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AGRICULTURAL DETERMINANTS OF BIOGENIC POLLUTION OF SURFACE WATERS IN THE DNIPRO RIVER BASIN

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The necessity of conducting research on the impact of sources of pollution of the Dnipro River depending on their impact is determined. It has been established that the Dnipro River basin is a multi-sectoral complex that covers 48% of the territory of Ukraine and accumulates 80% of water resources. It is noted that the Dnipro River basin has a high natural and socio-economic value, as it meets the drinking needs of 70% of the population of Ukraine. It is established that the sources of water pollution are industrial complexes, agriculture, and urban agglomerations. It is proved that deforestation, intensification of agriculture, hydromelioration, the functioning of the Dnipro reservoirs cascade, and intensive use of water resources are the causes of the Dnipro River basin destruction. It has been determined that agricultural development of the catchment areas has caused soil erosion, which is the most important mechanism of substance migration on the earth's surface, causing up to 17 billion tons of mineral particles and 3.5 billion tons of dissolved substances to enter the seas, oceans and internal runoff zones annually. It is established that high concentrations of mineral particles in surface runoff reduce water quality, which requires additional costs for their treatment, repair of the water supply network, and restoration of irrigation networks. The article has calculated the zonal hazard of nutrient pollution of surface waters within the multi-level sub-basins of the transboundary Dnipro River, which is a consequence of soil-erosion processes. It is established that the sub-basins located in the mixed forest zone or the upper part of the transboundary river Dnipro have the lowest potential for diffuse pollution by suspended solids. It is proved that in order to assess the degree of danger of soil-erosion pollution of water bodies with phosphorus, it is necessary to establish "ecologically limiting" values of the actual concentration. It is proved that the river sub-basins of the Lower Dnipro River, located in the steppe zone, are potentially dangerous in accordance with the indicators of dissolved phosphorus concentration in the waters. The necessity of developing adaptive landscape erosion control projects with elements of soil protection agriculture is determined.

Keywords: biogenic pollution, erosion, land-use, Dnipro River, catchment area, modeling.

Statement of the problem. One of the largest transboundary rivers in Europe is the Dnipro River with a basin area of about 511 thousand km², 57.3% of which is located within Ukraine. The Dnipro basin covers more than

48% of Ukraine's territory and accumulates about 80% of its water resources, which satisfies the food and drinking needs of more than 70% of Ukraine's population [1]. The Dnipro River basin is a diversified complex with high natural and socio-economic value. However, the current state of the catchment area is characterized by a complex and tense environmental situation caused by economic activity and military aggression by russia.

Large industrial complexes (over 60% of industrial production), agricultural land (agrogenic transformation of the basin in general is over 55%, and over 70% within part of Ukraine), and the largest urban agglomerations are concentrated in the Dnipro basin. Deforestation, chemicalisation of agriculture, hydromelioration, the operation of the Dnipro reservoirs cascade, intensive use of water resources (over 5000 million m^3 per year) and discharge of significant volumes of polluted water (over 400 million m^3 per year), etc. have had a destructive impact [2–4].

The environmental situation has been further complicated by the consequences of russia's full-scale military invasion of Ukraine. The aggressor country not only takes the lives of thousands of people, but also exerts catastrophic pressure on the environment of our country, destroying the species composition of flora and fauna, polluting water sources, destroying the fertile soil layer, poisoning it with oil products and heavy metals. The state of water resources is adversely affected by shell bursts, flooded vehicles, fuel and lubricant spills, damaged or destroyed dams, coastal abrasion, destruction of bridges and construction of artificial water retaining structures, creation of fortifications in coastal water protection zones, destruction of floodplain ecosystems, and destruction of sewage treatment plants with subsequent discharge of untreated sewage into natural sources. Thus, the intensity of economic impact and the consequences of military aggression have been the reasons for the transformation of the territories and waters of the Dnipro basin, which necessitates the search for rational ways to restore ecological systems, optimize natural resource use and integrated river basin management.

In this context, the search for an optimal mechanism of rational environmental management based on the principles of anti-erosion organization of the territory aimed at preserving soil fertility and reducing the level of diffuse pollution of surface waters becomes more relevant.

It has been established that erosion is a single complex of processes of soil cover destruction, movement and redistribution of sediments on slopes during surface water runoff, which causes the process of migration and redistribution of mineral and chemical substances in landscapes and the land-ocean system [5–7]. Soil erosion is the most powerful mechanism of substance migration on the earth's surface in the agriculturally developed areas of catchment basins [8, 9]. With the flow of rivers (about 45 thousand km^3), 17 billion tons of mineral particles and 3.5 billion tons of dissolved substances enter the seas, oceans and inland runoff zones annually [10]. The significant impact of natural and anthropogenic erosion on the formation of the basin component of river sediment runoff is evidenced by a 5-8-fold increase in sediment runoff modules from agriculturally developed lowland river catchments [11; 12].

