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COMPLEX SPACE MONITORING DATA ANALYSIS TO DETERMINE ENVIRONMENTAL TRENDS OF POLAND-UKRAINE BORDER AREAS

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Abstract
A comprehensive approach to assessing the current ecological status of the Poland-Ukraine border areas has been considered, identifying possible negative effects associated with river water pollution. The main environmental impact factors that are directly related to the negative effects of anthropogenic load on the changing ecological status of the border areas and adjacent terrain have been identified. Particular attention was paid to the pollution monitoring data analysis of the Ukrainian part of the Western Bug basin. Using the space monitoring results, pollution sources that were not recorded in the official reports were identified. Their negative impact on the change of quality of life within the border areas was assessed. The integration specificities of heterogeneous time-differentiated ecosystem monitoring data were considered. The integration expediency of interdisciplinary joint analysis methods of decryption data and field observations for making operational decisions to prevent negative consequences of possible changes in the ecological status is shown. Modelling was utilized to determine the estimated contamination time of the river systems of Western Bug and Vistula from the Ukraine territory. The tendency of further changes in the ecological status of the analyzed areas has been ascertained, including the assessment of possible negative consequences.

Keywords: **Environmental state; Western Bug; Pollution; Remote sensing; Space monitoring.**

1. INTRODUCTION

The ecological state deterioration of the of the Western Bug river basin poses a direct threat to the environment and residents of Poland, Ukraine, Belarus and the Baltic countries. Therefore, the study topic is relevant and many scientists and scientific organizations are concerned with this problem. For example, the Western Bug basin environmental status analysis that was performed by Hagemann N., Blumensaat F. [1], Zabokritskaya M.R., Khilchevsky V.K. [2], Ertel, A.-M., Lupo, A., Scheifhacken, N. [3] and others. These studies analyze the long-term chemical regime of the Western Bug River basin surface waters and determine the impact of wastewater sources and agriculture on it. An overview of existing methods for assessing the current ecological status of monitored objects with the identification of possible change trends, performed by Falconer R.A., Binliang Lin, Harpin R. [4], Arle, J., Mohaupt, V. [5], Kurbatova I.E. [6], etc. showed that solving these issues takes great time and carries considerable material costs. This is due to the fact that a lot of developments in this area are dedicated to environmental analysis and decision-making about its current state separately from contact measurements. Other approaches are devoted to the development of data processing algorithms and to making appropriate decisions based on aerospace research only. It should also be noted that detecting the change dynamics in the current state of the observed terrain only on the basis of space monitoring of the Earth is associated with the processing of large amounts of information and requires a significant increase in requirements for information resources. Therefore, a comprehensive approach to the interoperable processing of different space monitoring data obtained from different equipment and then supplemented with a priori information about the monitored object is proposed.

Recently, to solve various problems related to the environmental assessment of the current state of individual areas, especially to determine the trends of its possible changes, Earth remote sensing (ERS) data is used. As it is well known, the space monitoring data contains information about the object observation properties in different conditions and at certain intervals. However, to solve the problems associated with the prediction of the dynamics found in images of various objects or phenomena that may cause future technological disasters, this data is insufficient. It is necessary to establish causality of negative changes by methods of analogy, deep analysis of the studied area (taking into account it's specificity), definition of informative material factors that influence the occurrence of these changes, and the use of additional data from other sources. However, there are difficulties caused by the specific provision of timely informational support of joint space monitoring data analysis and experimental data. This is due to the fact that the analysis of data that was obtained from different sources at different times involves the use of a large number of variables and factors, which in turn leads to a rapid accumulation of experimental data and comprehensive integration difficulty. Thus, the accuracy of predictive models that determine trends in distribution of different pollution types and consequently assess the possible negative environmental change requires not only regular series of observations, but also the presence of effective processing methods. As such, it is expedient to use a single unified approach to the formation of geoinformation models, describing their macro and micro dynamics based on the integration of time differentiated heterogeneous space monitoring data and contact measurements, as well as statistical measurements using GIS technology and expert assessments [7].

If we consider assessments of the current ecological status of the monitoring object, which are determined only on the basis of statistical data or contact measurements, we can conclude that there is an incomplete correlation with the current state. As is well known, the data from environmental reports [8–11] does not always correspond to reality and some indicators related to environmental assessment of the current ecological state (that are available from public sources), are somewhat understated. Therefore, the definition of further environmental change trends with the assessment of possible negative consequences only using this data cannot be objective and requires more development of new, more precise integration methods and methodologies for time differentiated and heterogeneous monitoring data. Unlike modern monitoring methods that are based on data from the wastewater volume reports of enterprises, this assessment includes not only wastewater environmental impact, but also unaccounted potential sources of contamination, identified on the basis of distance and contact methods.

Therefore, the purpose of the study is the improvement of the assessment quality of the current ecological status of the observed terrain areas, with an addition of determination possible changes or trends. To achieve this goal, it is proposed to utilize a comprehensive approach to the interoperable processing of different space monitoring data obtained from differing equipment and to supplement that data with a priori information about the monitoring object. It is advisable to carry out an analysis of the current environmental state, as set example, in a small part of the Ukraine-Poland border area, in order to put into practice a comprehensive approach to identifying the possible negative effects associated with river water pollution. The results of the analysis will allow to draw conclusions regarding the quality of later life within the border areas and adjacent sections of the terrain, which are directly related to the negative effects of anthropogenic load on the changing ecological status of these territories. Foremost, it is proposed to monitor the pollution of the Ukrainian part of the Western Bug basin with an assessment of possible negative effects in the border areas.

