSES IN THE SERET RIVER (LEFT TRIBUTARY OF THE DNISTER RIVER)

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Abstract. Sources of the Seret River are located near Ratyshchi village in Ternopil region. The river has the length of 248 km, the catchment area is about 3,900 km^2. During the last 15 years seven small hydropower stations (SHPS) have been constructed in the Seret riverbed (Zahidhydroenergo, Velykohaivs'ka, Lux-2, Yanivs'ka, Chortkivs'ka, Bilche-Zolotets'ka, Bilche-Zolotets'ka-2, and Kasperivs'ka). Since all the SHPS are situated in the Seret riverbed and have a dam which decelerate water flow velocity, they influence the water runoff, sediments runoff, and water quality. After their building the cases of flooding of villages, overgrowing of the river bed reservoirs by algae plants became more often, and the long-term dynamics of the water and sediments runoff changed. To assess the water and sediments runoff changes in the catchment and to ascertain correlation between these changes and the SHPS the monitoring data sets of the Hydro-Meteorological Survey of Ukraine and the Carpathian Hydrological Observatory were analyzed. Recently the observations on the water runoff are implemented at two gauging stations: Velyka Berezovytsia village and Chortkiv city. The sediments runoff data are collected by the Chortkiv gauging station. The assessment of the water and sediments runoff changes in the Seret River in the period 1948–2022 and ascertaining of the role of water regulating by dams and reservoirs of small hydropower stations in the riverbed have been carried out. We also carried out a comparison of the sediments runoff module for the Seret River and the neighbouring Koropets River.

Keywords: river, small hydropower station, water runoff, sediments runoff.

1. Introduction

Under the conditions of the global climate change and high intensity of manmade transformation of the river systems the topic of amount and quality of water resources has very high priority. Water quality and water runoff of the big rivers in Ukraine directly depend on the state of their tributaries. Tributaries in the catchment system form the river network structure and hydrologic regime and determine the overall hydroecological state of the main river. That is why it is important to study the small and medium rivers, like the Seret. The Seret catchment is affected by the significant manmade influences and is characterized by the high indexes of transformation, especially since the second half of the 20th century. Only during the last 15 years seven small hydropower stations (SHPS) have been constructed in the Seret riverbed. Due to the necessary of dam building a water reservoir is formed upstream. Such reservoir catches up the noticeable part of sediments and lowers the water flow velocity. In its turn the decrease in water flow velocity causes worsening of self-purification abilities of the river. In case of high amounts of organic matter in the water the intensification of overgrowing by water plants and eutrofication processes are observed.

The main goal of this research is assessment of the water and sediments runoff changes in the Seret River for the period of 1948–2022 and ascertaining of the role of water regulating by dams and reservoirs of small hydropower stations in the riverbed. The object of research is the river system of Seret and small hydropower stations with their dams and reservoirs. The subject matter is parameters of the water and sediments runoff, and precipitation for the studied period.

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The topic of the manmade activities influence on the water and sediments runoff in the rivers of the Upper Dnister and Podillia Highland is reviewed in recent scientific papers of I. Kovalchuk, L. Tsaryk, O. Pylypovych, A. Mykhnovych, Y. Andreychuk and others (Kovalchuk, 2013; Kovalchuk et al., 2018; Tsaryk et al., 2023; Pylypovych, Kovalchuk, 2017; V. Khilchevskyi et al., 2013; Pylypovych, Morozovs'ka, 2023; Morozovs'ka, Pylypovych, 2021; Mykhnovych, 2019; Andreychuk, Kovalchuk, 2004).

2. Experimental part

2.1. Study sites

The Seret River starts near Ratyshchi village in Ternopil region where several rivers, namely the Seret Pravyi, the Seret Livyi, the Vyatyna and the Hrabarka, are joined together. The length of the Seret is 248 km, the catchment area is about 3,900 km^2. The river catchment is located within the two administrative regions, i.e. Lviv and Ternopil, and three administrative districts, i.e. Zolochiv (Lviv region), Ternopil and Chortkiv (Ternopil region).

Geologically the river basin is situated on the Ternopil Plateau, which is a part of the Volyn-Podillia plate within the Eastern-European platform. In the upper part the Seret flows on the flat and bogged terrains. Downstream Ternopil city the Seret has a mountain character and V-shape river valley. Concerning the relief, in the northern part the valley has lower cutting in the mother rocks and is characterized by the slight slopes and opens sediments of Upper Cretaceous and Neogene. The bottom of the valley is bogged with pit lands. The floodplain is relatively wide. In the south the river valley is deeply cut in the Podillia Plateau surface and opens sediments of Silurian, Devonian, Jurassic, Cretaceous and Neogene periods (Kostiuk, 2013).

Within the Seret river bed there are eight small hydropower stations (Fig.1): Zahidhydroenergo, Velykohaivs'ka, Lux-2, Yanivs'ka, Chortkivs'ka, Bilche-Zolotets'ka, Bilche-Zolotets'ka-2, and Kasperivs'ka. Most of them are newly constructed during 2009–2021. The Kasperivs'ka SHPS has been functioning for more than 60 years. According to the classification, most of them belong to the Micro type. Their capacity is less then 1 Megawatt, and only the Kasperivs'ka one has the capacity of 9.38 Megawatt (Table 1). All SHPS function according to green tariff amounting to 11–15 eurocents in UAH equivalent.

Table 1

The main parameters of SHPS in the Seret river basin

Number	Name of the SHPS	Type	Capacity, megawatt	Localisation	Year of construction
1	Zahidhydroenergo,	Riverbed	0.18	Horischiy Ivachiv village	2021
2	Velykohaivs'ka	Riverbed	0.15	Dychkiv village, Hnizna River (left tributary of the Seret)	2019
3	Lux-2	Riverbed	0.08	Myshkovychi village	2019
4	Yanivs'ka	Riverbed	0.66	Dolyna village	2012
5	Chortkivs'ka	Riverbed	0.2	Chortkiv town	2018
6	Bilche-Zolotets'ka	Riverbed	0.63	Bilche-Zolote village	2009
7	Bilche-Zolotets'ka-2	Riverbed	1.44	Bilche-Zolote village	2014
8	Kasperivs'ka	Riverbed	9.38	Kasperivtsi village	1963

Since all SHPS are situated in the Seret riverbed and have a dam which decelerate water flow velocity, they influence the water runoff, sediments runoff, and water quality. For example, the zone of the impact on the water flow velocity is thirty times larger than the river bed width (Afanasyev et al., 2019). In its turn the velocity deceleration can affect the hydrological conditions during 50% of the time along the thirty river bed widths downstream. Also the velocity deceleration can change the ecological conditions of the river – thermal and oxygenic regimes as well as the biodiversity. By the river bank strengthening the zone of impact on the erosion-accumulation regime amounts the distance equal to two riverbed widths (Afanasyev, et al., 2019). Besides that, the water reservoir by the dam affects the water runoff due to increasing of evaporation and catches up the sediments runoff and causes their accumulation on the bottom.

Sometimes the SHPS constructing can reinforce the flooding processes during the floods, enhance the river water pollution and eutrophication, affects the water and sediments runoff and other. For instance, the Zakhidhydroenergo hydropower station, upon being reconstructed, replaced the old hydro-engineering objects. But even during building works, in 2020 some emergency was observed, which was caused by unsatisfactory state of the dam and inability of water runoff regulation. So during the flood of 29.09.2020–01.10.2020, which was caused by heavy rains, some terrains, private economies and houses on the floodplain in Ivachiv Horishniy village were flooded. After the incident the Zakhidhydroenergo Company has set the lifting mechanism in the dam body of the Horishnio-Ivachivs'kyi water reservoir.

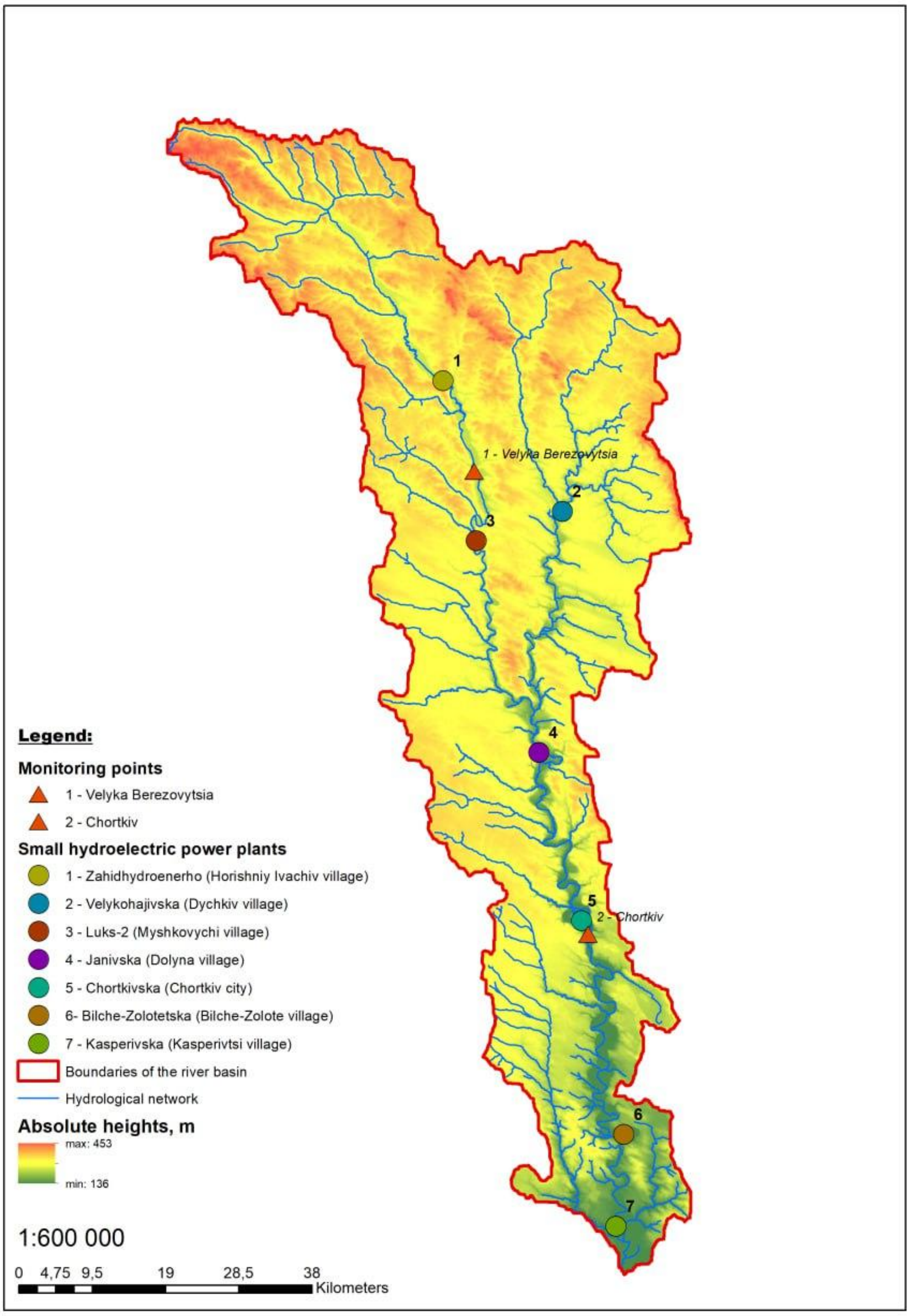

Fig. 1. The SHPS and the gauging stations localization in the Seret river basin (SHPS: 1 – Zahidhydroenergo; 2 – Velykohaivs'ka; 3 – Lux-2; 4 – Yanivs'ka; 5 – Chortkivs'k; 6 – Bilche-Zolotets'ka and Bilche-Zolotets'ka-2; 7 – Kasperivs'ka)

Fig.2. The dam of the Lux-2 SHPS and the water reservoir with the marks of the growing up and possible eutrophication (Butsniv village, Ternopil district, Ternopil region)

There were also some problems during building of Lux-2 SHPS. In 2020 local community activists declared some breaches of the law during the construction and the station was commissioned without the required Commission of the Regional authority on the environment report on the environmental impact. The documented some problems. On the satellite image from the Google service some processes of overgrowing by water plants in the lower part of the dam reservoir can be observed. Obviously the overgrowing can be caused by the water flow velocity deceleration and organic matter accumulation in the water body (Fig. 2).