It has been determined that two consequences of soil-erosion migration are of the greatest importance for assessing the ecological state of landscapes and surface waters [1]: 1) removal of nutrients from arable slopes, primarily biogens (nitrogen, phosphorus and potassium – NPK) contained in the soil and applied fertilizers; 2) reduction in the quality and pollution of water resources due to erosion accumulation of mineral and chemical substances, including toxic and radioactive ones.

In recent decades, against the backdrop of declining natural soil fertility [13–15], there has been a significant increase (2-fold) in global grain production due to the intensification or “chemicalisation” of agriculture [16]. This has led to a significant increase in soil-erosion migration of highly toxic substances (heavy metals, pesticides, radionuclides) and deterioration of the ecological state of a large part of the catchment area, erosion and channel systems outside the primary sources of pollution. Biogenic substances entering aquatic ecosystems together with mineral substrate from slopes contribute to eutrophication of water bodies and reduce the quality of water resources [17; 18]. The sources of nitrogen, phosphorus and potassium in natural waters are industrial and domestic wastewater, but the bulk of the total nutrient inputs come from agricultural sources [19; 20]. The modulus of river runoff of phosphorus from agriculturally developed areas is 10-15 times higher than that of forested areas [1].

It has been established that high concentrations of mineral particles in surface runoff reduce water quality [21], which requires additional costs for water treatment, repair and restoration of irrigation networks, and in the long term will cause siltation and degradation of river systems. Erosion removes both gross and mobile forms of nutrients from the topsoil. Gross forms have transferred with soil washout, while mobile forms have transferred with melt and rainwater runoff. Mineral nitrogen is carried away mainly by surface water, while phosphorus, which is most strongly bound to the soil substrate, is carried away with small soil particles.

The greatest losses of nutrients are observed in the cultivation of row crops, less – In fields occupied by continuous sowing crops, annual and perennial grasses. The insufficient duration of the observation series, the lack of a single methodology and the variety of research conditions do not make it possible to determine the rate of nutrient removal for any natural zone [22], it can be noted that the intensity of gross removal of mobile forms of NPK is proportional to the intensity of mineral substrate flushing, and the removal of mobile forms with sediment runoff is an order of magnitude higher than the removal in solution.

From an ecological perspective, it is important to assess the migration of mobile forms of nutrients (yield reduction, eutrophication of water bodies). Their content in sediments, as well as the proportion of dissolved substances, depends on many factors: erosion intensity, crop cultivation technology, season, etc. Depending on these factors, the ratio of total nutrient removal to dissolved sediment varies widely. The concentration of ions in summer floods is 1.8–3.1 times higher than during floods [23].

It has determined that at a sufficiently high spatial variation of migration of mobile forms of biogens (up to 60–70%), determination of their quantity is impossible without erosion modeling, which describes each local episode of runoff in separate catchment basins of different orders (such as the RUSLE model) [24; 25]. At the present stage, the territorial assessment of nutrient migration can be carried out based on actual data on the content of their gross and mobile forms in arable soils of the regions and the territorial distribution of the intensity of mineral substrate washout from arable land. Thanks to soil surveys, the territorial distribution of nutrients on arable land is presented in national atlases, reference and scientific literature.

It has been established that the content of biogens largely depends on the humus content and mechanical composition of soils, which allows the use of soil maps reflecting the distribution of genetic soil types and their particle size distribution for territorial assessments [26]. For example, the average gross phosphorus content in sod-podzolic and light grey forest soils is 0.05–0.16%, in grey forest soils – 0.10–0.20%, in dark grey forest soils – 0.12–0.28%, in podzolic, leached, typical and ordinary black soils – 0.17–0.35%, in southern black soils – 0.14–0.19%, in chestnut soils – 0.03–0.16%. The content of mobile forms of nutrients, especially nitrogen, varies depending on the composition of the parent rocks, the season, and the amount of fertilizer applied. On an area of several hectares, the coefficients of variation in the content of mobile phosphorus can be up to 56% and potassium up to 51% [27].

Analysis of recent research and publications. According to the research of I. P. Kovalchuk [28], in Western Podillia, the average value of the coefficients of sediment transport beyond the slopes from flushing has been in the range of 18–24%, in ploughed catchment areas with melt water runoff in the range of 44–54% and with storm water runoff – 38–51%. For many regions, the accumulation of sediment mass from slopes within the land network ranges from 50 to 70%. It is believed that in flat areas, on average, no more than 10–20% of the total amount of sediment from slopes enters rivers [29].To date, models of soil erosion and soil-erosion migration of chemicals and sediments have been developed that simulate water runoff, transport and accumulation of sediments within slopes and small (up to 400 ha) field catchments – the CREAMS and WEPP models [30]. However, it is currently impossible to obtain primary input data for large-scale assessments using these models.