2. MATERIALS AND METHODS

2.1. Research subjects

The object of the study is the determination of change dynamics in the ecological status of the Western Bug River basin border areas. As presented in the current literature [2] the territory of the Ukrainian part of the Western Bug river basin occupies only 28% of the total. Western Bug River has a total length of 772 km, the part that is situated in Ukraine – 392 km. Specifically, 185 km of the river is the border between Ukraine and Poland. Administratively, the Western Bug river basin is located in Lviv and Volyn regions [2]. Upper Western Bug basin is located within the Lviv region. The river basin spans 9 districts, which house up to 328.3 thousand persons and include 2 cities: Lviv and Chervonohrad with the total number of inhabitants counting almost 800 thousand persons. In the Volyn region, the Western Bug River is cross-border. It's basin pans 7 administrative districts with a population of 145.7 thousand persons, and 2 cities with a population of about 90 thousand [12].

In order to determine the trend of possible changes in the ecological status of the Ukraine-Poland border areas, it is necessary to carry out a geo-economic analysis of the studied area and to establish relationships between statistical and other a priori data from open information sources. The analysis results are the basis for the creation of an integrated environmental monitoring system.

2.2. Materials

Monitoring system inputs included Earth Remote Sensing (ERS) data from Sentinel satellites [13], WorldView, Ikonos, GeoEye, QuickBird [14] and SRTM models [15]. The study references and utilizes data on hydrological, hydrometeorological and hydrochemical parameters of the Western Bug river basin [2, 16], Departments of Ecology and Natural Resources of Lviv and Volyn Regional State Administration reports [8–9], data from the State Statistics Service of Ukraine on population [12] and on morbidity [10-11].

2.3. Monitoring system for the ecological status of the Western Bug river basin in the border areas based on space exploration data and contact measurements integration

As a result of the analysis of existing ecosystem monitoring data processing methods [4–6], it was determined that the Western Bug river basin pollution assessment should be carried out in 4 stages:

1) collection, processing and filing of incoming contact and distance data on the Ukrainian part of the Western Bug basin;
2) determination of the main types of pollution sources in the Western Bug river basin;
3) construction of geomodels for the potential contamination areas of Vistula and Western Bug river basins depending on hydrometeorological conditions and emergencies occurrence;
4) evaluation of possible adverse pollution effects of the Western Bug and Vistula river in the border areas.

2.4. Integration characteristics of time differentiated heterogenous ecosystem monitoring data

To implement the proposed space monitoring stages (paragraph 2.3), especially when locating the areas of major pollution on space imagery and to identify potential pollution sources and ways of their migration, a relationship was established between changes in indicators obtained by contact methods and decoding features on space imagery as well as compliance of these changes to open source statistical data.

The long-term hydrological and hydrochemical data from various sources of information make it possible to identify the regime of the river system of the Western Bug and to come to contradictions between the different agencies data. Contact information identifies existing pollutants – enterprises and organizations that are sources of wastewater. A temporal and spatial analysis of the discharge volume and the type of pollutants is carried out.

Remote sensing data allows to identify potential pollution sources that are not taken into account when assessing the environmental status of river basins and the possibility of emergencies arising from them. The task of prompt imagery acquisition is particularly important when assessing the effects of natural disasters and the localization of their distribution zone. A way out of this situation can be seen in new approaches to time distribution forecasting of pollutants during the interval between obtaining images only with a priori information. Since not all problems can have analytical solutions, the most significant emphasis must be placed on a priori data analysis relating to the identification of potentially dangerous sites by analyzing their properties, statistical analysis and data from official environmental reports and so on.

That is, integration of interdisciplinary methods of joint decryption data analysis and field observations is needed to make operational decisions to prevent the negative consequences of possible changes in the ecological status. That integration should only be done on a priori data in the context of limited a priori information. With regard to the space monitoring data processing, specifically thematic decryption, which is a joint analysis of images of the same area acquired at different times and with different spatial resolution in a "criterion of trees" hierarchical image view structure. Meaning – to conduct satellite imagery splitting into fragments consistent with their indexing, until the inside of the fragment has not reached the level of homogeneity. As criteria, the partitioning features that have different priorities are used, whereby each of the fragments correspond to the weights in the interval from 0 to 1. Thus, each fragment that is a part of a zone has assigned its own attribute according to the probability of falling into the most dangerous area, and each node area has assigned a spatial index. Provided that satellite images are a large amount of image elements, segmentation results presented in the form of fragments (not in the form of elements as in a traditional case) with codes that determine their belonging to the branches of the "criterion tree" that correspond to the different classes of objects. For this, during selection, the image segments are defined not only by their centers but also by their limits. To determine the degree of closeness between indicators of the forestry fragment with a localized anomaly and indicators of adjacent pieces, a correlation analysis is performed. The result is a raster image, split into fragments, where the areas with less density are large cell data blocks, and higher density – small cell data blocks, that are dependent on the largest number of breakdown factors. Raster image segmentation using the "criterion trees" method allows to keep space monitoring data with its acquisition methods taken into account.

For joint analysis of imagery which was obtained from various sources, it is appropriate to use "criterion trees" that went through automatic photogrammetric normalization with decomposition into cells by geographical coordinates, thus reducing the computational error that accumulates during multiple algebraic and geometric operations due to the use of a coordinate systems with large values [17]. When determining the object topology, it is proposed to perform this operation in an internal "criterion tree". It should be noted that conducting overlay operations when obtaining the differential "criterion tree", that indexes all connected fragment image overlays, consists of traversing all the trees on their existing branches. In those nodes where no tree branches out, the attribute value is transferred to all subsequent sub-levels. The result is a general tree that contains all the attributes of the analyzed fragments. When analyzing the spatial vector data indices assigned a dedicated segment are used for faster access to objects of interest in a certain part of an image. Indexing of spatial objects is used to reduce computational complexity of the search procedure of complex shape anomalies, especially when overlaying polygons. To clarify the boundaries of localized areas that are dangerous, the isomorphism property is used for set theory operations. To combine quantitative and qualitative characteristics, structuring and formalizing the internal mathematical language of "criterion trees" and the possibility of conducting operations with spatial indexes, priority values of tree tops, and time series values – the following algorithm is used [17]:

1. Phasing (fuzziness introduction) of algebra conversion results $B_{ij}^{K_{nm}}$ using algebras $A_{ij}^{K_{nm}}$:
$B_{ij}^{K_{nm}} \oplus A_{ij}^{K_{nm}} \Rightarrow \overline{B_{ij}^{K_{nm}}}$.
2. Generation of productive algebra interaction rules:
$A_{ij}^{K_{nm}} \oplus \overline{B_{ij}^{K_{nm}}} \Rightarrow \overline{D_{ij}^{K_{nm}}}$.
3. Consistency determination of converted algebras (aggregation): $\overline{D_{ij}^{K_{nm}}} \oplus \overline{B_{ij}^{K_{nm}}} \Rightarrow D_{ij}^{K_{nm}}$.
4. Accumulation of aggregation results:
$\overline{D_{ij}^{K_{nm}}} \Rightarrow \bar{C}_{AB}^{K_{nm}}$.
5. Dephasing (sharpness introduction) of algebra values
$$\overline{C_{ij}^{K_{nm}}}:\ C_{AB}^{K_{nm}} = \frac{\sum_{i,j=1}^{l} \overline{B_{ij}^{K_{nm}}}\bar{C}_{AB}^{K_{nm}}}{\sum_{i,j=1}^{l} \bar{C}_{AB}^{K_{nm}}}.$$

Where: $A_{ij}^{K_{nm}}$ – atomic algebras which define the operations performed on the root fragments of "criterion trees", that adhere to criteria, which are evaluated using qualitative characteristics with minimum weight coefficients, where *i, j* – coordinates of the tree vertices;

K_{nm} – the tree index in the database, according to the nesting level inside the tree *n* and number of fragment that contains relevant geographical and rectangular coordinates;

$B_{ij}^{K_{nm}}$ – operations, performed on tree fragment roots that meet the criteria that are measured with quantitative characteristics;

$\bar{C}_{AB}^{K_{nm}}$ – "composite" algebras, which perform operations, based on atomic algebras.

When conducting operations according to the submitted algorithm, algebras, which are the input data for each of the operations, are antecedent, and output algebras – consequent. The presented algorithm algebras $D_{ij}^{K_{nm}}; \overline{D_{ij}^{K_{nm}}}$ when conducting operations, define the conformity between a set of quantitative characteristics of atomic algebras to production rules that determine the conditions of their possible interactions. When conducting thematic deciphering, this allows the consideration of additional features, which, under standard methods, are usually discarded; tracing causal relationships of anomaly occurrence and data preparation for forecasting the further pollution spread with degree impact evaluation on the studied ecosystem. For the rejection of redundancy factors, which affect the concentration level of contamination and the extent of their distribution, when forming the informative set of features, it is advisable to use the inverted Floyd algorithm for constructing a matrix of maximum impact, using an enhancement graph with nodes that correspond to the algebraic operation results with "criterion trees" (composite algebras – $C_{ij}^{K_{nm}}$). Based on these values $C_{ij}^{K_{nm}}$ and the results of analytical description of the relationship graph vertices, the factors of maximum impact are determined. Matrix values analysis allows to prioritize the impact of random factors that determine the ecological status change trend [18].

Unlike existing classical methods, during thematic imagery processing of images which were obtained by remote means, an additional analysis was carried out by indirect decryption features. For example, by smoke and by different numerical characteristics of smoke plumes it is possible to conclude about the degree of pollution the emissions are adding onto the atmosphere. For this purpose, the segmentation of the analyzed images further evaluated its intermediate results. In our case, the evaluation was conducted on the basis of distance analysis between the centers of localized segments inside segment variances and other quantitative criteria, as well as through calculated correlation of selected fragments with the appropriate attributes based on prior information. Because a comprehensive analysis of heterogeneous time-differentiated data was made, it was advisable to use estimates, derived from the coherence method. Because this approach to data organization allows to quickly access spatial data and calculate a variety of geometric and topological characteristics, track their dynamics. Additionally, in case of thematic processing of space imagery, the optimal color subband was selected to determine the quantitative indices of the decryption features using the graph structures method, determined by the minimum cross sections on the contamination zones histogram and zones corresponding to the terrain sections with a "relatively clean index" – these are areas which have minimal pollution level. The choice of the optimal subband color is required when segmenting the image and when refining the interlocal image fragment. According to the graph structure method, when determining uniformity level within the analyzed fragment, each pixel corresponds to a graph node, and the distance between them determines the weight of the edge, which describes the difference in color. However, it has been determined that the use of the HSV model is the most appropriate and informative for analyzing the amount of emissions by enterprises from the space imagery decryption results. In this case, the intensity of the selected color is considered as the edge weight, and the adjacent vertices with the minimum weight are contracted into one. This is due to the fact that the localization of contamination zones, taking into account the shade value, prevents errors of the 1st and 2nd kind. To obtain integral indicators of the pollution level on individual elements, it is necessary to carry out a brightness analysis, which will increase proportionally to the intensity of emission release into the air. When processing panchromatic space images, it is advisable to use fractal imaging techniques.

The use of this approach for space monitoring data processing allows to draw conclusions not only on space imagery with ultra-high spatial resolution, but also on the analysis of a set of archival images supplemented by ERS data at the time of analysis, which have medium and high spatial resolutions.

2.5. Geomodel construction methods for potential contamination zones with assessment of possible negative consequences

To determine the trend of changes in the ecological status of the Ukraine-Poland border areas, it is proposed to simulate the potential pollution zones in accordance with the types and degree of their concentration, with the calculation of the potential contamination time of the Western Bug and Vistula basin depending on the hydrological regime and meteorological conditions.

It should be noted that in constructing geomodels of probable contamination zones of the Western Bug and Vistula basin, it is advisable to consider 3 possible variants for improving the assessment quality of the negative pollution effects: the “static” model during summer-autumn and autumn-winter boundaries, at the lowest water levels; “dynamic” – designed for significant river water level elevation, which occurs during waterfalls in February-March or floods at any time; “emergency”, which allows to determine the possible pollution type in emergencies and to calculate the time of its advancement to strategic objects.