2.2. Materials and Methods

To investigate the changes of the water and sediments runoff the methods of observation, expedition, map analysis, GIS-modelling, statistical analysis were used. The Hydro-Meteorological Survey of Ukraine provided the observation data sets on the water discharge, sediments runoff, and precipitation. Daily parameters of water discharge and precipitation as well as yearly parameters of water discharge, sediments discharge and runoff modules were analyzed. The topographical, thematic maps and satellite images were used. Also in the summer of 2022 the field investigations of the riverbed and floodplains in the zones of the SHPS impacts was carried out.

Recently the observations on the water runoff are have been implemented at two gauging stations: Velyka Berezovytsia and Chortkiv (Fig. 1). The sediments runoff data are collected by the Chortkiv gauging station. The analyzed hydro-meteorological data sets for the period of 1948–2022 were provided by the Lviv Regional Centre of Hydrometeorology and the Carpathian Hydrological Observatory.

3. Results and Discussion

The changes in annual water and sediments dynamics for the long period in the Seret river basin have been assessed concerning the SHPS impacts on the hydrological regime.

The water discharges in the Seret river near Velyka Berezovytsia village usually fluctuate between 1.37 and 9.8 m^3/s, and near Chorkiv town — between 2.5 m^3/s and 20.1 m^3/s in the years with low water runoff. During the years with medium water runoff the water discharge amount 60 – 90 m^3/s. Maximal moment water discharge of the extreme flood was observed on 5.04.1956 – 313 m^3/s, minimal moment discharge was observed on 2.07.1960 – 0,23 m^3/s.

The curve of daily water discharge in Chortkiv quite often does not correlate with the daily precipitation. This fact can be explained by the water regulation effects of the SHPS dams and reservoirs in the riverbed. For example, during heavy rains in August and

September 2020 we do not observe peaks on the water discharge graph (Fig. 3). In the other case in the middle of July 2020 we can see significant peaks on the water discharge graph without heavy rains. Such peaks can be caused by the water discharge from the reservoir of the Chortkiv SHPS. The hydrograph, which was built for the Velyka Berezovytsia gauging station confirms that. Here, the daily water discharges correlate much more with the daily precipitation (Fig. 4). Only one SHPS is located 18.5 km upstream from the gauging station (Zakhidhydroenergo in Horishniy Ivachiv village).

The average annual water discharge for the long-time period in the Seret (Chortkiv) is 14.8 m^3/s. The maximal average annual water discharge in this period amounts to 23.6 m^3/s (1980), the minimal – 6.3 m^3/s (2020). The average annual water discharges are characterized by the trend-line of decreasing after 2009 (Fig. 5).

The average sediments runoff in the Seret varies between 0.46 and 2.7 кg/sec. The maximal moment parameter during a flood can amount 110 kg/sec, for example in April of 1996. During the year with medium water runoff, the graph curve illustrates increasing of the sediments runoff from May till July and decreasing during winter months (Fig. 6).

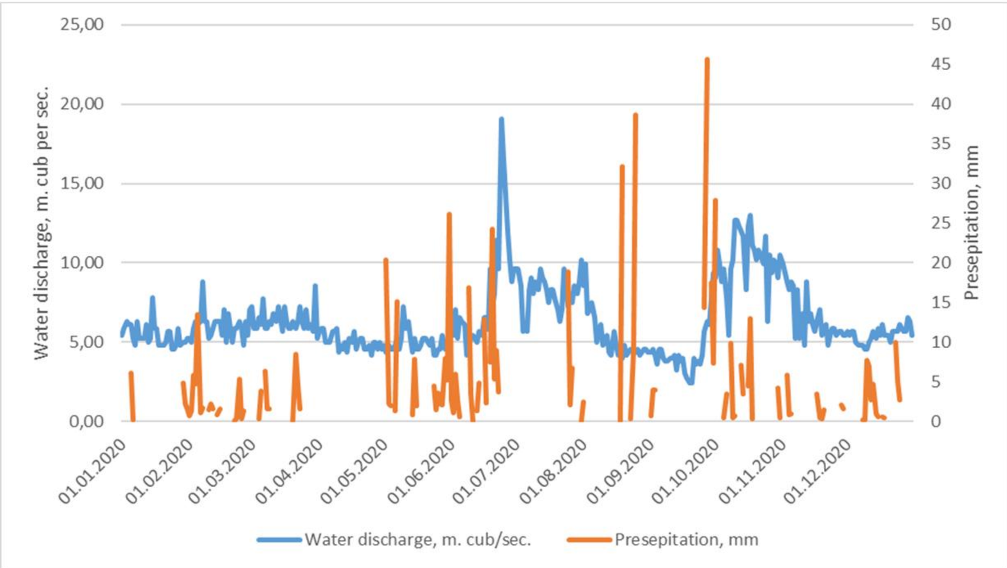

Fig. 3. The daily discharges and daily precipitation curves for the Seret near Chortkiv

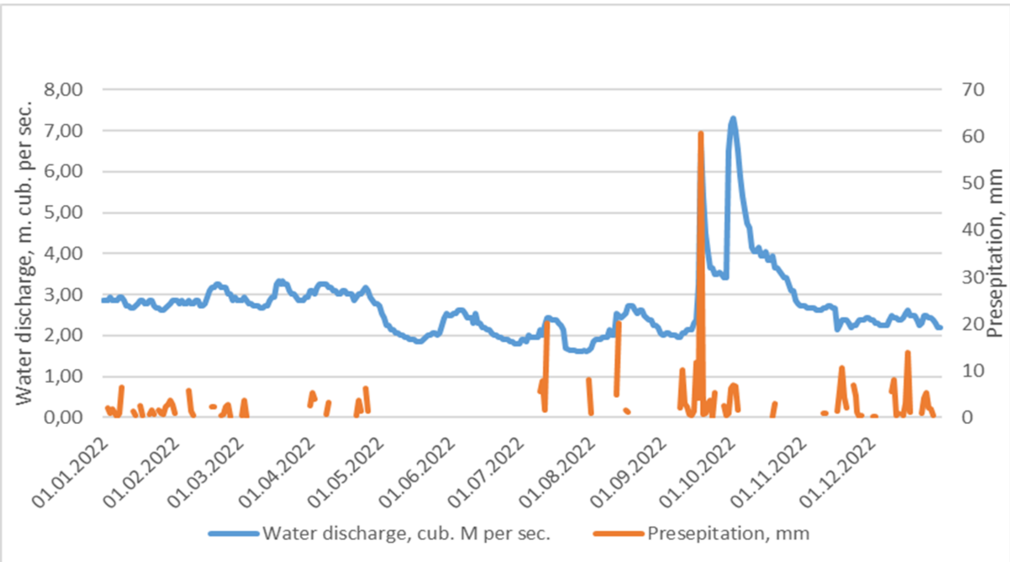

Fig.4. The daily discharges and daily precipitation curves for the Seret near Velyka Berezovytsia

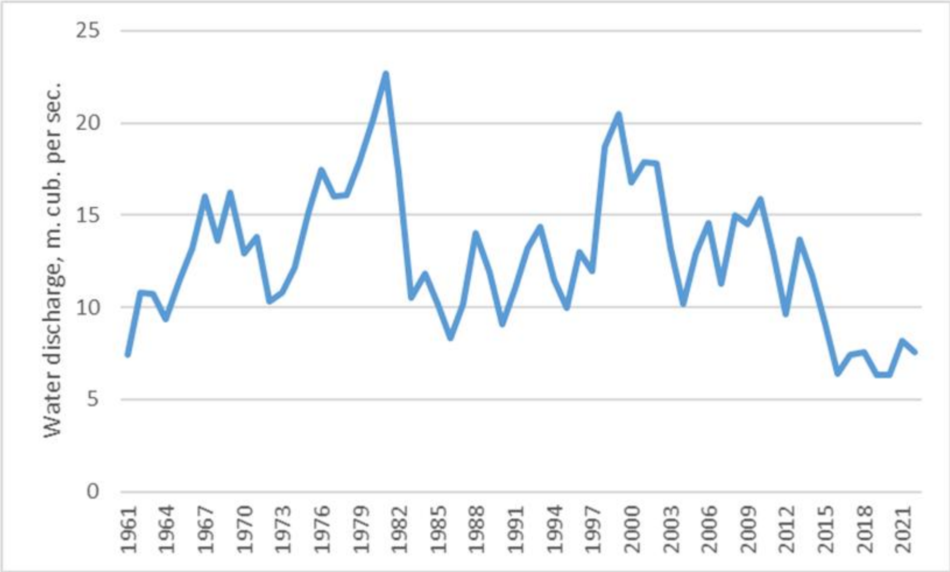

Fig. 5. The average annual water discharge in the Seret river near Chortkiv during the period 1961 – 2022

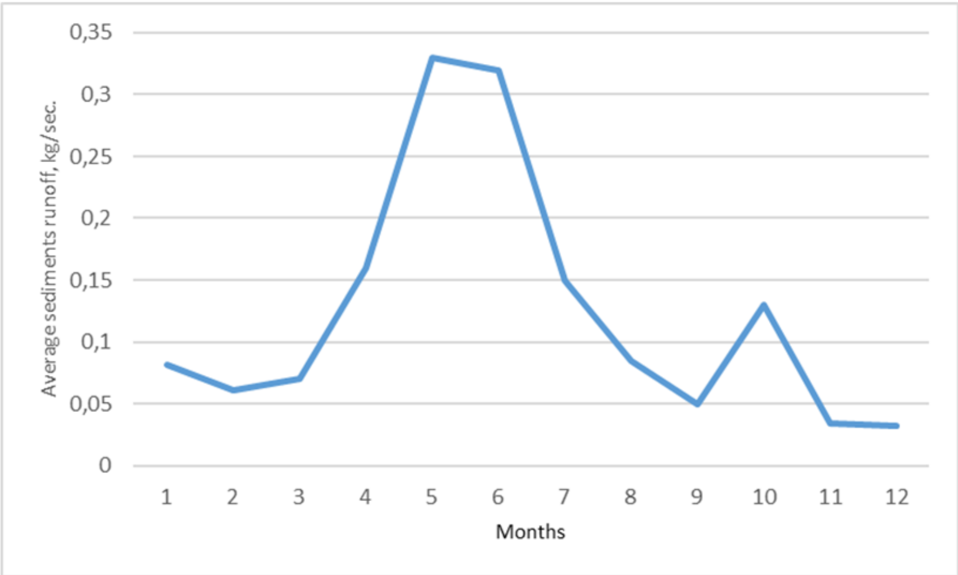

Fig. 6. Monthly sediments runoff distribution in 2019 (low in water runoff) in the Seret (Chortkiv)

The important parameter, which describes the overall denudation intensity in the river basin, is the sediments runoff module. The annual average sediments runoff module is an integral parameter of the erosion-accumulation processes intensity in the river basin. During the long period the wide range fluctuations and significant amplitudes usually characterize this parameter. For the Seret river this parameter changes from 1.1 (1959, 2018) to 73 (1956, 1969) t/km^2 per year.

The long-term fluctuations of the sediments runoff module can be spread across several typical periods. The series of years with low and high sediments runoff form a long-time graph with noticeable tendencies of differently directed changes – decreasing or increasing. We allocated several sub-periods in the sediments runoff graph for the Seret River: 1948 – 1959; 1960 – 1972; 1973 – 1986; 1987 – 2000; 2001 – 2019 (Fig. 7). As we can see on Fig. 7, every sub-period lasted for about 11 – 13 years, and it generally correlates with the Sun activity cycles. Every sub-period also has noticeable maximum and minimum. However, the period of 2001 – 2019 is a little exceptional. Absence of noticeable maximum, minimum, slight amplitudes and significant decreasing of the sediments runoff characterizes this sub-period of the whole graph. We can assume that such decreasing of the sediments runoff may be related to water runoff regulating by a few dams and reservoirs, which belong to SHPS and were constructed after 2009 (except the Kasperivs'ka one).