Klymenko O. [31] in his works has noted that the river basin is a complex socio-economic and ecological system with the definition of general and additional classification features that should be used to develop a strategy for sustainable development of regions. Korobov R. in his co-authorship [32] considered the river basin as a natural unit that has the greatest vulnerability to climate change. Dyakov O. [33] emphasized the need for wide and consistent implementation of the principles of management and legal regulation in the field of use and protection of water bodies based on the basin approach. Shveebs G. [34] proposed the allocation and study of natural and economic units on the basis of the basin approach in order to optimize nature management. Scientists M. Klymenko [35], O. Likho [36], and I. Netrobchuk [37] noted that a small river basin is a complex self-regulating system that has the ability to function regardless of changes in external conditions and is an important indicator of the environmental condition of transboundary catchment areas, due to the level of anthropogenic load on its components of landscape ecosystems, which are a set of biogeocenoses on a homogeneous area of the earth's surface, interconnected by genetic (by origin), historical (history of development and exploitation), geochemical (geochemical compounds, water runoff, transfer of organic and mineral substances) and biotic links (animal migration, transfer of spores and living plant material) and covered by a certain type of economic use [38].

Objective. To establish the patterns of biogenic pollution of surface waters of the Dnipro River basin as a result of extensive agricultural land use.

Research methods and materials. The calculation of the zonal hazard of nutrient pollution of surface waters as a result of soil-erosion processes was carried out within the multi-level sub-basins of the transboundary Dnipro River. Preliminary hydrological modeling [39] has identified 776 sub-basins ranging in size from 1.9 to 22680.2 km² of the IV–IX orders. The total length of the erosion network of the Dnipro River basin is 53267.3 km, including 90% of the length of watercourses of 1–4 orders. The area drained by thalwegs of the 1st–4th order is 58.4%, 5th and 6th order – 33%, 7th–9th order – 8.6%. Thus, the main channel is fed with sediments from the upper and middle reaches (91.4%), while the lower reaches of the Dnipro River are fed with local sediments (1.8%).

The erosion potential of the Dnipro River catchment has deen previously assessed based on the calculation of average annual flushing rates in the spring and summer period using the modified empirical and statistical model RUSLE (Revised Universal Soil Loss Equation) [5; 11]. As a result of the geomodelling, a raster model has been created that enabled quantitative assessment of mineral substrate washout and nutrient removal from slopes based on a single methodology for quantitative territorial erosion assessment.

Sediment load reduction in large watercourses and rivers is assessed using the 'sediment input coefficient' (Kn). For the Dnipro River sub-basins, Kn was calculated using the following formula:

$$K_n = 0.25F^{0.2} \quad (1)$$

where, F – raster of the basin or sub-basin area, ha.

The calculation of diffuse pollution by suspended solids (DPSS, thousand tons) in the Dnipro River basin as a result of the water-erosion process has been carried out using the ArcGIS Raster Calculator using the formula:

$$DPSS = \frac{F \cdot P \cdot A \cdot K}{100} \quad (2),$$

where, F – raster of the catchment area of a catchment basin or sub-basin, ha; P – raster of the ploughed area of a catchment basin or sub-basin,%; A – raster of suspended solids removal from arable land with runoff, t/ha; K – raster of the coefficient of suspended solids reaching the river network (from 0.10 to 0.20).

To spatially assess the potential of soil-erosion phosphorus concentration in channel streams at the foot of the slope, we used the indicator of conditional concentration of gross phosphorus (CCP, mg/dm^3), which is calculated by the formula:

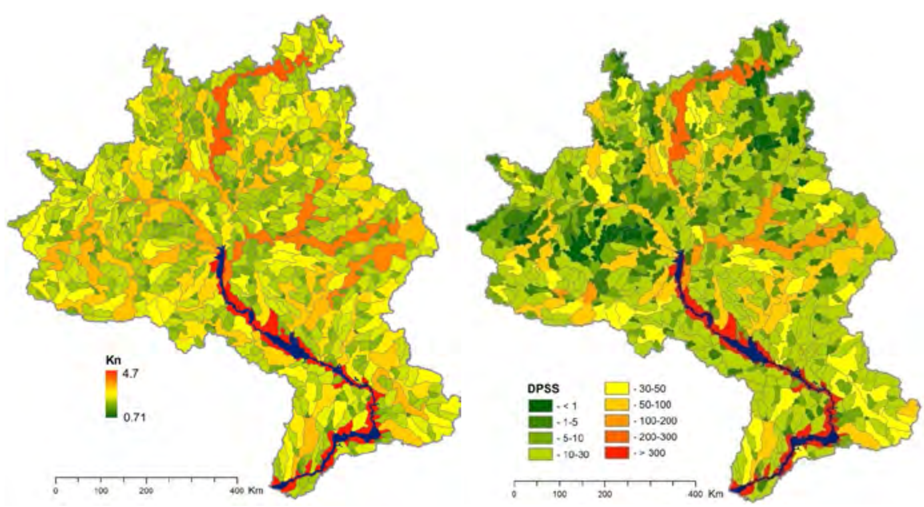
$$\mathrm{CCp} = \frac{10 \cdot \mathrm{A} \cdot \mathrm{S} \cdot \mathrm{P}}{H} \quad (3),$$