This approach further allows to assess the impact of pollutants on human health, taking into account the potential pollutants location and their migration paths in the Western Bug basin river border areas.

3. PRACTICAL IMPLEMENTATION OF THE POLAND-UKRAINE BORDER AREAS ENVIRONMENTAL STATE ASSESSMENT METHOD WITH DETERMINATION OF ITS CHANGE TRENDS

3.1. Analysis of well-known pollution sources of the Western Bug river basin with determination of specificity of its geomorphological and hydrological characteristics

To determine the hydrological and geomorphological characteristics of the Western Bug river basin, a digital terrain model (DTM) was built by the authors, according to the data, provided by the Shuttle Radar Topography (SRTM) model (Fig. 1). SRTM model is derived from radar interferometry with a 90m spatial resolution and absolute error limited to 8.8 m [19]. The river flow velocity at its various sites was identified.

As shown in Fig. 1, Western Bug river basin has a heterogeneous geomorphological structure, which impacts its hydrological features, which require additional consideration when defining the timing and direction of pollutants migration.

The emission analysis from publicly available information sources shows that Ukraine conducts constant monitoring of hydrological and hydrochemical parameters of surface and underground waters, as well as sewage volume, their purity and quality indicators. Each year, all types of enterprises submit a report – form № 2TP WI according to order № 78 dated 16.03.2015 released by Ministry of Ecology and Natural Resources of Ukraine “On Approval of state Order of water use accounting” [20]. This data allows to estimate the stress degree on river systems, but does not take into account other potential pollution sources of surface and underground hydrosphere and decide on the direction of finding the most dangerous areas in terms of pollution. But space monitoring data analysis allows to reveal not only potential pollution sources that are the subject of monitoring, but also those that are not included in official reports. Among the countless potential sources of contamination, ones that should be noted: authorized and unauthorized solid waste landfills, mining dumps, power plants (ash dumps), chemical industry, etc., as well as septic tanks for distilleries and sugar factories, enrichment plants and so on (Fig. 2).

As displayed on the map constructed by the paper authors as a result of research (Fig. 2) – 33 stationary sources of wastewater are identified, listed in Table 1 [2]. These sources, per year, discharge about 217 million m^3 of wastewater into the Western Bug river system, of which about 10.5% are not treated. Analysis of Table. 1 shows that the largest pollution source is the sewage treatment plants, whose share accounts for approximately 90.82% of all waste. Specifically, Lvivvodokanal accounts for 80% of all waste.

3.2. Determination of unaccounted potential pollution sources based on Earth space monitoring data

Satellite imagery thematic decoding results revealed 54 potential sources of contamination, specifically 22 dumps, 21 mining dumps, 2 septic dumps, 1 ash dump, 7 food production septic tanks, 1 landfill from the Khimvolokno factory. The visualization of the obtained results is presented in Fig. 3.

It should be noted that among all of the identified potential pollution sources (Fig. 3), special attention should be paid to landfills. Before decoding and mapping solid waste landfills to satellite imagery, it is necessary to identify the main features between authorized and unauthorized solid waste dumping. Deciphered landfill signs have object characteristics by which they can be identified, selected and interpreted among others. It is important to clearly separate the authorized and unauthorized solid waste dumping, as authorized (legal) landfills are built properly, taking into account the sanitary rules and regulations [21], and with the elements of gas and water collection.

Detection of these pollution sources in space imagery was carried out based on decryption features (Table 2), developed by study authors and presented in the article [22].