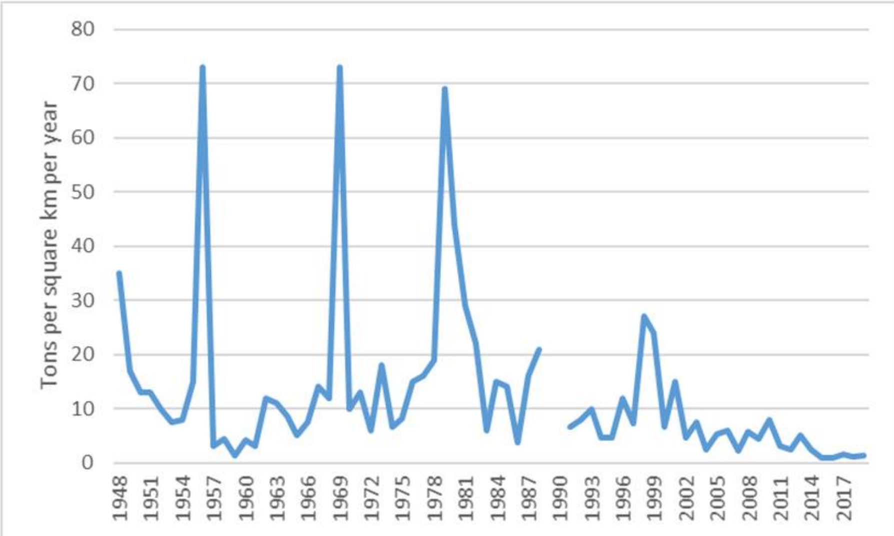

Fig.7. The long-term dynamics of the sediments runoff module in the Seret River (Chortkiv) during 1948 – 2019 (according to the data of the Hydro-meteorological Survey of Ukraine)

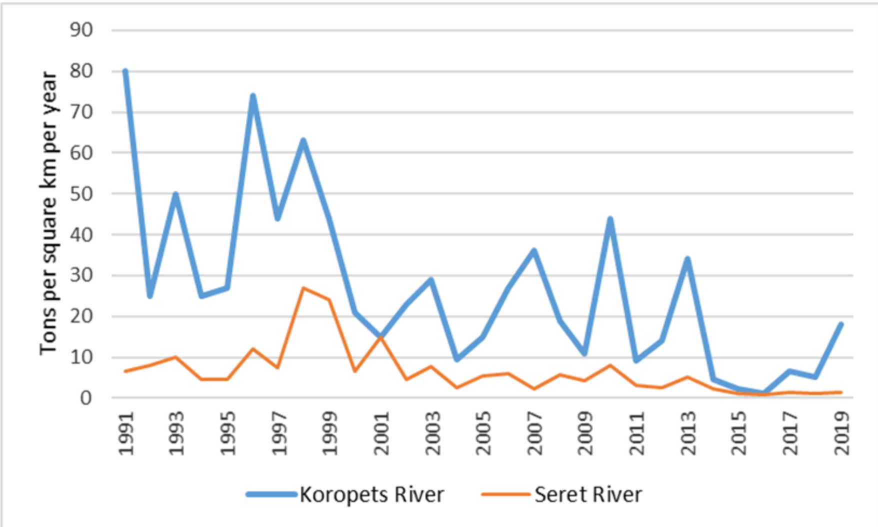

Fig.8. Comparison of annual average sediments runoff modules in the Seret River (Chortkiv) and the Koropets' River (Koropets' village) during 1991 – 2019 (according to the data of the Hydro-Meteorological Survey of Ukraine)

If we compare the sediments runoff dynamics of the Seret River with other rivers of Podillia, for example Koropets' River, we can see that in the Koropets' catchment the decreasing after 2001 is less significant, the fluctuations and peaks are more noticeable. That fact can be interpreted as the confirmation of more natural regime of the runoff distribution.

4. Conclusions

During last 15 years, seven SHPS were constructed in the Seret River bed, which produce noticeable impacts on the hydrologic regime. After their building the cases of flooding of villages, overgrowing of the river bed reservoirs by algae plants became more frequent, and the long-term dynamics of the water and sediments runoff was changed. To assess the water and sediments runoff changes in the catchment and to ascertain correlation between these changes and the SHPS functioning we analyzed the monitoring data sets of the Hydro-Meteorological Survey of Ukraine and the Carpathian Hydrological Observatory.

The investigation results have shown that daily water discharges in the Seret River near Velyka Berezovytsia village fluctuates between 1.37 and 9.8 m^3/s, and near Chortkiv town — from 2.5 m^3/s to 20.1 m^3/s during low water runoff years.

The average annual water discharge in the Seret (Chortkiv) is 14.8 m^3/s. Maximum from the average annual water discharge amounts to 58.6 m^3/s (1969), and minimum of this parameter is 6.3 m^3/s (2020). The noticeable tendency of decreasing of the average annual water discharge is observed after 2009.

Daily water discharges in the Seret (Chortkiv) sometimes do not correlate with the daily precipitation. It may be explained by the regulating effects of dams and water reservoirs in the Seret river bed.

In the long-term graph of the sediments runoff module fluctuations in the Seret River we identified the series of sub-periods with noticeable tendencies of differently directed changes – decreasing or increasing: 1948 – 1959; 1960 – 1972; 1973 – 1986; 1987 – 2000; 2001 – 2019 (Figure 7). The period of 2001 – 2019 is a little different. Absence of noticeable maximum, minimum, slight amplitudes and significant decreasing of the sediments runoff characterizes this sub-period. We can assume that such decreasing of graph peaks may be explained by water runoff regulating by SHPS dams and reservoirs, which were constructed after 2009 (except the Kasperivs'ka one).

Comparing the long-term sediments runoff dynamics of the Seret River with the neighboring Koropets' River testifies that decreasing after 2001 in the Koropets' is less significant, the fluctuations and peaks are more noticeable. That fact can be considered as the confirmation of the SHPS influence on the water and sediments runoff regime and distribution.

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ENVIRONMENTAL PROBLEMS

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INTERNAL AND EXTERNAL FACTORS OF USE AND CONSERVATION OF WATER RESOURCES IN ZHYTOMYR REGION

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Abstract. The water resources of Zhytomyr region are an important national asset, the condition of which affects people's health, economic development and the "good" environmental condition of the region. The current state of water resources in Zhytomyr region is of some concern due to a number of challenges, including: water pollution with organic materials, nutrients and toxic elements due to incomplete or no wastewater treatment, leaching of pollutants from agricultural land and plastic waste. The challenges also include limited access to quality drinking water in some regions, underdeveloped water supply and sanitation systems, unregulated water consumption and violations of water protection regulations, and hydromorphological changes related to hydropower and water flow regulation, including problems with coastal protection zones and water protection zones, as well as the effects of climate change, including floods and droughts.Taking this into consideration, conducting a SWOT analysis for the use and conservation of water resources in Zhytomyr region gets a particular relevance. The purpose of the study is to conduct a SWOT analysis that will not only allow a deeper analysis of the strengths and weaknesses of the regional water management system, but also to identify potential opportunities for improvement and risk reduction. The SWOT analysis will serve as the basis for developing strategies that will promote the conservation and rational use of water resources, strengthen the environmental well-being of the region, and ensure sustainable economic development and public health in Zhytomyr Region.

Keywords: environmental safety, water resources management, sustainable development, SWOT-analysis.

1. Introduction

The hydrographic network of Zhytomyr region is located within the Prypiat River sub-basin (56% of the territory or 16.6 thousand km^2) and the Middle Dnipro (44 %), or 13.2 thousand km^2. The average river runoff is 3300 million m^3, of which 2800 million m^3 is generated in the region. Surface water resources in the region are formed mainly from local runoff in the river network, mainly on its own territory, due to precipitation, as well as transit runoff coming from neighboring regions. The water content of the region's rivers is quite uneven across seasons and climatic zones. Thus, the water content of the rivers in the northern regions is 1.5-2 times higher than in the southern regions, up to 70% of the river runoff falls on spring floods or summer floods, and only 30 % – on the rest of the year. There are no large rivers in the structure of the hydrographic network; the medium-sized rivers include the Teteriv, Sluch, Irsha, Ubort, Stviga, Slovechna, Uzh, and Irpin (Regional reports on the state of the environment in Ukraine, 2023).

There are 53 reservoirs in the Zhytomyr region, with a total area of 7.6 thousand hectares and a total volume of 165.6 million m^3 and 2075 ponds with a total area of 12.3 thousand hectares and a total volume of 148.9 million m^3, of which 4 reservoirs with a total area of 0.48 thousand hectares are on the balance of the Pripyat River Basin Management Unit (here and after – RBMU) (Denyshi Reservoir, located in the village of Denyshi. 255 hectares; Otsechne Reservoir, located in the village of Teterivka, 320 hectares; Zhytomyr Reservoir, located in Zhytomyr, 390 hectares;

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Malyn Reservoir, located in Malyn, 805 hectares) and 61 ponds with a total area of 1.1 thousand hectares, as well as 61.6 km of protective dams. 76 rivers with a length of 1110.5 km are registered as main canals, and 361 hydraulic structures have been built on them. The use of artificial water bodies in the region is carried out to meet the needs of energy, drinking water supply and domestic needs of the population (Environmental passport of Zhytomyr region, 2023). Most of the ponds in Zhytomyr region are built on small rivers and streams, and as a result, their water flow is regulated by 30-60 %.

The source of water supply for the population and economic sectors of the region is surface water – 65.34 million m^3 (77%) and groundwater – 19.89 million m^3 (23 %). The largest source of water supply is the Teteriv River basin, a right tributary of the Dnipro, from which 52.457 million m^3 were withdrawn in 2022, or 62.0 % of the total water intake in the region (Regional reports on the state of the environment in Ukraine, 2023).

In total, in 2022, 52.61 million m^3 of wastewater was discharged into the region's surface water bodies, including "normatively clean without treatment" – 26.89 million m^3, "normatively treated at treatment facilities" – 24.43 million m^3, "insufficiently treated" – 1.105 million m^3, "polluted without treatment" – 0.184 million m^3 of return (waste) water (Agency of Water Resources of Ukraine, 2023).

In accordance with the Water Framework Directive (Directive 2000/60/EC, 2000), the Prypiat RBMU provides diagnostic water monitoring and analysis of the quality status of surface water bodies in the Prypiat and Middle Dnipro sub-basin within Zhytomyr Region at 14 monitoring sites for chemical (priority) substances and chemical (basin-specific) substances. Of these, seven surface water bodies on the Teteriv, Sluch, Irsha, Hnylopyat, Uzh and Viznya rivers and 1 transboundary water body, the Ubort River, Rudnia Khochynska village, Korosten district, are monitored for chemical and physicochemical parameters, and water is abstracted to meet the drinking and household needs of the population. Priority and basin-specific indicators are determined by the Water Laboratory of the Northern Region of the Interregional Office of the Dnipro Reservoirs Protection Arrays, Vyshhorod. In total, in 2022, 88 samples were taken in Zhytomyr region and 1760 measurements of surface water composition and properties were performed. The portal "Monitoring and Environmental Assessment of the Quality of Surface Waters of Ukraine" is updated with the measurement results on a monthly basis (Portal of open data of state monitoring, 2023).

In 2022, emergency discharges of wastewater from sewage pumping stations in Zhytomyr were recorded. Zhytomyr of the ME "Zhytomyrvodokanal" in the amount of 2.8 thousand m^3 into the Teteriv River and its tributary Kamyanka River, and the wash water at the water treatment plant of the IInd lift from the washing of filters and contact clarifiers from the water supply treatment facilities was discharged into the Teteriv River without treatment in the amount of 111.2 thousand m^3. Thus, according to the State Ecological Inspectorate of the Polissia District (State Ecological Inspectorate of Polissya District, 2021), it is the Zhytomyrvodokanal that is the main polluter of surface water bodies in Zhytomyr region (the Teteriv and Kamianka rivers).

Thus, the geographical location and characteristics of the hydrographic network of Zhytomyr Oblast, spread between the sub-basins of the Prypiat and Dnipro rivers, together with the huge volume of river runoff generated mainly in the region, emphasize the importance of surface water resources for the region. At the same time, the presence of a large number of reservoirs, ponds and hydraulic structures, as well as the diverse use of water bodies to meet energy, drinking water and other domestic needs, underscores the complexity of managing and preserving these resources. The diversity of water sources, including both surface and groundwater, requires an integrated approach to water use. Therefore, the implementation of SWOT-analyzing the use and conservation of water resources in Zhytomyr region is a relevant and necessary step. Such an analysis will identify strengths, such as the significant amount of water resources and the diversity of water bodies that can be used for various purposes. At the same time, weaknesses will be identified, including existing challenges related to water pollution and inefficient wastewater treatment facilities. The analysis will identify opportunities for improvement, such as infrastructure modernization and the introduction of innovative water treatment technologies, as well as threats, including those related to climate change and uncontrolled use of water resources. In the context of the recently resumed reconstruction of the sewage treatment plant in Zhytomyr with funding from the World Bank, the SWOT analysis will be an important tool for assessing the current state of water resources, identifying management priorities, and planning further steps to ensure sustainable use and conservation of the region's water resources. This approach will help to ensure efficient water supply for the needs of the population and economy, as well as contribute to the preservation of the ecological balance in the region.