where A is a raster of the intensity of leaching on arable land, t/ha; S is a raster of the share of arable land in the catchment, %; P is a raster of the gross phosphorus content in the arable layer, %; H is a raster of the average long-term surface water runoff layer (mm).

In order to identify the factors of soil erosion processes and potential surface water pollution in the Dnipro River basin, satellite images were interpreted to determine the share of arable land in the catchment area and soil and climate maps have been vectorised to obtain spatial rasters of the average long-term surface water runoff layer and gross phosphorus content in the arable layer in the soils of the Dnipro River basin. ArcGIS 10.6 software has been used for spatial analysis and modeling.

Research results and discussion. Over the past 20–30 years, the phosphate content of wastewater entering the wastewater treatment plants of cities fed by the Dnipro River has increased tenfold. In addition to deviations from the norm of sanitary and chemical indicators, there is an increase in microbiological and viral contamination, and there is constant natural and anthropogenic destruction and landslides in the coastal zones of the Dnipro River, especially in the buffer zones of reservoirs. A preliminary analysis [2] of the degree of ploughing and forestation indicates high environmental vulnerability and severe degradation of land resources on more than 70 per cent of the transboundary basin, which leads to significant disruption of the functioning of the Dnipro River geohydroecosystems. Regulation of the river's flow as a result of the construction of six reservoir cascades has led to stagnation of water, intensive accumulation of erosion products and waterlogging of a large part of the Dnipro, especially in the lower reaches of the river [40]. The significant deterioration in the quality of the Dnipro water, which has been used for drinking purposes by 70–80% of the population of Ukraine, greatly complicated the process of its preparation to the level of drinking water quality, as the water treatment plants on the Dnipro were built about 40–50 years ago and are designed for higher (class I-II) water quality than the one we have in the middle and lower reaches of the transboundary river today (class III–IV). Therefore, the implementation of modern, scientifically based soil and water protection measures developed on the basis of basin management approaches remains an urgent and priority task [41; 42].

Erosion and slope geosystems are the upper link of the cascade erosion and channel system, which is the main source of water and sediments for the lower links. Assessment of the impact of the soil-erosion component of nutrient migration on water pollution should take into account the peculiarities of sediment transport on slopes on pasture and forested slopes paragenetically linked to arable land, and, most importantly, the transformation of sediment runoff in the lower parts of erosion channel geosystems (in the land network and rivers). Most of the erosion products have transported to the lower unploughed areas of slopes, to the bottoms of gullies and beams, and to the floodplains of small rivers. The intensity of accumulation depends on many factors: the spatial



a *b*

Fig. 1. **Reduction of sediment runoff (*a*) and diffuse pollution by suspended solids (*b*) in the Dnipro River sub-basins**

distribution of different lands, the density of terrain dissection, and the territorial structure of landscapes in the catchments.

It has proposed to use the dependence of the "sediment supply coefficient" (Kn) on the river basin area for spatial modeling of changes in the mass of migrant biogens within the erosion channel systems of the Dnipro River basin. The spatial assessment of sub-basins by Kn has shown in Figure 1*a*.

One of the most important integrating indicators of the agricultural load on water bodies in the Dnipro catchment area is diffuse suspended sediment pollution (DSSP), which occurs through the washing away of agricultural land with the subsequent accumulation of pesticides and chemicals used in intensive agriculture in water resources. In addition, local sources of pollution, or “hot spots”, should be taken into account, including discharges from sewage treatment plants in large cities in the direction of the Dnipro River.

The vast majority of sub-basins (about 95%) with an DSSP value of less than 5 thousand tons per year (Fig. 1*b*) have located in the mixed forest zone (upper reaches of the Dnipro River) and cover about 82.2 thousand hectares or 16.1% of the total area of the transboundary basin (Table 1). Almost 91% of the catchment area of the Dnipro River basin has had a value of the DSSP of less than 100 thousand tons per year, including 38.14% of the area where the DSSP varies between 10–30 thousand tons per year. For 9.16% of the transboundary basin, the value of the DSSP is more than 100 thousand tons per year, including the territories of sub-basins of the VI–IX orders.