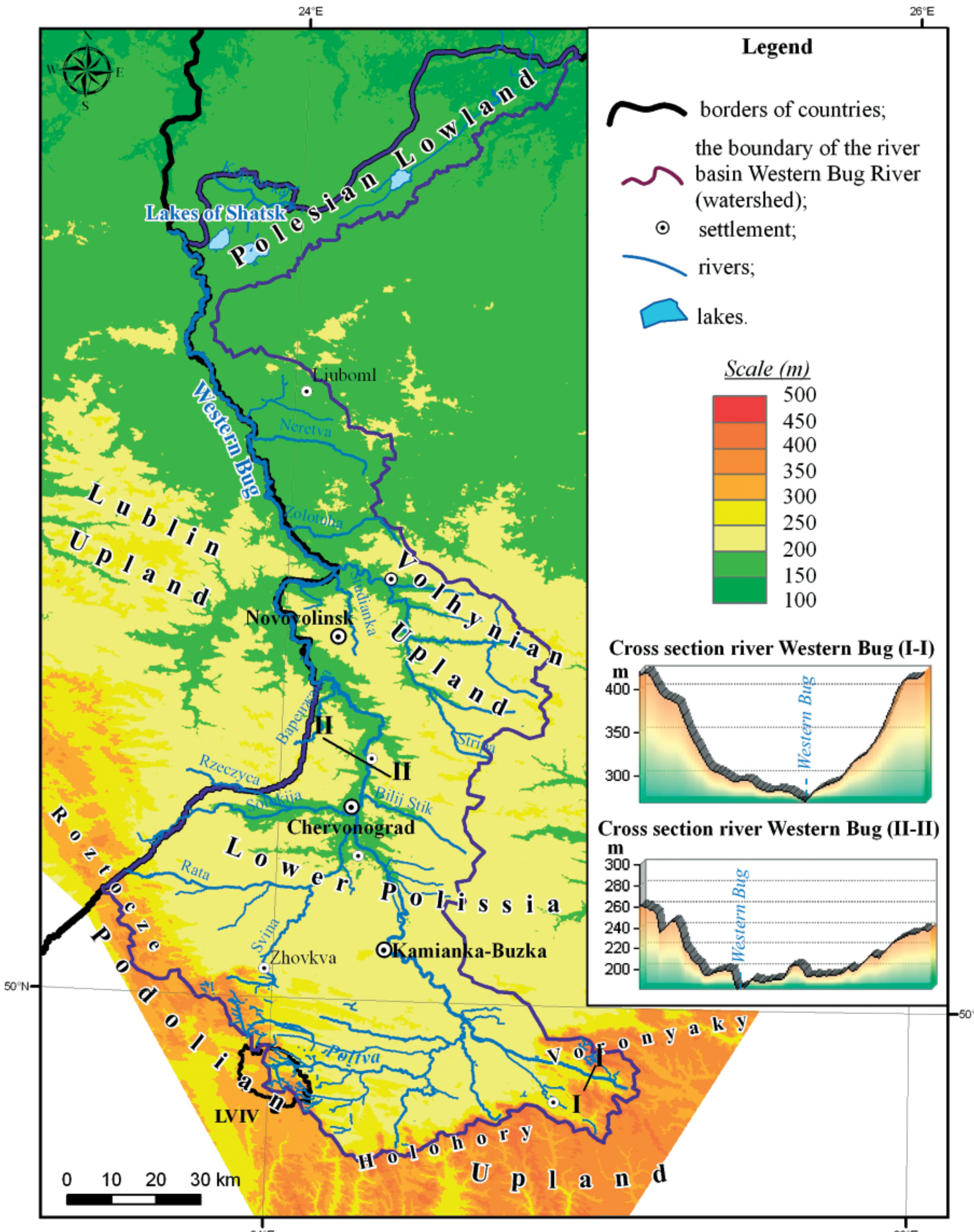

Figure 1.
DTM visualization of the Western Bug river basin according to the SRTM model data

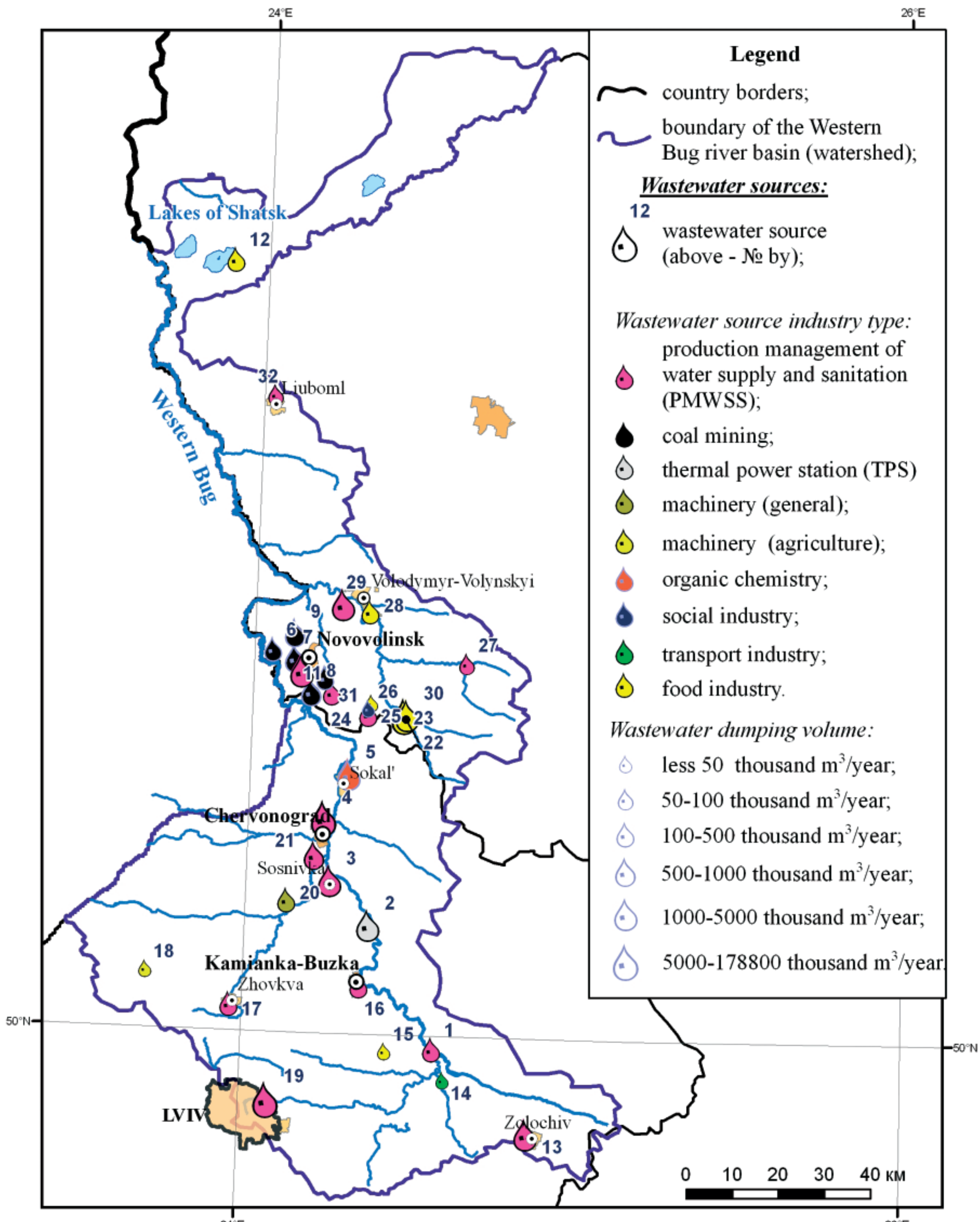

Figure 2.
Wastewater sources map of Western Bug river basin

Table 1.
The list of stationary wastewater sources in the Western Bug river basin according to M.R. Zabokricka [2]