2. Materials and Methods

The term SWOT is formed by the first letters of the words: (Strengths) strengths and (Weaknesses) weaknesses, (Opportunities) opportunities and (Threats) threats (Integrated spatial planning for amalgamated hromadas, 2018). The SWOT philosophy can be summarized as: build on strengths, eliminate weaknesses, and seize opportunities. SWOT analysis is a qualitative tool that allows to understand the community's strengths and weaknesses, identify opportunities and external factors that may hinder the achievement of development goals. Strengths and weaknesses include internal aspects, factors, and resources-those that are owned by the communities in the region or that the communities can control. Strengths and weaknesses determine the current state of water resources. Examining the strengths and weaknesses of water use and conservation in Zhytomyr region can be useful for understanding the environmental, economic, and social aspects of water management. Opportunities and threats are external factors and trends that can affect the development of a community but are not under its control. For example, geographic location determines opportunities or threats. Opportunities and threats also reflect possible future changes caused by these factors.

Thus, the following main stages of SWOT analysis can be distinguished:

– *Preparatory stage:* at this stage, a group of experts was formed and methodological approaches to the analysis were developed. The main goals and objectives of the study were also defined. A group of 16 experts was formed to conduct the assessment. These experts were selected on the basis of their professional experience and knowledge in water resources management, ecology, hydrology and related sciences. To ensure a comprehensive analysis, the expert group included representatives from different fields of expertise, which allowed for a variety of perspectives and aspects of the water sector;

– *Information collection*: the experts were provided with information on the current state of water resources in Zhytomyr region, including data on their quantity, quality, main problems and challenges;

– *Assessment of factors*: experts identified and assessed key internal and external factors that affect the use and conservation of water resources. The expert assessment of the mutual influences between internal and external factors of water resources use and conservation in Zhytomyr region was carried out as follows:

1) first, it is necessary to collect expert ratings for each factor on a 7-point Miller scale, where 1 means the weakest impact and 7 means the strongest (Foresight, 2023);

2) after collecting the data, they are aggregated, i.e., for each factor, the average values of the ratings from all experts are calculated and such data are normalized in the range from 0 to 1;

3) based on the normalized data, indicators are calculated for each group of factors. These indicators allow us to determine the effectiveness of internal and external factors of water resources use and conservation in Zhytomyr city united territorial communities (here and after – UTC).

– *Analysis and synthesis:* based on the assessments, experts conducted an analysis that allowed them to identify the most important factors. These factors were divided into four categories of SWOT analysis.

3. Results and Discussion

As a result of the work of the expert group, the most important internal (Table 1) and external factors (Table 2) that affect the use and conservation of water resources in Zhytomyr region were identified and evaluated on a 7-point Miller scale (1 – minimum value, 7 – maximum value).

Fig. 1 shows the distribution of strengths by the values of the effectiveness indicator. The effectiveness indicator characterizes the ability of a strength to influence opportunities and threats.

The analysis shows that the development of water supply and wastewater infrastructure (S2), modern water treatment technologies (S3), availability of qualified personnel (S8), greening of industry (S9), and international cooperation (S10) are the most effective areas for investment and effort. They help not only to improve water management but also to reduce potential water-related threats. Investing in these areas can bring significant benefits, including improved water quality, more stable water supplies, and improved environmental conditions.

Focusing on these strengths will ensure more sustainable and effective water management.

After analyzing the weaknesses by the values of the performance indicator, it was found that critical weaknesses (Fig. 2) indicate the main challenges in the field of water resources management:

– Lack of comprehensive integrated water resources management (W3): This indicates the need to develop and implement coherent management strategies that cover all aspects of water resources;

Table 1

The most significant internal factors of the use and preservation of water resources of Zhytomyr region

Strong factors (indicators) of use and conservation of water resources of Zhytomyr region		Quantitative values	Weak factors (indicators) of the use and conservation of water resources of Zhytomyr region		Quantitative values
S1	The presence of numerous reservoirs and water bodies	5.63	W1	Water pollution	6.44
S2	Development of water supply and drainage infrastructure	5.19	W2	Clogging with household waste	5.81
S3	Introduction of modern water purification technologies	5.06	W3	Lack of comprehensive integrated management of water resources:	5.75
S4	Availability of recreational and ecological zones	5.19	W4	Lack of drinking water in some areas of the region and unsatisfactory quality of drinking water as a whole	5.44
S5	Involvement of the public in the protection of water resources	4.88	W5	Insufficient level of development of water supply and drainage in some settlements, lack of sewage systems	5.81
S6	Water activity: open water competition "Teteriv Open ", championship of Ukraine "Drakons" in Teteriv, etc.	5.0	W6	Uncontrolled use of water resources and water protection zones	5.88
S7	The presence of reservoirs that can be used for the production of renewable energy.	4.56	W7	Non-compliance with the regime of coastal protective strips and water protection zones	5.5
S8	Availability of qualified personnel to work in the field of water resources protection	5.5	W8	Inefficient use of water both in industry and in the population	6.31
S9	Gradual greening of industry	5.31	W9	Outdated infrastructure and technologies	5.75
S10	International cooperation, cooperation with MFIs	5.63	W10	Insufficient cooperation between local self-government bodies, business and the public	5.13
-	-	–	W11	Insufficient awareness of the population	5.31
-	-	–	W12	Lack of financial resources	5.44
-	-	–	W13	Loss of local biodiversity and increase in biological invasions	5.94
-	-	–	W14	Lack of alternative sources of drinking water	5.31

Table 2

The most important external factors of the use and preservation of water resources of Zhytomyr region

Factors determining new opportunities for the use and conservation of water resources of Zhytomyr region		Quantitative values	Factors determining threats to the use and preservation of water resources of Zhytomyr region		Quantitative values
1		2	3		4
O1	Development of tourism and water recreation	5.56	T1	Climate change (including floods and droughts)	5.69
O2	Implementation of new water purification and water supply technologies	6.31	T2	Hydromorphological changes	5.69
O3	Infrastructure improvement: modernization of dams and reservoirs and flexible management of reservoirs	6.06	T3	War and the impact of military operations on water resources	5.88

Продовження

1		2	3		4
O4	Facilitating and encouraging the introduction of technologies for the economical use of water resources and the installation of local treatment facilities by business entities	5.88	T4	Increasing pollution of water resources by industrial, agricultural and household waste	6.31
O5	Creating favorable conditions for attracting investments in infrastructure development	5.81	T5	Uncontrolled drilling of wells, as well as excessive extraction of groundwater	5.81
O6	Increasing public awareness of the importance of preserving water resources	5.81	T6	Soil erosion and clogging of watercourses	5.75
O7	Development of a system for monitoring the state of water resources	6.31	T7	Loss of biodiversity of aquatic ecosystems	5.75
O8	Development of cooperation between authorities, enterprises, public organizations and citizens	5.5	T8	Lack of effective management of water resources	6.13
O9	Development and implementation of a program of activities for the revitalization and decontamination of small rivers	6.25	T9	Non-compliance with the regime of coastal protective strips and water protection zones	5.75
O1 0	Development of integrated storm sewerage and treatment systems	6.19	T10	Conflicts over water resources	4.88
O1 1	Promotion of cooperation with scientists and conducting scientific research	6.0	T11	Threat to public health	5.56
-	-	-	T12	Impact on economic development	5.31

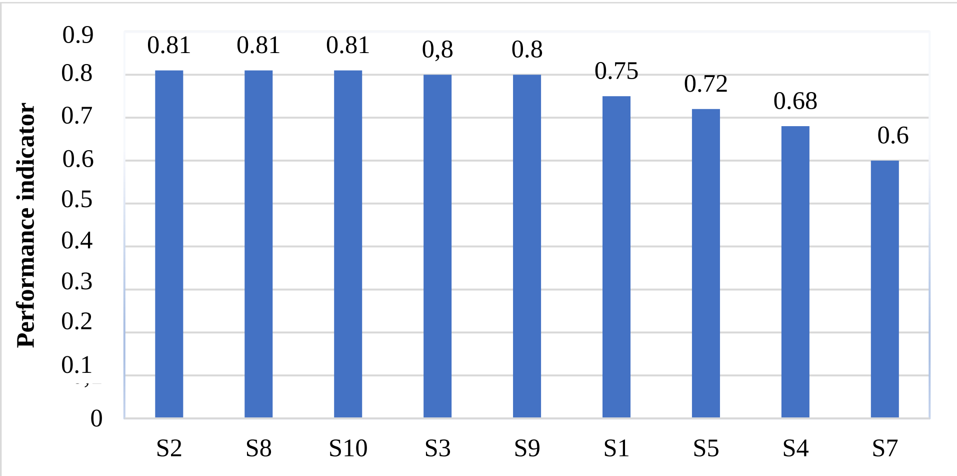

Fig. 1. Distribution of strengths by performance indicator values

- uncontrolled use of water resources and water protection zones (W6): This indicates the need to strengthen the control and monitoring of water use, as well as the protection of water protection zones;

– Uneconomical use of water by industry and population (W8): This emphasizes the need to promote the efficient use of water resources and to educate the public and industrial enterprises about the importance of water conservation;

– water pollution (W1): This emphasizes the problem of water pollution and the need to take measures to reduce and control pollutants.

The Weaknesses Effectiveness Indicator characterizes the ability of a weakness to influence opportunities and threats (calculated on the basis of the values of the Weaknesses Indicator and the Strengthening of Threats Indicator).

Thus, these weaknesses are the most critical, as they have the greatest impact on the environment and human health. To address them, measures should be taken to establish an effective water management system, control the use of water resources and water protection zones, and raise public awareness of the importance of water conservation and preventing water pollution.

The possibilities are distributed according to the values of the feasibility indicator (Fig. 3), which characterizes the ability to perceive the positive effects of strengths and resist the influence of weaknesses (calculated on the basis of the values of the indicator of sensitivity to the influence of strengths and the indicator of sustainability to the influence of weaknesses). The values of the feasibility indicator indicate how feasible it is to realize certain opportunities in the context of strengths and weaknesses. High values of this indicator mean that the realization of a certain opportunity, despite the existing weaknesses, is quite likely and effective.

Thus, the opportunities with the highest feasibility indicators, and thus with the highest chances of successful implementation within Zhytomyr region, are the following:

O9. Development and implementation of a program of measures for the revitalization and decontamination of small rivers;

O10. Development of integrated stormwater management and treatment systems;