Table 1. **Distribution of the territory by the level of diffuse pollution by suspended solids in the Dnipro River basin**

DSSP, thsd tons	area, thousand km²	% of the total area
< 1	18.9	3.70
1–5	63.3	12.40
5–10	66.4	12.99
10–30	194.9	38.14
30–50	55.8	10.93
50–100	64.9	12.70
100–200	14.9	2.92
200–300	9.1	1.79
> 300	22.7	4.45
Total	**511.0**	100.0

Surface runoff from slopes is only a part of the surface river runoff, which also includes groundwater and overflow, the share of which in the total surface runoff varies in landscape zones, which makes it difficult to directly calculate the removal of biogens at monitoring runoff sites.

On the territory of the transboundary Dnipro basin, the factors influencing the CCP (Fig. 2) have a marked latitudinal zonation. The average long-term layer of surface runoff (H, mm) decreases from 290 to 5 mm in the direction of the Dnipro River flow (Fig. 2*a*).

For subbasins in the mixed forest zone, the *H* value is 51–290 mm with a variation level (V%) of 38.0%, in the forest-steppe zone, the *H* value is 45–140 mm (V – 33.5%), and in the steppe zone, the *H* value is 5–56 mm (V – 44.5%). The share of arable land in the watershed (*S,*%) of individual sub-basins in the mixed forest zone (Fig. 2*b*) is within 0–56% (V – 58.0%), in the forest-steppe zone *S* – 0–60% (V – 30.7%), in the steppe zone *S* – 10–76% (V – 39.0%). The average value of gross phosphorus content in the tilth layer (*P*,%) of agricultural landscapes of catchment sub-basins in the mixed forest zone (Fig. 2*c*) varies from 0.02 mm/dm³ to 0.21 mm/dm³ (V – 53.3%), in the forest-steppe zone *P* – 0.03–0.32 (V% – 23.5%), in the steppe zone *P*– 0.06–0.32 (V – 19.7%).

Zonal changes in the erosion potential of precipitation, soil erosion, relief factors, land use culture and the implementation of soil protection measures determine the specifics of the territorial distribution of the intensity of water-erosion processes, primarily on arable land (*A*, t/ha). The intensity of washout on arable land in the transboundary basin of the Dnipro River in some local territorial units reaches the level of 29 t/ha (Fig. 2*d*). On average, in the mixed forest zone, the *A* value is: on the plains – up to 6.2 t/ha, on the slopes – up to 9.0 t/ha; in the forest-steppe zone: on the plains – up to 3.6 t/ha, on the slopes – up to 6.4 t/ha; in the steppe zone: on the plains – up to 2.4 t/ha, on the slopes – up to 6.5 t/ha.

On the basis of the presented raster models, the indicator has been calculated and a spatial model of the distribution of soil-erosion potential of phosphorus concentration in channel streams at the foot of the slope within each sub-basin of the Dnipro River was created (Fig. 3). Surface waters formed in the catchments of the forest-steppe and steppe zones of the transboundary basin have had the highest values of CCP, which increased the risk of eutrophication and overgrowth of water bodies and river channels in these zones.

The spatial concentration of gross phosphorus from north to south (Fig. 3*b*) and from west to east (Fig. 3*c*) in the Dnipro basin has increased exponentially, due to the high degree of ploughing and low values of the average annual water runoff layer compared to the forest zone. In river sub-basins with a high degree of ploughed slopes, the risk of water pollution increases as soil-erosion intensity of phosphorus removal increases.

The main factor in the zonal differentiation of phosphorus inputs to water bodies is the river runoff layer, the modulus of sediment runoff from slopes and the degree of ploughing of individual sub-basins. In the catchment area, these factors increase the relative and absolute phosphorus supply to water bodies in the direction of the Dnipro River flow (from north to south).