№ on the map	Name, source discharges	type	The volume of waste water, thous. m^3	Water facility, which receives wastewater
1	Production Management of Water Supply and Sanitation (PMWSS) city. Busk	PMWSS	279.9	r. Western Bug
2	Dobrotvir thermal power station (TPS)	TPS	1219.1	r. Western Bug
3	PMWSS city. Sosnivka	PMWSS	1341.0	r. Western Bug
4	PMWSS, Chervonograd	PMWSS	7529.2	r. Western Bug
5	DP "Cascade" Sockal	Organic chemistry	2452.2	r. Western Bug
6	Coal mine № 10	Coal Mining	346.7	r. Western Bug
7	Coal mine № 1	Coal Mining	652.7	r. Western Bug
8	Coal mine № 9	Coal Mining	640.6	r. Western Bug
9	Mine Buzhnska city. Novo-Volynsk	Coal Mining	977.2	r. Western Bug
10	PMWSS city. IPB	PMWSS	3868.0	r. Western Bug
11	PMWSS city. Blagodatnoe	PMWSS	158.0	r. Western Bug
12	Volynrybhosp JSC m. Shack	Food (fish)	183.0	r. Western Bug
13	PMWSS city. Zolocev	PMWSS	1910.0	r. Zolochivka
14	Railway Station, p. Red	Transport	24.1	r. Holohirka
15	Art. gardening with disobedience	Food (horticulture)	11.0	r.Dumny
16	PMWSS, Kamyanka-Buzska	PMWSS	389.8	r. Kamenka
17	PMWSS city. Zhovkivska	PMWSS	345.3	r.Svynya
18	MIA Lviv city. Mahera	Mechanical Engineering (Agriculture)	22.0	r. White
19	Livivodokanal	PMWSS	178799.9	r. Poltva
20	Plant "Tepel" m. Large Bridges	Engineering	178.0	r. Rath
21	PMWSS, m.Hirnyk	PMWSS	839.1	r. Rath
22	PSHP "Pavlvska fish" Ivanychi area	Food (fish)	11417.0	r.Strypa
23	JSC "Pavlivka brewery plant"	Food (beer)	18.3	r.Strypa
24	PMWSS city. Ivanichi	PMWSS	126.0	r.Luha
25	PE "Yevropatsukor" (Ivanychi sugar plant)	Food (sugar)	6.6	r.Luha
26	Ivanychi boarding school	Social security	3.3	r.Luha
27	PMWSS city. Lokachi	PMWSS	60.0	r. Pig
28	OJSC "Vladimir-sugar"	Food (sugar)	331.1	r.Luha
29	PMWSS city. Vladimir-Volyn	PMWSS	1518.3	r.Luha
30	Volyn fish-water-reclamation plant	Food (fish)	1114.7	r.Luha
31	Coal mine № 5	Coal Mining	346.5	r. Studianka
32	PMWSS city. Liuboml	PMWSS	74.4	r.Hapa
33	Zabolotivskyy Vegetable Plant	Food (vegetable)	3.1	Can. Tours

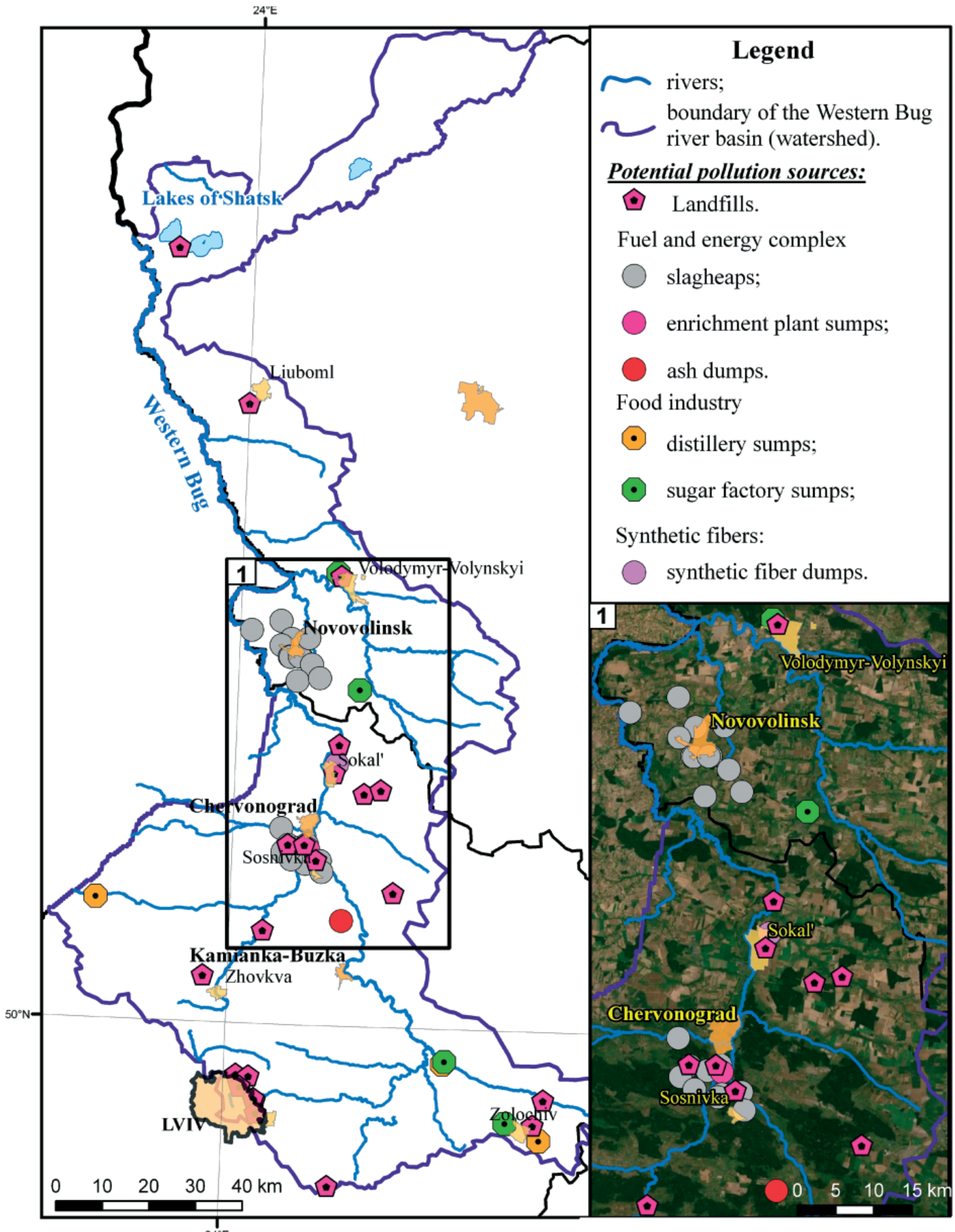

Figure 3.
Map of potential Western Bug basin pollution sources

Table 2.
Deciphering signs of authorized and unauthorized dumps [22]