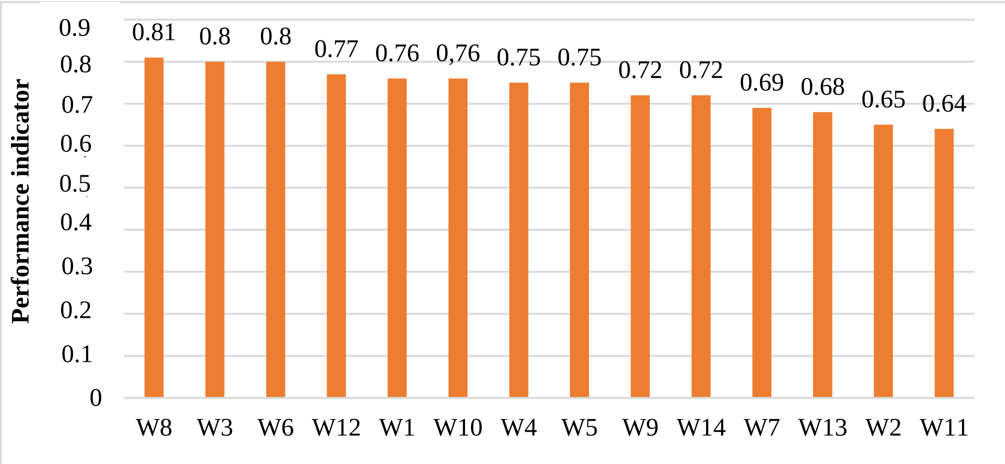

Fig. 2. Distribution of weaknesses by performance indicator values

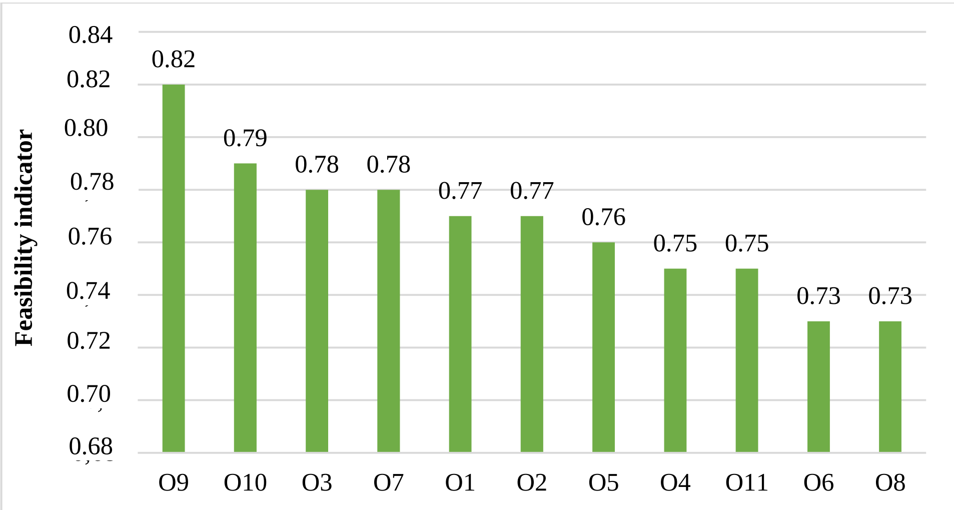

Fig. 3. Distribution of opportunities by the values of the feasibility indicator

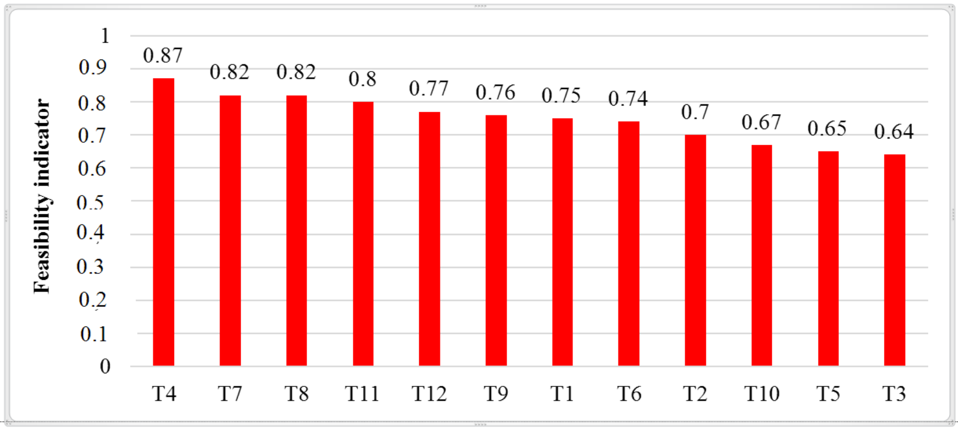

Fig.4. Distribution of threats by the values of the feasibility indicator

O7. Development of a water resources monitoring system;

O3. Improvement of infrastructure: modernization of dams and reservoirs and flexible reservoir management.

Thus, these areas should be considered as priorities for investment and development.

The study also assessed the feasibility of the identified threats. The higher the value of the feasibility indicator for a particular threat, the more likely it is that this threat may arise or worsen due to the impact of weaknesses. At the same time, strengths can offset or reduce these threats. Thus, for effective water resources management, it is necessary to take this indicator into account in order to understand the risks and plan strategies to minimize or eliminate them. According to the analysis (Fig. 4), it was found that the following threats have the highest feasibility indicator scores:

T4. Increased pollution of water resources by industrial, agricultural and household waste;

T7. Loss of biodiversity of aquatic ecosystems;

T8. Lack of effective water resources management;

T11. Threat to public health.

Threats with high feasibility scores indicate serious risks to water management. To minimize these threats, it is necessary to: introduce stricter regulations on pollutants, strengthen control over emissions from industry, agriculture, and domestic sources; introduce measures to protect aquatic ecosystems, including banning or restricting activities that harm biodiversity; develop and implement integrated approaches to water management, engage experts, and take into account international experience; ensure the quality of drinking water, and regularly monitor and respond to water quality problems. Implementation of these measures will require joint efforts of the government, the public and the private sector.

4. Conclusion

The data analysis points to key aspects that need to be considered to improve water management in the community. Strengths, such as the development of water supply and sanitation infrastructure (S2), availability of qualified staff (S8), and international cooperation (S10), if further developed and focused on, can contribute to more sustainable and efficient water management. At the same time, the most critical weaknesses need to be addressed, which include the uneconomical use of water (W8), lack of integrated management (W3), and uncontrolled use of water resources (W6). These challenges need to be addressed immediately to prevent further deterioration. At the same time, potential areas for investment and development, such as the revitalization of small rivers (O9), the development of integrated sewerage systems (O10), and the development of monitoring systems (O7), should be considered as a priority. Investing in these areas can help solve existing problems and strengthen community water resources. Indicators of the feasibility of threats, such as increasing water pollution (T4), loss of biodiversity (T7) and lack of effective management (T8), should be part of the ongoing risk analysis. Understanding these risks will help in formulating strategies to minimize or eliminate them.

Therefore, a water resources management strategy should be multidimensional, taking into account strengths, weaknesses, opportunities for development, and potential threats. The water management strategy should have a comprehensive approach that includes technical improvements, human resource development, international partnerships, and active community participation to ensure sustainable water management.

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DISSECTING BIOCHEMICAL MECHANISMS THAT MEDIATE TOLERANCE TO MILITARY CHEMICAL STRESSORS IN DIVERSE MALACOLOGICAL SYSTEMS

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Abstract. The ongoing military conflict in Ukraine has severely contaminated freshwater ecosystems with heavy metal pollutants including lead from ammunition and explosives. This study investigates the physiological and biochemical mechanisms of resistance in the freshwater mollusks. This study examines how freshwater mollusks, specifically *Planorbarius corneus* and *Viviparus viviparus*, resist lead compounds. Lead pollution from military activities poses a significant threat to aquatic life due to its toxicity and bioaccumulation. The research investigated species-specific responses to lead exposure, revealing differences in adaptations. Both mollusk species showed increased levels of carotenoids and proteins when exposed to higher lead concentrations, indicating a compensatory response to oxidative stress. These findings enhance our understanding of adaptive mechanisms against lead toxicity in aquatic environments affected by military pollution.

Keywords: environmental safety, military activity, molluscs, toxicants.

1. Introduction

According to the State Ecological Inspectorate of Ukraine, in the 500 days of of the war on the territory of Ukraine, Russia has caused losses of about 60 billion hryvnias as a result of man-made pollution, water pollution and unauthorized use of water resources.

The problem of heavy metal pollution of water bodies as a result of military operations is real and serious. Heavy metals, such as lead, cadmium, mercury and nickel are toxic to aquatic organisms and humans. It has been established that military operations can lead to the pollution of water bodies with heavy metals in several ways, metals in several ways. First, explosives used in military operations often contain used in military operations often contain heavy metals. During the explosion, these substances can form lead aerosols that can get into the water. Second, fires that occur during military operations can lead to the destruction of buildings and structures containing heavy metals.

This can lead to heavy metal spills into the environment, including water. Thirdly, household waste that is thrown away during military during military operations may contain heavy metals such as paints, batteries, and lead products.

This garbage can end up in water, where heavy metals can dissolve.

Lead (and its compounds) is one of the most poisonous heavy metals. It is found in all components of the environment: in rocks, soils, natural waters, the atmosphere, and living organisms, rocks, soils, natural waters, the atmosphere, and living organisms. Lead can actively disperse into the environment in the course of human economic activity. Lead is a poison that affects all living things, but especially causes changes in the nervous system, blood and blood vessels. It actively effects on protein synthesis, energy balance of the cell

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and its genetic apparatus. All lead compounds act, in general, it seems that the difference in toxicity is explained by by their unequal solubility in body fluids. Numerous observations show that even at high observations, even with a high content of metal ions in the body of animals, some indicators of their functional state can remain unaffected for a long time unaffected.

Lead compounds are not primary constituents in the explosive core of military ordnance. However, lead compounds have historically played several roles in the context of military ammunition and ordnance:

1. Lead compounds, especially lead styphnate and lead azide, have been used in the primers of ammunition. Primers are the small charge that ignites the main propellant in a cartridge or shell. When the firing pin of a firearm strikes the primer, it ignites, and this, in turn, ignites the main propellant that sends the bullet or projectile down the barrel.

2. While the explosive charge does not contain lead, the bullets themselves in many types of ammunition are made of lead or a lead alloy. Lead has been traditionally favored for bullets due to its density, malleability, and relative cheapness.

3. Some military ordnance, like certain types of torpedoes or other equipment, might use lead as counterweights or ballasts because of its high density.

4. Lead-acid batteries have been used extensively in military applications, from vehicles to backup power systems.

However, there has been a shift in recent years due to environmental and health concerns:

• The U.S. military and other organizations around the world have been moving toward "green bullets" or lead-free ammunition. This is primarily due to the environmental impact of lead as well as the health risks to personnel during training exercises.

• Efforts have been made to transition away from lead-based primers in favour of more environmentally friendly alternatives.

• At firing ranges and decommissioned military sites, efforts are often made to manage or remediate lead contamination, whether from bullets, lead-based primers, or other sources.

In summary, while lead compounds are not a primary component in the explosive material of military ordnance, they have historically been associated with various components of ammunition and other military equipment. Modern trends are shifting towards reducing or eliminating lead from these applications due to environmental and health concerns.

The release of lead compounds into water bodies as a result of military operations is a concern because of the potential impacts on environmental health and ecosystems, particularly aquatic organisms. Here's an overview of this issue:

Sources of Lead from Military Operations:

• Historically, bullets and shot for firearms have been made primarily of lead. When these bullets or pellets end up in water bodies, they can leach lead over time.

• Military bases often have firing ranges where substantial amounts of ammunition are discharged. If these ranges are near or within watersheds, lead can make its way into water bodies.

• Beyond ammunition, some military equipment and materials may also contain lead, though these are less commonly direct sources of aquatic contamination.

Toxicity of Lead to Aquatic Organisms:

1. Like many heavy metals, lead can be bioaccumulated. This means that organisms at the base of the food chain, like plankton or small invertebrates, might ingest lead. Predators that eat these smaller organisms can then accumulate higher concentrations of lead in their bodies, which poses a risk to any organisms that feed on them.

2. At high enough concentrations, lead can be directly toxic to aquatic organisms. This can lead to physiological disruptions, reproductive issues, or even death.

3. Even at lower levels, chronic exposure to lead can affect the growth, behaviour, reproduction, and overall health of aquatic species.

4. Some species are more sensitive to lead contamination than others, and exposure can lead to significant declines in their populations.

5. Once lead enters the food chain, it poses a threat not only to aquatic organisms but also to larger predators, including birds and mammals that feed on aquatic life. For example, waterfowl may ingest lead pellets directly, leading to lead poisoning.

6. If lead-contaminated water is used as a source of drinking water or if aquatic organisms with accumulated lead are consumed by humans, there are potential health risks. Chronic exposure to even low levels of lead can have harmful effects on human health, particularly in children.

Analysis of recent research and publications. In the work "Ecological safety of of Ukraine", M. Khylko warns that it is dangerous to eat fish caught in the waters of the Black and Azov Seas is dangerous to consume because of possible poisoning with fatal poisoning.

In their joint work, Garasym A., Kelm N. draw attention to Russia's seizure of water supply facilities, which leads to shallowing of rivers and reduction of flora and fauna in aquatic ecosystems. Also, the temporary supply of water to Crimea of water to Crimea may also result in an aggravation of water shortages both on the mainland mainland and on the peninsula. Basically, an increase in water resources to Crimea from the South of Ukraine resources to Crimea from the South of Ukraine is necessary because of the greater availability of water resources in the southern regions with water resources, as well as the water of the southern are the largest consumers. Another problem is the significant impact of climate change on of climate change on a drier climate in Crimea. Scientists say that starting in 2041 local surface runoff may stop in dry years in Kherson, Odesa, Mykolaiv, Dnipro, and Zaporizhzhia regions. For example, in Zaporizhzhia region, the "climate runoff" could decrease by 10 times, in Dnipropetrovska oblast – by 6 times, in Mykolaivska oblast – by 3.6 times, and in Crimea – by half.

Khylko M. in his work emphasizes: as a result of emergencies situations in operational water supply and sewerage facilities during the conduct of hostilities and due to the cessation of the functioning of enterprises in the the occupied territories, surface and groundwater is being polluted of the region. In particular, intense pollution occurs due to the failure of industrial and municipal industrial and municipal wastewater treatment plants, emergency discharges polluted waters due to power outages, as well as pollution by the combustion products of ammunition and because of fuel and lubricant spills materials.

The intensity of metal intake into the body depends on the form of the metal compound and the presence of complexing agents. Most of the metals accumulates in the kidneys, liver, bone tissue, spleen, and some glands of animals. They are usually bound to lipoprotein membrane formations.

Most often, irreversible binding of sulfhydryl groups occurs of enzymes. Changes in enzymatic activity lead to disorders of transport, respiration, and protein synthesis (Jorge, 2007).

The ability of aquatic organisms to accumulate metals has been used to indicate water pollution. The following organisms can serve as indicator organisms' aquatic organisms that have been in the study area for a long time.