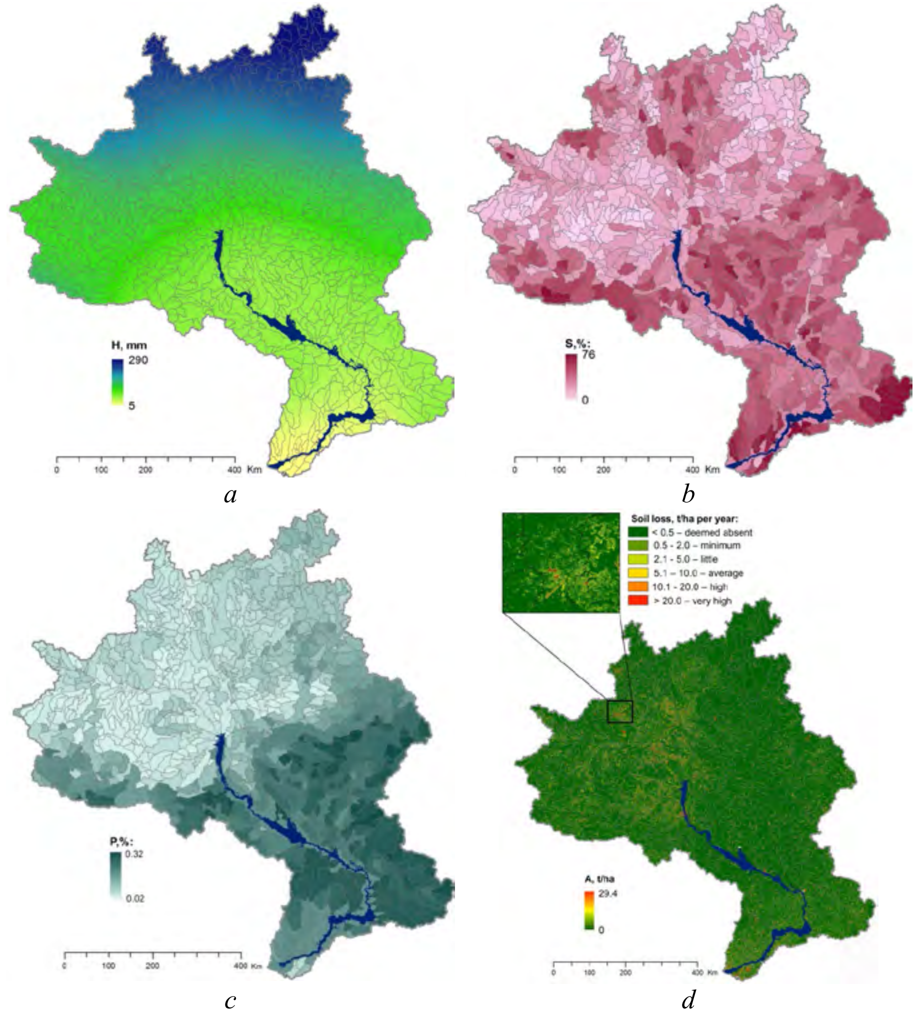
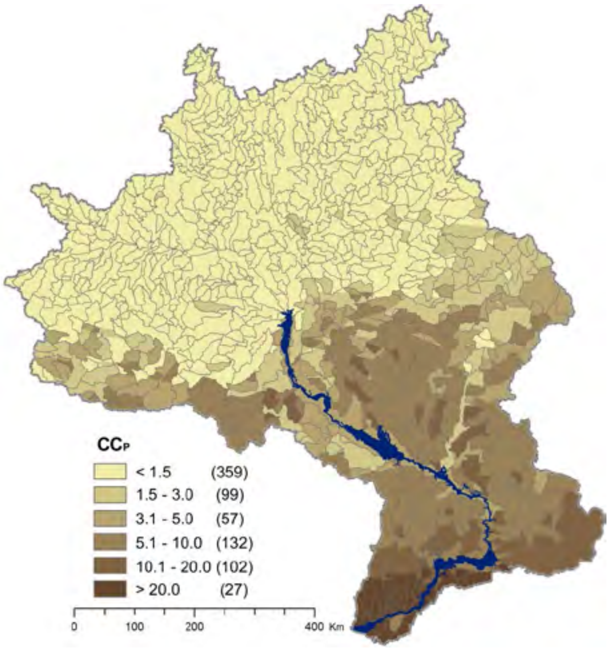


Fig. 2. **Distribution of factors influencing the risk of phosphorus pollution of surface waters in the Dnipro River basin:**
a **– average perennial layer of surface water runoff (H, mm);** ***b*** **– share of arable land in the catchment area (S,%);** ***c*****– gross phosphorus content in the arable layer (P,%);** ***d*** **– intensity of leaching on arable land (A, t/ha)**

The actual concentration of dissolved phosphorus in river waters is much lower than the CCp value, because the CCp indicator takes into account all the gross phosphorus carried away from slopes, and river waters are highly "clarified" compared to flows from slopes. The resulting spatial raster model of CCp values allows for a reliable assessment of the risk of soil and erosion pollution of water with phosphorus in individual sub-basins and the entire

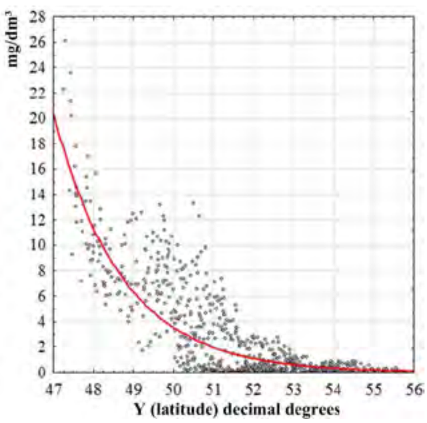


Spatial distribution function of CCP values

$$CCp = 650.95 + 4.47x - 0.018x^2 - 26.59y + 0.262y^2 - 0.061xy,\ r^2 = 0.76$$

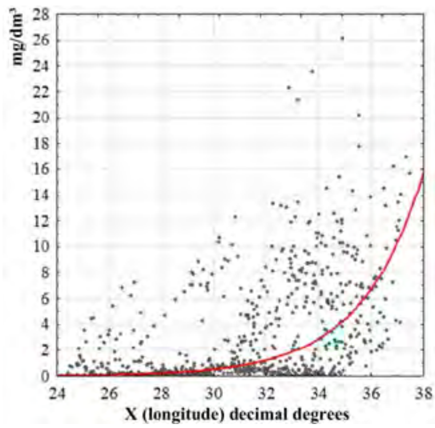
where, x – longitude, decimal degrees, y – latitude, decimal degrees