№by	descramble signs	Authorized landfill	Unauthorized dumps
Direct descramble signs			
1	Bound	clear	blurred
2	Form	polygon with rounded corners	irregular, rounded or elongated linearly along roadsides and railroads car
3	Shadow	is falling from ledges	no
4	Color	mostly light gray, white, gray, dark gray	mostly light gray, white, gray, dark gray
5	Structure	grainy, spotted	spotted
descramble indirect signs			
6	The protective coating (reclamation)	present, light brown (loam, clay)	no
7	Vegetation in place dumping trash	observed several years after reclamation	there is usually a pattern: overgrowth from the center to the periphery landfill; if no constant flow of garbage
8	The main access road	there are usually two lane roads	missing. There are hiking trails or unpaved one lane roads
9	Fence	present	no
10	Working machines	present	no
11	Checkpoint and office buildings	present	missing
12	Draining channel	visible if the surface; not detected if the underground	missing
13	Location	land that are designated for landfills are earmarked 11.02 "For the location and operation of the main, auxiliary and ancillary buildings of processing, engineering and other industries". Spatial information on ranges landfills contained in the Public cadastral map	surroundings settlements and industrial zones. Often found around the settlements of rural type buildings along the road. Illegal dumps are often located in the ravines and gullies and forest belts

Additional analysis of the industry in the border areas as well as analysis of products of household economic activities, residential buildings, agricultural fields, etc., showed that there are many different types of possible pollution sources, which, in combination, are not included in the assessment of Western Bug river basin pollution.

The following possible pollution sources were identified:

1) authorized and unauthorized landfills;

2) coal industry dumps and septic tanks;

3) ash dumps of thermal power plants;

4) septic tanks of sugar factories and distilleries;

5) plant dumps of synthetic fiber factories.

According to the methodology developed for thematic processing of eco-monitoring data, all identified pollution sources were divided into classes: enterprises and organizations producing wastewater, and those that could potentially pollute the environment.

Among them, one of the main pollution sites are landfills. The analysis of localized different landfill types, which were identified by space imagery, in the Western Bug river basin revealed that there are 22 landfills with a total area of 72.4 ha, of which 4 are sanctioned, 18 are unauthorized. That means that there are more unauthorized landfills.

Of course, when designing landfills according to the norms, it is obligatory to waterproof them to prevent the filtrate from entering groundwater [21, 23, 24]. At the landfill, a pond is organized to collect the filtrate, which is subsequently cleaned. However, for unauthorized landfills, this is not the case. And this further increases the overall pollution level, because the filtrate directly enters the groundwater.

3.3. Specific analysis of negative impact of identified pollution sources on the Western Bug basin ecological state

According to the modelling results, the time of contamination penetration from landfills to the first level from the surface aquifer surface was calculated for the landfills, highlighted by the space images. For some of them the time to get there is less than a day. For example, for a landfill near the Yelichovich village, the filtration time is 9–12 days, and for unauthorized Sasivsky – 1–2 days. It should be noted that the Sasiv unauthorized landfill is located in the floodplain of the Western Bug river, so contaminants will quickly (1–2 days) reach the level of groundwater that feeds the Western Bug river, which is a border river between European Union and Belarus [22].

The danger from landfills lies primarily in the filtrate, which is formed as a result of the entry of atmospheric water into the landfill body and its enrichment with toxic components. Thus, the content of mercury and iron filtrate can exceed the maximum permissible concentrations (MPC) by 2500 times, ammonia nitrogen 1000 times, phenols 400 times, petroleum 150 times, chlorides 30 times, heavy metals (lead, cadmium, copper, zinc, nickel, chrome, manganese, etc.) 10–60 times. Filtrate infiltration into soil, groundwater and surface water leads to the complete destruction of flora and fauna and the impossibility of its use in the national economy. This is especially true for the landfill location near Chervonograd, which poses a direct risk of groundwater contamination and surface water contamination due to it being situated in the floodplain – in the river flood zone. In case of significant waterfalls and floods, it is possible to flood the landfill, with organic compounds and heavy metals entering into the basin of the Western Bug river [25].

As a result of the analysis of the degree of influence on the pollution level concentration in Western Bug basin region, that the maximum degree of influence of the dumps and coal mining industry septic tanks located within the basin was determined. Calculations of heap volume and the heavy metals content in them were conducted utilizing remote sensing data, and their environmental impact was assessed.