Metals enter the body of aquatic organisms mainly with food. This was revealed in the absorption of zinc, cobalt, and iron by the mollusk Mytilus edulis. Aquatic organisms directly through body surface, gills, scales, and urine (De Lisi, 2013) excrete excess metals.

Cations Hg^{2+}, Cu^{2+}, Pb^{2+}, Zn^{2+}, Cd^{2+} inhibit the activity of adenylate cyclase in the smooth muscle tissue and hepatopancreas of freshwater bivalves (*Anodonta cygnea*) and gastropods (*Coretus corneus*, *Viviparus contectus*) molluscs in the following order: Hg^{2+}; Cu^{2+}; Pb^{2+}; Zn^{2+}; Cd^{2+} (Harbar, 2021).

The toxicity of substances for aquatic organisms is affected by the presence of other compounds, forms of the substance under study, water hardness, light and temperature conditions, oxygen concentration, pH, flow velocity, lighting, the presence of complexing agents, synergism, and the condition of biological objects. Toxicity can be determined by the ability of metals to concentrate (Gandziura, 2023).

Metals in the body of animals affect many vital organs, tissues, and structures, including the gills organs, tissues, and structures, including the gills. These toxicants change the function of blood; hearts of aquatic animals, damage the gills, and disrupt biochemical processes. All this is reflected in the overall functional state of aquatic animals and their respiration (Uvayeva, 2023).

Chemically active cell groups are sensitive to the action of metals, especially heavy ones, which are associated with the membrane, and as a result, the permeability of the membranes is impaired.

The high sensitivity of the respiratory function to toxic substances is due to by the fact that the respiratory surface of the gills of aquatic organisms is in direct contact with pollutants and is the first to be affected by them. With increase in gill ventilation in response to mechanical impact, the amount of of suspended particles that come into contact with the gills increases. All this causes damage to the of the epithelium and the entire gas exchange surface (Alam, 2023).

In the course of research, it was found that in case of intoxication with many chemicals in animals, the direct relationship between the activity of the between the activity of the gill ventilation apparatus and the activity of the heart (fish, daphnia, molluscs), as well as between the intensity of total gas exchange and the activity of cytochrome oxidase in in the gills of fish. The same disorders are observed in animals exposed to temperature, hypoxia, and hypercapnia (Shahbaa, 2020).

According to the results of our own field research of post-military water of the village of Moshchun, Bucha district, Kyiv region in the aquatic environment and bottom sediments of fishery and recreational water bodies were found all classes of heavy metals, including lead compounds, a highly toxic a highly toxic heavy metal. For all items, there are significant exceedances of the MPCs fish. (Maksymenko, 2022).

The aim of the study is to establish physiological and biochemical mechanisms of resistance of *Planorbarius corneus* L. and *Viviparus viviparus* L. to the effects of chemical war stressors (in our case, lead compounds). Thus, because the of the analysis, one of the main chemical stressors of war, which violates enantiostasis and homeostasis of hydroecosystems is lead and its compounds.

2. Materials and Methods

Before starting the study, animals were acclimatized to laboratory conditions for 14 days at temperature of 18-20 o C. pH = 7.2-7.4. In the laboratory, the mollusks were placed in glass 6 liter glass containers with 10 specimens each. To prevent the influence of their own exometabolites on the experimental mollusks, the water in the aquariums was changed daily with fresh water of the same quality every day. Only non-invasive individuals were selected for the study in order to avoid the influence of the biotic factor on the studied parameters. The animals were placed in Pb^{2+} solutions at concentrations of 1/2CL50, 1/4CL50, 1/8CL50. As a control was used settled (24 hours) tap water.

The toxicological experiment consisted of an orientation (aimed at determination of the CL50 value for individuals exposed to different concentrations of of selected pesticides and heavy metals) and the main experiment (3 concentrations (1/8CL50, 1/4CL50, 1/2CL50) were selected and used in the main experiment). The solutions were prepared in water dechlorinated by settling (1 day).

The used solutions were replaced with fresh ones after 24 hours. In the toxicological experiment, the exposure was 7 days. The experimental data obtained were processed using the "Excel" program package.

The content of total carotenoids was determined by the method of V.M. Karnaukhov (and modern modifications of the method) (Uvayeva, 2023). Chromatographic method for the separation of carotenoids. The method of thin-layer chromatography (TLC) involves the application of tissue extracts onto a silica gel plate with subsequent separation in a particular or other solvent system. Spectra of the visible region. This method is one of the of the criteria in the identification of carotenoids and is used for quantitative determination of the identified carotenoids. In the study, the spectra of the spectrophotometer SF-2000 were used in the study to take spectra of the visible region. The obtained spectra were compared with those described in the works of other authors (Jorge, 2007). After identification, the content of carotenoids in the sample was determined. To do this, according to the data absorption spectra, the optical density of the pigment at 450 nm was noted. After determining the content of each carotenoid, their percentage ratio was calculated.

The content of carotenoid pigments was determined in hemolymph, hepatopancreas, mantle, and foot. The content of total protein was determined by the Lowry method. The calibration graph was constructed in the range of concentrations from 0.025 to 0.250 mg of the standard protein sample by measuring the optical density of the solutions at 750 nm.

3. Results and Discussion

The creation of a compensatory of a compensatory reaction by the mollusk organism based on the variability of the amount of of carotenoid pigments and protein levels in the hemolymph.

Species specificity of carotenoid pigments and total protein content in the hemolymph of the studied freshwater mollusks under standard conditions of the aquatic environment.

According to the data obtained on the content of carotenoid pigments and and total protein in the hemolymph of mollusks (*Planorbarius corneus*, *Viviparus viviparus*) revealed species specificity. Thus, the content of total carotenoids under under standard conditions (t = 18 °C, pH = 7.2-7.4) in *Planorbarius corneus* is 0.3202 ± 0.0217 mg/100g of tissue, while in the foregill mollusk *Viviparus viviparus* is twice as high (Table 1).

The content of carotenoid pigments (β-carotene, xanthophylls) was determined in hemolymph, hepatopancreas, mantle, and foot (Figs. 1, 2).

Table 1

Content of total carotenoids (mg/100g) in the studied mollusks

Mollusc species	Carotenoid content
Planorbarius corneus	0.3202±0.0217
Viviparus viviparus	0.6942±0.0476

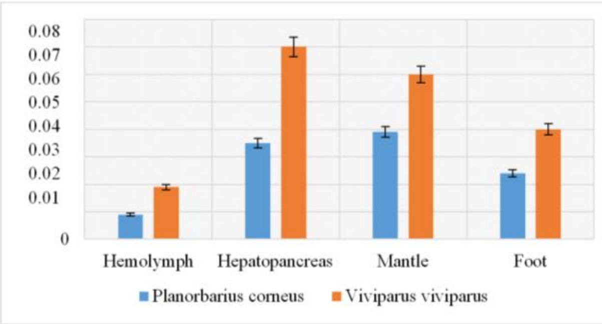

Fig. 1. β-Carotene content in Planorbarius corneus and Viviparus viviparus

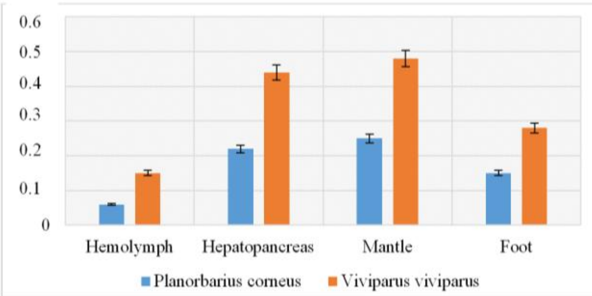

Fig.2. Xanthophyll content in Planorbarius corneus and Viviparus viviparus

The increased content of β-carotene and xanthophyll's was observed in the mollusk *Viviparus viviparus*. At the same time, their distribution is the same for the two mollusk species is characterized by an increased amount in the hepatopancreas and mantle.

The content of total protein in the hemolymph of molluscs is presented in Table 2.

The data obtained suggests that the species studied react differently to extreme environmental changes to extreme changes in environmental factors.

Planorbarius corneus.

The semi-lethal concentration (CL_{50}) of lead ions is – 0.13 mol/L^{-1}. When studying the effect of lead on the content of carotenoids in the tissues of in mollusc tissues, the results are presented in Table 3.

The content of carotenoids in the tissues of coils was significantly higher than in control animals at toxicant concentrations of $1/2CL_{50}$ and $1/8CL_{50}$. The results of lead exposure on the content of β-carotene and xanthophylls are shown in Figs. 3, 4.

In molluscs, the content of carotenoids in lead salt solutions in almost all concentrations increased, which confirms Karnaukhov's assumption about the role of carotenoids in overcoming environmental pollution. Thus, in biochemical sphere adequately responds to the effects of heavy metal salt in lungfish metal salt.

At a lead concentration of $1/2CL_{50}$, metabolic stimulation was detected, which led to a significant increase in β-carotene and xanthophylls in the foot by 2.7-2.9 times and in the hepatopancreas by 3.6-3.8 times compared to the control.

When studying the effect of lead on the content of total hemolymph protein of mollusks, the results presented in Table 4 were obtained.

Table 2

Total protein content (%) in hemolymph of P.corneus and V.viviparus

Type of mollusk	min-max	M±m
Planorbarius corneus	4.3-8.2	5.96±0.43
Viviparus viviparus	4.0-10.2	7.93±0.04

Table 3

Carotenoid content in mollusc tissues exposed to different concentrations of lead solution

Characteristics	Toxicant concentration			
	Control (pure water)	1/8 CL_{50}	1/4 CL_{50}	1/2 CL_{50}
Carotenoid content, mg/100g	0.3202±0,0217	0.6071±0,0602*	0.3703±0.0511	0.7253±0.0412*

* $P<0.05$

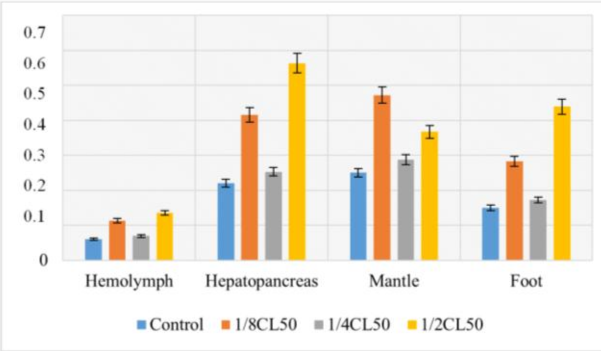

Fig. 3. The content of β-carotene in molluscs exposed to different concentrations of different concentrations of lead solution

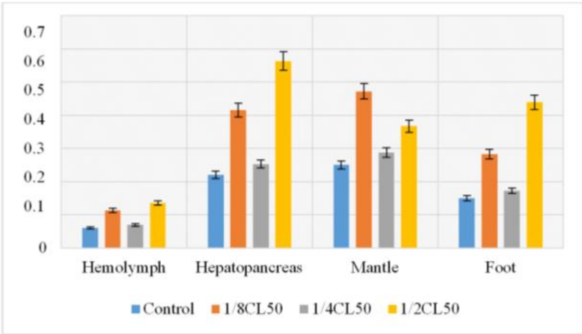

Fig. 4. Xanthophyll content in molluscs exposed to different concentrations of lead different concentrations of lead solution

Table 4

The content of total protein in the hemolymph of mollusks exposed to different concentrations of under the influence of different concentrations of lead solution

Controlling		1/8 CL_{50}		1/4 CL_{50}		1/2 CL_{50}	
Min-max	M±m	Min-max	M±m	Min-max	M±m	Min-max	M±m
4.3-7.1	5.21±0.43	5.6-8.7	7.89±0.17	5.0-6.5	5.42±0.11	4.7-6,9	6.0±0.16

Table 5

The content of carotenoids in the tissues of mollusks exposed t o different concentrations of lead solution

Characteristics	Toxicant concentration			
	Control (pure water)	1/8 CL_{50}	1/4 CL_{50}	1/2 CL_{50}
Carotenoid content, mg/100g	0.6942±0.0476	0.9611±0.0241*	1.1474±0.0475*	2.9828±0.1394*

* $P<0.05$

Table 6

The content of total protein in the hemolymph of mollusks exposed to different concentrations of under the influence of different concentrations of lead solution

Controlling		1/8 CL_{50}		1/4 CL_{50}		1/2 CL_{50}	
Min-max	M±m	Min-max	M±m	Min-max	M±m	Min-max	M±m
4.0-10.2	7.93±0.04	4.9-9.5	7.02±0.18	5.0-10.9	8,42±0.14	6.2-11.7	10.10±0.07

Under the influence of lead, the content of total protein in the hemolymph statistically increases statistically. This means that mollusks are in the second stage of the pathological process, namely the stage of process, namely the stimulation stage. The greatest increase was found at 1.5 times the concentration of 1/8CL_{50}.