a



$$CCp = 1.70 \cdot 10^{13} \cdot \exp^{-0.584x},\ r^2 = 0.99$$

b



$$CCp = 1.56 \cdot 10^{-6} \cdot \exp^{0.424x},\ r^2 = 0.98$$

c

Fig. 3. **Spatial distribution of soil-erosion phosphorus inputs to surface waters in selected sub-basins of the Dnipro River transboundary watershed:** ***a*** **– cartogram and spatial distribution model;** ***b*****– south → north;** ***c*** **– west → east**

Dnipro basin. To assess the degree of danger of soil-erosion pollution of water bodies with phosphorus, it is necessary to determine the “ecologically limiting” values of the actual concentration and their impact on eutrophication.

Researchers have found that algae do not develop at soluble phosphorus content of up to 0.01 mg/dm³, while “blooming” of water can be observed at a phosphorus content of 0.01–0.025 mg/dm³, and optimal algal growth has observed at concentrations of 0.09–1.8 mg/dm³. Thus, the first ecologically limiting value of the concentration of dissolved phosphorus in water, which has begun the blooming of water, can be taken as a concentration of 0.01 mg/dm³. Limit values of the CCp, taking into account the ratio of gross and mobile forms and sediment input coefficients, should be much higher – for medium and large rivers, at least 1 mg/dm³.Water has contained about 10% of gross phosphorus in dissolved form. A limit value of more than 20 mg/dm³ corresponds to an excess of the actual phosphorus concentration of 0.2 mg/dm³.

In accordance with the “Methodology for the establishment and use of environmental standards for the quality of surface waters of land and estuaries of Ukraine” [43], an environmental classification of water by phosphate is established. Class I has included waters with a phosphorus content of less than 0.015 mg/dm³, Class II – 0.015-0.050 mg/dm³, Class III – 0.051-0.200 mg/dm³, Class IV – 0.201–0.300 mg/dm³, and Class V – more than 0.300 mg/dm³. In accordance with the methodology, 6 categories of land have deen identified and the area of the Dnipro catchment basin was calculated according to the degree of potential danger of phosphorus water pollution as a result of soil-erosion processes (Table 2).

Table 2. **Characteristics of potential gross phosphorus inputs to the surface waters of the Dnipro River basin**

Phosphorus concentration in channel streams at the foot of the slope, mg/dm³	Danger dissolved phosphorus concentration in river waters, mg/dm³	Area, thousand km²	%
<1.5	<0.015	257.8	50.5
1.5–3.0	0.015–0.030	55.2	10.8
3.1–5.0	0.031–0.050	54.3	10.6
5.1–10.0	0.051–0.100	99.5	19.5
10.1–20.0	0.101–0.200	30.9	6.1
>20.0	>0.200	13.3	2.6
Total	–	511.0	100.0

It has been established that for 359 sub-basins with a total area of 257.8 thousand km² (50.5% of the total territory of the transboundary basin), the potential phosphorus concentration in channel streams at the foot of the slope as a result of agricultural activities is < 1.5 mg/dm³, i.e. the soluble phosphorus content in the waters of sub-basins, mainly in the mixed forest zone, is < 0.015 mg/dm³ and their quality corresponds to the first class. According to the phosphorus indicator, the waters of 156 sub-basins, which are mainly located in the forest-steppe zone, are classified as Class II (21.4%).For a significant part of water bodies and watercourses in 234 sub-basins of the forest-steppe and steppe zones, with a total area of 130.4 thousand km² (25.6%), the potential phosphorus concentration has been in the range of 0.051–0.200 mg/dm³ and the surface water quality corresponds to Class III. The highest potential hazard in terms of dissolved phosphorus concentration in water is in the river sub-basins of the Lower Dnipro located in the steppe zone. As a result of water-erosion processes in the upper and middle reaches of the Dnipro River and the accumulation of local sediments from agricultural land, the phosphorus concentration in the lower part of the Dnipro exceeds 0.200 mg/dm³. It has been determined that for 27 sub-basins with a total area of 13.3 thousand km² (2.6%), water bodies can potentially be classified as Class IV and V, with a high degree of danger of eutrophication, overgrowth and siltation of floodplain water bodies and river channels.