Viviparus viviparus.

The semi-lethal concentration of lead ions is – 0.13 mol/L^{-1}. When studying the effect of lead on the content of carotenoids in the tissues of in mollusc tissues, the results are presented in Table 5.

The results of lead exposure on the content of β-carotene and xanthophylls are shown in Figs. 5, 6.

The content of carotenoid pigments in the tissues and organs of live births significantly increased at all concentrations of lead ions.

There was a significant increase in xanthophylls (2.3 times) in the hepatopancreas and foot at lead concentrations of 1/2CL_{50}. This indicates the development of a compensatory reaction of the body to the action of a toxic environment, and activation of free radical oxidation processes.

In the study of the effect of lead on the content of total protein in the hemolymph in the hemolymph of mollusks, the results presented in Table 6 were obtained.

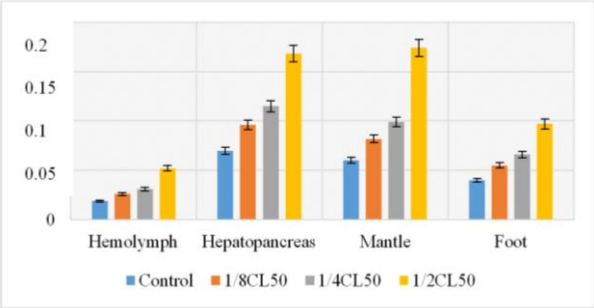

Fig. 5. The content of β-carotene in molluscs exposed to different concentrations of lead solution

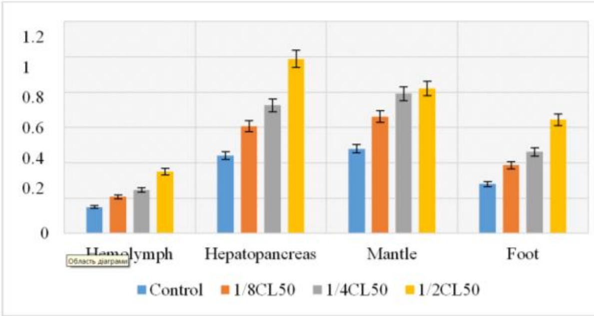

Fig.6. The content of xanthophylls in the organisms of mollusks exposed to different concentrations of under the influence of different concentrations of lead solution

Table 6

The content of total protein in the hemolymph of mollusks exposed to different concentrations of under the influence of different concentrations of lead solution

Controlling		1/8 CL_{50}		1/4 CL_{50}		1/2 CL_{50}	
Min-max	M±m	Min-max	M±m	Min-max	M±m	Min-max	M±m
4.0-10.2	7.93±0.04	4.9-9.5	7.02±0.18	5.0-10.9	8,42±0.14	6.2-11.7	10.10±0.07

After exposure of animals to a solution of 1/8CL 50, the metabolic rate slightly decreases slightly. The mollusks acclimatize to the conditions of this environment. At concentrations of 1/4CL_{50} and 1/2CL_{50}, an increase in total protein in the hemolymph, which indicates an increase in metabolism as a protective reaction of the organism.

4. Conclusion

1. As a result of the analysis, one of the main chemical stressors of of war, which disrupts the enantiostasis and homeostasis of hydroecosystems, is lead and its and its compounds.

2. To determine the adaptive mechanisms of *Planorbarius corneus* L. and *Viviparus viviparus* L. to the toxic effects of chemical warfare stressors, the compensatory reaction of the the compensatory reaction of the mollusk organism based on the variability of the amount of carotenoid pigments and protein levels in the hemolymph.

3. According to the data obtained for the studied mollusks for all studied indicators under standard conditions of the aquatic environment (without the influence of toxicants), species specificity was found. Thus, the maximum content of of carotenoids (β-carotene and xanthophylls) under standard conditions was noted in **Planorbarius corneus* is more than 2 times lower. Indicators of total protein in hemolymph of control animals are also species-specific. *V. viviparus*, this indicator is 1.3 times higher, compared to *P. corneus*. The data obtained suggest that the studied species respond in different ways to extreme changes in environmental factors environmental factors.

4. The content of carotenoid pigments and hemolymph proteins in two species of the studied mollusks increased significantly with increasing concentration of of lead chloride solution. The degree of resistance to lead compounds: *Viviparus viviparus=Planorbarius corneus*.

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IMPROVEMENT OF THE CLEANING SYSTEM OF OIL GAS FLOWS USING AN AERODYNAMIC INSERT

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Abstract. Air pollution is becoming a problem due to inefficient technological processes that accompany the mechanical processing of solid materials in various industries, including metalworking and woodworking, coal enrichment, coal burning in thermal power plants, metallurgy and construction materials industries. The problem is relevant for cement factories, since some of them use outdated equipment. Fine dust in this context becomes particularly important because the particle size of this dust affects the quality and grade of the concrete produced. Given the specifics of cement production and the goals of our research, which are to effectively collect small particles, it is important to note that wet cement production methods are not the best solution. The ideal solution for the problem of cleaning dust and gas flows in the cement industry is the use of a two-stage dust collection system, which combines an advanced cyclone and a bag filter. The system's periodic shaking mechanism allows for effective capture and control of fine dust particles, ensuring high quality cement production and reducing environmental impact. The combination of a cyclone, an acoustic coalescer and a block of bag filters, which is equipped with a periodic cleaning mechanism, as well as the addition of a system for collecting fine dust using a collector funnel, will split the collected dust into two fractions: fine (a = 10^{-5} to 10^{-7}m) and coarse (a > 10^{-4}m). The first fraction can be used to produce high-quality cement of high cost in the cement industry. The second fraction returns to the main technological process at its finishing stage.

Keywords: air, cement industry, cleaning, dust flows

1. Introduction

Cement dust and its constituent compounds (oxides of some metals) are harmful irritants to the respiratory tract. Excessive presence in the air of settlements and in the working zone causes irritation in the upper compartments of the lungs, leading to chronic diseases (such as bronchitis and tracheitis). In some cases, these processes can even result in oncological diseases.

Dust collection equipment, as per regulatory documents (particularly the state standard SSBP – GOST 12.2.043-82), is classified based on the physical phenomena occurring during their operation. They are divided into gravitational, inertial, filtering, and electrical types (Batluk, Paranyak, 2012). A more comprehensive approach, proposed in, categorizes all types of structures and equipment for protecting the biosphere from dust into two groups: dry and wet dust collectors (Polupindko,.Paranyak,, 2015).

All dust-collecting devices and devices in which the dry-cleaning method is implemented (Polupindko,. Paranyak,, 2015) are divided into three groups: dust-collecting chambers, the principle of operation of which is the action of the weight force (gravitational method); inertial dust collectors – the basis of the work is the forces of inertia; cyclones (battery cyclones) in which centrifugal forces prevail.

The efficiency of the conventional cyclones described above lies at the level of 60-80%, battery cyclones – 97-99%, bag filters – 99.5-99.7%, but due to the low heat resistance of synthetic fabrics (1300 °C) and glass fabrics (2300 °C) due to clogging of the filter element, their efficiency decreases over time.

The ideal solution to the problem of cleaning dust and gas flows for the cement industry is a two-stage dust collection system, which combines an improved cyclone with a bag filter, which, with the

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help of a specially designed mechanism, is periodically shaken (Grave et al., 2021).

2. Theoretical part

Existing dust collection systems are often cumbersome and will not always cope effectively with dust collection, especially when it has a wide range of particle sizes from 10^{-7}- 10^{-4}m. This problem is of particular importance in the cement industry, where production is accompanied by a wide variety of dispersed dust composition.

Significant is the fact that the production of cement has a high degree of influence on the quality of concrete, and this, in turn, directly affects the construction industry and the environment. Fine dust, qualitatively captured and controlled, can have a positive effect not only on the environment, but also on the economic state of cement production, since a high grade of concrete leads to an increase in demand for products. Thus, improved dust collection systems become key to achieving improved production efficiency and reducing its environmental impact.

A known dust collecting system comprising a double wall diffuser type cyclone, the outer wall of which is solid, and the inner perforated inlet and outlet branch pipes of dusty and purified air; respectively connected to a narrower and wider part of the annular gap of the diffuser; located in the annular gap of the spiral guide of dust air movement attached to the inner wall of the diffuser; acoustic emitter, outlet branch pipe of trapped dust, as well as a louver-type dispersed dust separator (Batluk, Paranyak, 2012). The dust collection system is described in sufficient detail on p. 93-95, and its scheme is shown in Fig. 21 (p. 94) of the specified monograph.

However, even with the presence of these dust-collecting systems, we face significant restrictions on their effectiveness, particularly in terms of dust collection. One of the main reasons for this is the inability of some systems to separate a fine dust fraction from the main stream of the dust-air mixture (Polupindko,.Paranyak,, 2015).

The acting forces characteristic of the known dust collection system – and this is gravitational, centrifugal, and at the last stage in front of the louver separator, acoustic coagulation, do not provide the necessary purity of the "purified" air.

It should also be emphasized that the fine fraction of certain types of industrial dust, in particular cement dust, is crucial for the quality of concrete. Thinner fractions of cement contribute to a high grade of concrete, and this, in turn, affects the strength of concrete structures and their resistance to aggressive environments, including precipitation.

Thus, the optimal solution to the problem of air purification in the cement industry requires the improvement of dust collection systems to ensure high quality products and reduce the negative impact on the environment.

In addition, it is important to note that in the case of catching fine dust particles together with other fractions, their further separation can be quite problematic, sometimes even impossible. This stage of the separation requires large financial and resource costs, which significantly increases production costs and complicates the technological equipment of the enterprise.

In practice, this can lead to a decrease in the competitiveness of the enterprise, since increased costs and process complications can affect the cost of production and product quality. The need for careful separation of fine dust particles creates serious technical and financial challenges for cement companies seeking to achieve a high grade of concrete and improve the economic result of their activities (Serebryansky et al., 2014).

3. Experimental part

Proposed dust collection system provides higher efficiency of dust cleaning and separate dust collection of fine dust. In the developed design of the dust collection system, the following stages of cleaning work:

– under the action of centrifugal forces in the annular space between the double wall of the cyclone body of the diffuser type;

– under the action of inertia forces in the same space, since the flow of dusty dust-air mixture is supplied to the narrower part of the diffuser;

– under the action of gravitational forces on particles of dust particles;

– centrifugal forces in the space between the inner wall of the cyclone body and the bag filter unit;

– under the action of inertia forces in the space between the perforated wall and the bag filter unit;

– under the action of acoustic field forces for short-term coagulation of fine-dispersed dust;

– under action of dynamic resistance forces passing through layer of porous material only particles of dust particles of smaller size (Yakuba et al., 2017).

Thanks to the above-mentioned cleaning steps, the dust collection system that we propose achieves a significant increase in its efficiency. This is achieved through an integrated approach and an optimal combination of different acting forces per fraction of dust during the purification process.

A special role in improving efficiency is played by the combination of a cyclone, an acoustic coalescer and a block of bag filters. This unit of bag filters is additionally equipped with a mechanism of periodic shaking, which contributes to increasing the duration of its effective operation (Dubynin et al., 2005).

It is also important to note the introduction of an addition to the dust collection system – a collecting funnel for fine dust. This allows the system to separate the trapped dust into two fractions. The first fraction, which contains fine dust, can be used to produce high-grade cement, which in turn is a product of high cost in the cement industry. The second fraction returns to the main technological process at its finishing stage, optimizing the use of resources and ensuring a more efficient production cycle. This integrated approach allows us to achieve optimal results both in terms of the production of high-quality cement and in terms of sustainable and effective dust management (Ratushnyak, Lyalyuk, 2005).

A schematic diagram depicting a dust collection system is illustrated in Fig. 1.

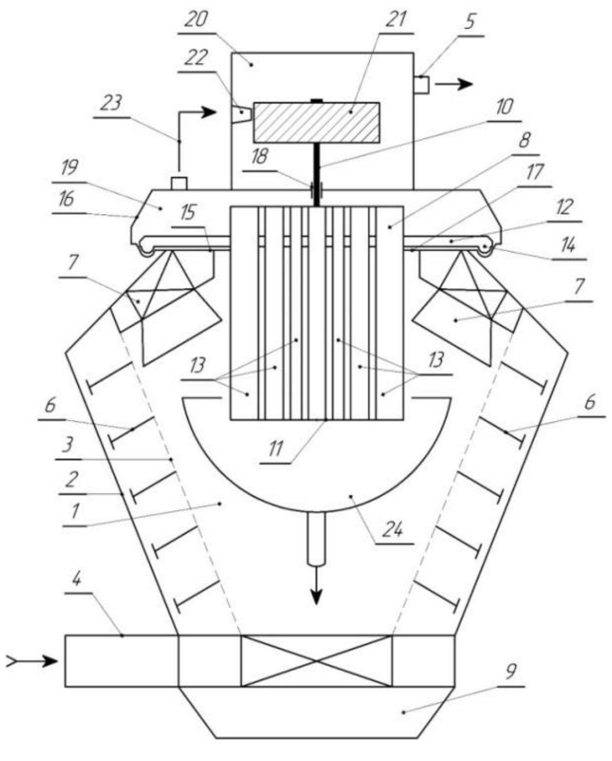

Fig. 1. Structural diagram of the dust collection system based on an improved cyclone, acoustic radiator-coalescer and aerodynamic insert in the form of a bag filter with a periodic shaking mechanism

The developed dust collection system contains a cyclone 1 of a diffuser type with a double wall, the outer wall 2 of which is continuous, and the inner 3 is perforated, the inlet 4 branch pipes of dusty and the outlet 5 branch pipes of purified air, which are respectively connected to the narrower and wider part of the annular gap of the diffuser. Located in the annular gap of the diffuser between the solid wall 2 and the perforated wall 3 is a spiral guide 6 for the movement of dusty air attached to the inner wall 3, the dusty air moving upward from below (Plashikhin et al., 2010).

Acoustic radiator 7 is installed in upper part of diffuser in annular gap between inner perforated wall 3 and finely dispersed dust separator 8, and in lower part of cyclone outlet branch pipe 9 is installed. In the developed dust collecting system, the fine dust separator 8 is made in the form of a block of bag filters (Petrushka et al., 2022).

The diagram of a bag filter unit can be found in Fig. 2.

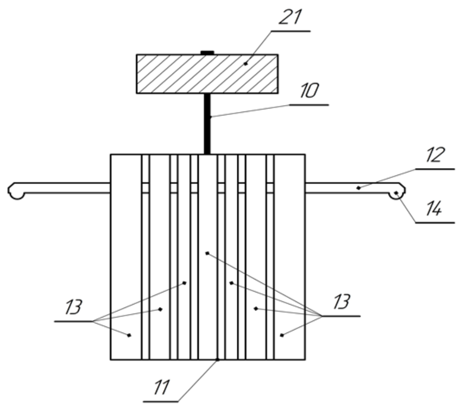

Fig.2. The diagram of a bag filter

It consists of arranged concentrically and rigidly fixed on shaft 10 between lower disk 11 of smaller diameter perpendicular to it and upper disk 12 of larger diameter, set of hoses 13 of different diameter from special filter material. The sleeves of the filter material along their length occupy at least 0.75 of the shaft length, and the sleeves of a smaller diameter are located closer to the shaft, and the sleeves of a larger diameter – further from the common shaft. The minimum number of sleeves is set from the aerodynamic relations of parameters (diameters and shaft rotation speed) to ensure conditions of uniformity of dust settling on the filter material (Petrushka et al., 2022).

Fig.3 shows the layout of bag filters in conic circles (minimum number – three), and each circle can be three or four.

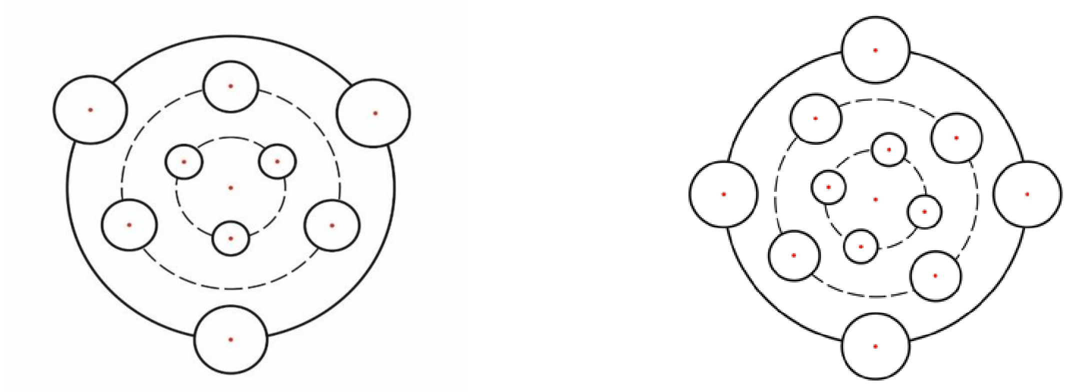

Fig.3. Layout of bag filters on the shaft

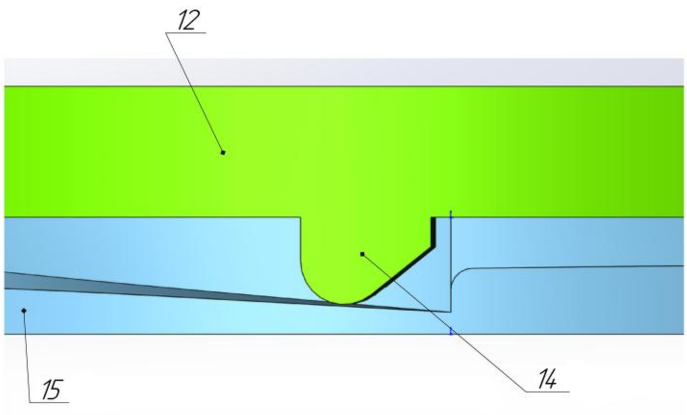

Fig. 4. A portion of the upper disc entering the annular depression of the upper flange that covers a portion of the cyclone body

The outlet of all the sleeves protrudes beyond the edge of the upper disc 12, on the lower surface of which there are uniformly protruding three or four support cams 14, which enter the annular depression of the upper flange 15, which closes the wider part of the annular gap of the cyclone body 1.

Part of the volume above the outlets of the bag filters, which is bounded from above by a solid partition 16, from below by a slot gap 17 between the flange 15 and the movable disk 12, and in the center of the partition 18 there is a gland seal 18 for the shaft 10 of the filter unit, forms a clean air chamber 19. Chamber of smaller diameter 20 for air turbine 21 with nozzle 22, which is directed to upper part of turbine wheel 21, and connected with clean air chamber 19 by means of air duct 23, is rigidly fixed on top of said partition 16, outlet branch pipe 5 of cleaned air is connected on opposite side of air turbine chamber (Petrushka et al., 2022).

The annular depression of the upper part of the flange 15, covering the annular gap of the cyclone body, has a profile, respectively divided into three or four zones, which are characterized by a sequential slow rise at an angle of 5-10 degrees, and a sharp descent in the opposite direction at an angle within 85-90 degrees. Thus, in the dust collecting system, it is possible to convert the rotational motion of the shaft of the bag filter unit to its inverse available for periodic shaking of fine dust from the filter surface of the bag filters into the collecting funnel 24. The above funnel is located inside the cyclone under the bag filter unit (see Fig.2), fine dust is collected in this collecting funnel, which is strained from the filter material of the bag filters (Petrushka et al., 2022).

In Fig. 4 shows in colour a part of the upper disc 12 with support cams 14 (movable member) entering the annular depression of the upper flange 15 (fixed member) which covers the wider part of the cyclone body 1.

The dust collection system operates as follows. The flow of dusty air, taken from the working zone, or from the technological apparatus under dynamic pressure, is directed to the lower (narrower) part of the diffuser-type cyclone 1 through its inlet branch pipe 4, and enters the space between its solid wall 2 and the inner 3 perforated wall. In this annular space a spiral guide 6 is arranged and rigidly fixed to the inner wall 3, by means of which the flow is swirled and raised upwards. Coarsely dispersed dust particles in the course of the dust-air flow (first heavier and then lighter) penetrate under gravel and centrifugal forces through the perforated holes of the inner wall 3 and descend through the branch pipe 9 of the collected dust into the collecting bin (not shown in the diagram, since the composition of the dust collection system is not included).

Dust-air flow with smaller particles of dust particles in the upper wider part of the cyclone 1 of diffuser type penetrates into its internal cavity. Here this flow is influenced by an acoustic field which is generated by an acoustic radiator 7 which is in the form of an annular diffuser. It is attached to the inside of the confuser, which covers the wider part of the cyclone, and promotes coagulation (enlargement) of small dust particles into their larger fractions. The flow of enlarged dust particles under the influence of gravitational forces is spontaneously divided into two flows: larger (coarser) dust particles fall down towards the branch pipe 9, and then into the bunker, and the rest are somewhat smaller, reflected from the separator 8, also fall, like the previous ones, into the bunker. But some of them, thanks to their small tonus, fall into the collecting funnel 24.

And the smallest (finely dispersed dust particles that have not undergone acoustic coagulation) fall into the zone of the separator 8, specially designed in the form of a block of bag filters (see Fig. 2).

A characteristic feature of their design is that bag filters are made from a combination of natural and synthetic fibrous materials, mainly from organic high-molecular compounds. Their specific composition is selected taking into account the range of operating temperatures of the dust-air mixture. Depending on the performance of the dust collection system, which is related to the power of the sources of generation and emission of the dust-air mixture, we recommend the smallest number of concentric circles, on the trajectories of which three or four sleeves are located, in accordance with Figures 3a and 3b. In each specific case for variants 3a and 3b on each of three concentric circles, fabric sleeves should be located on the basis of condition of maximum blowing by dust-air flow which is achieved by change of angular distance between sleeves on each trajectory.

Thus, the captured fine dust particles at the first moment of time from the beginning of the dust collection system operation accumulate on the surface of the filter material of the bag filters, and at a certain thickness, the efficiency of the filter material of the bag filters begins to decrease.

In the proposed dust collection system, in order to avoid this drawback, a periodic shaking mechanism developed by the authors operates. It is formed by two units, which include the upper part of the cyclone body (flange 15 as a fixed element) and the upper disk 12 of the bag filter unit with support cams 14 on its lower part. The periodic shaking mechanism for cleaning the filter surface of the bag filters operates according to the following algorithm. The dust-free air leaves the inside of the bag filters, the upper side of which protrudes slightly beyond the edge of the upper disc 12 of the bag filter unit, and enters the clean air chamber 19, which is formed by the upper flange 15 on the underside and the solid partition 16 on top. From the chamber of air 19 through the air duct 23 into the chamber of 20, of smaller diameter behind the chamber of 19 clean air, in the chamber 20 on the upper part of the shaft 10 the block of bag filters the air turbine of the 21 is rigidly fixed. At the level of the upper edge of the air turbine 21, a nozzle 22, which is also rigidly attached to the inside of the chamber 20, and connected to the air duct 23, fits closely. At the same time, under the action of the reactive force of the air jet, the turbine 21 rotates, and with it the entire block of bag filters. The support cams 14 located on the lower surface of the disc 12 move along the annular depression of the upper flange 15, which covers the wider part of the annular gap of the cyclone body 1. Due to the special profile of the annular depression on the upper surface of the flange 15, the bag filter unit first slowly rises, and then sharply falls down under its own weight, while shaking off the dust accumulated on the surface of the filter material. Due to this, the filtering ability of the specified material is restored, and in the next period of rotation the procedure is repeated. Such cycles during one full circle can be three or four, depending on the features of the selected design of the dust collection system, and this number is determined after several tests of the developed system, taking into account technological requirements. These requirements are generally included in the parametric and structural complexes, which can be used in the calculation of the dust collection system (Petrushka et al., 2022).

Construction of the dust collection system in compliance with all the conditions described above improves its performance, in particular increases the efficiency of dust collection, and also provides separation of finely dispersed fraction.

4. Conclusions

The introduction of the proposed system, which includes two elements – a cyclone and a bag filter, built in a single structure or complex housing, will be very effective for automatically shaking the captured fine dust into a special collecting funnel. It is important to note that before this shaking process in the inter-hull space of the cyclone, thanks to the spiral guide, according to the described features of its design, the dust cleaning efficiency is significantly increased and can compete with the existing bag filters of the GAL-GLk series of Agricon, the DLMV series of Donaldson and FRIR (purification degree 95 – -99.8%).

The effectiveness of this dust collection system, in particular in the context of cement production, determines the improvement of the environmental situation in the sanitary protection zone. Obtaining a fine fraction allows the manufacturer to obtain high-quality cement. At the same time, in the technological process of manufacturing concrete products, their strength, as well as the cost, will be much higher. This integrated approach not only contributes to the effective reduction of environmental impact, but also provides the company with competitive advantages, improving product quality and economic performance.

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