Conclusions. The process of soil-erosion migration of nutrients was modeled and the risk of surface water pollution in the Dnipro River basin was determined using geographic information systems and remote sensing technologies. The coefficient of sediment supply and the spatial distribution of diffuse pollution by suspended solids in the Dnipro basin as a result of the water-erosion process are calculated. It was found that the sub-basins located in the mixed forest zone or the upper part of the transboundary Dnipro River have had the lowest potential for diffuse pollution by suspended solids. Sub-basins of the VI-IX orders have had the highest value of diffuse pollution by suspended solids (more than 100 thousand tons per year). The spatial modeling of the conditional gross phosphorus concentration (CCp, mg/dm³) has revealed that surface waters formed in the forest-steppe and steppe catchments of the transboundary basin are characterized by high CCp values of 5 to 20 mg/dm³ and more. This spatial trend has been due to the high degree of ploughing and low values of the average annual water runoff layer. In accordance with the environmental standards for the quality of surface waters of land and estuaries in Ukraine, water bodies and watercourses located on 50.5% of the territory (mainly in the mixed forest zone) of the Dnipro basin have a potential phosphorus concentration of less than 0.015 mg/dm³ and their quality corresponds to Class I, for 21.4% of the water bodies in the catchment area (mainly in the forest-steppe zone) have a potential phosphorus content of 0.015–0.050 mg/dm³ and are classified as Class II; for 25.6% of the territory, the potential concentration in channel streams is 0.051–0.200 mg/dm³, which corresponds to Class III water quality; the river sub-basins of the Lower Dnipro are most at risk of dissolved phosphorus concentration in water (over 0.20 mg/dm³). In this zone, for 27 sub-basins with a

total area of 13.3 thousand km² (2.6%), water bodies can potentially be classified as Class IV–V and are at high risk of eutrophication, overgrowth and siltation of floodplain water bodies and river channels. The obtained results make it possible to study the process of soil-erosion migration of nutrients and determine the risk of surface water pollution in the Dnipro River basin. This makes it possible to develop the priority needs for implementing adaptive landscape erosion control design with elements of conservation agriculture to reduce agricultural impact within individual sub-basins and create the preconditions for the rational use and improvement of land and water resources in the transboundary Dnipro basin.

СІЛЬСЬКОГОСПОДАРСЬКА ОБУМОВЛЕНІСТЬ БІОГЕННОГО ЗАБРУДНЕННЯ ПОВЕРХНЕВИХ ВОД БАСЕЙНУ РІКИ ДНІПРО

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Визначено необхідність проведення досліджень впливу джерел забруднення ріки Дніпро в залежності від їх впливовості. Встановлено, що басейн ріки Дніпро є багатогалузевим комплексом, який охоплює який охоплює 48% території України, акумулює 80% водних ресурсів. Зазначено, що басейн ріки Дніпро має високу природну і соціально-економічну цінність, оскільки питні потреби 70% населення України. Встановлено, що джерелами забруднення водних ресурсів є промислові комплекси, сільське господарство, міські агломерації. Доведено, що причинами деструкції басейну ріки Дніпро є вирубування лісів, інтенсифікація сільського господарства, гідромеліорація, функціонування каскаду дніпровських водосховищ, інтенсивне використання водних ресурсів. Визначено, що сільськогосподарське освоєння територій водозбірних басейнів стало причиною ерозії ґрунтів, яка являється найбільш механізмом міграції речовин на земній поверхні, що стає причиною потрапляння у моря, океани і у зони внутрішнього стоку до 17 млрд т мінеральних часток та 3,5 млрд т розчинених речовин щороку. Встановлено, що високі концентрації мінеральних часток у поверхневому стоці знижують якість вод, що потребує додаткових витрати на їх очищення, ремонт мережі водопостачання, відновлення іригаційних мереж. Здійснено розрахунок зональної небезпеки забруднення біогенними речовинами поверхневих вод у межах різнорівневих суббасейнів транскордонної ріки Дніпро, що стало наслідком ґрунтово-ерозійних процесів. Встановлено, що найменший потенціал дифузного забруднення зваженими речовинами мають суббасейни, розташовані у зоні мішаних лісів або верхній частині течії транскордонної річки Дніпро. Доведено, що для оцінки ступеня небезпеки ґрунтово-ерозійного забруднення водойм фосфором необхідно встановлювати «екологічно граничні» значення фактичної концентрації. Доведено, що потенційну небезпеку у відповідності до показників концентрації розчиненого фосфору у водах, мають річкові суббасейни Нижнього Дніпра, які розміщені у степовій зоні. Визначено необхідність розробки адаптивно-ландшафтних протиерозійних проєктів з елементами ґрунтозахисного землеробства.

Ключові слова: біогенне забруднення, ерозія, землекористування, ріка Дніпро, водозбірний басейн, моделювання.

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