In order to determine the mass of heavy metals, the geometric schematization was first carried out in the waste heaps and sedimentation tanks. Two volumetric shapes that best fit the shape of these objects were identified: a slit cone and a slit pyramid. Literature

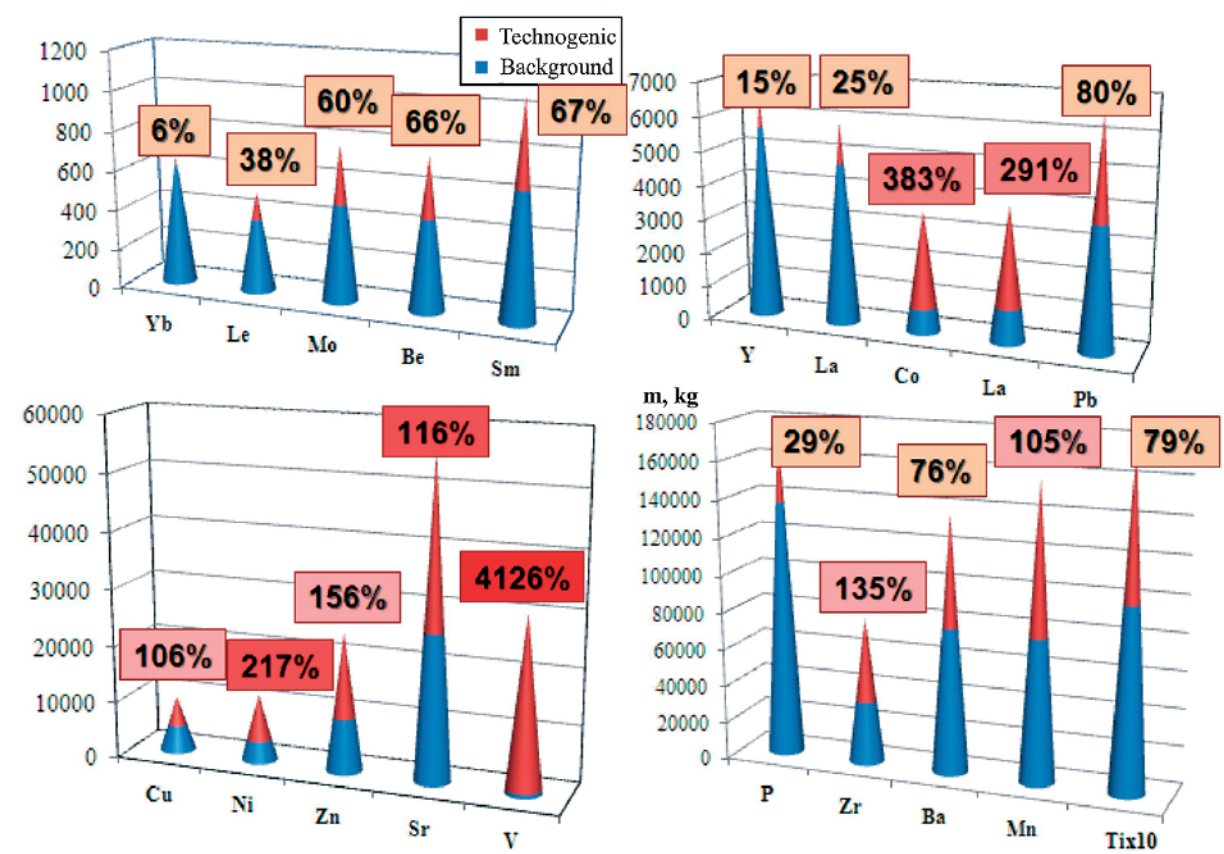

Figure 4.
Mass of chemical components in all defined heaps, ash ponds and sedimentation tanks

sources [26, 27] determine the average density, as well as the average content of dumps and sediments of heavy metals. Calculation of the mass of metals was carried out according to the schematization: a cut cone (1) and a cut pyramid (2).

$$m_i = \frac{1}{3}\pi\Delta H(R^2 + Rr + r^2)\cdot\rho\cdot(1-k_l)\cdot\left(1-k_p\right)\cdot\frac{1}{n}\sum_{i=1}^{n} c_i\,; \tag{1}$$

$$m_i = \frac{1}{3}H\left({S_b}^2 + \sqrt{S_b\cdot S_s} + {S_s}^2\right)\cdot\rho\cdot(1-k_l)\cdot\left(1-k_p\right)\cdot\frac{1}{n}\sum_{i=1}^{n} c_i\,, \tag{2}$$

where m_i – chemical element's weight in the landfill;

R – cone base radius;

r – truncated cone surface radius;

S_b – pyramid base area;

S_s – pyramid surface area;

ΔH – dump height. $\Delta H = H_t - H_b$, H_t – absolute height of the highest point, H_b – absolute height point of the base of the dump;

ρ – average density of the dump;

k_l – remaining loosening coefficient;

k_p – pore coefficient;

c_i – concentration of chemical elements in the dump;

$\frac{1}{n}\sum_{i=1}^{n} c_i$ – the average chemical element value in the dump.

According to calculation results, it is identified that the total mass of metals in the waste heaps, ash dumps and sedimentation tanks of the coal and energy industries is 2475,9 tonnes. The mass of some components is shown in Fig. 4. It should be noted that the vanadium content is 30.7 tons, which exceeds the background concentrations by 4126%. Significant exceedances of background values are observed for cobalt (by 383%), lanthanum (by 291%), nickel (by 217%), zinc (by 156%), zirconium (by 135%), strontium (by 116%), copper (by 106%). The entry of these heavy metals into the hydrosphere will lead to an increase in the number of diseases of local residents, as well as the death of flora and fauna. The movement of pollutants from these objects into surface waters and groundwater is possible due to precipitation or flooding.

According to ERS data, the artificial sludge plant in Sokal is a direct threat to the environment due to its high content of zinc, sulfur, iron, silicon and sodium [28].

Potential danger of bacteriological contamination of the transboundary Western Bug river basin territories is observed from 3 alcohol sumps and 4 sugar refineries, most of which are located within the floodplain.

The greatest danger from artificial sedimentation tanks and sludge collectors is the possible destruction of their dam during floods.

It should be noted that when obtaining a comprehensive assessment to determine the trend of further changes in the ecological status of the observed area of the terrain, there was a number of difficulties associated with uncertainty in decision making. Because some indicators did not exceed the MPC at the time of analysis, and the initial overall assessment of the contamination was positive, but their combinatorial impact with other factors, or the accumulation result of these substances over time, allowed to draw a completely different conclusion. In such cases, we used interval estimates, the analysis of which allowed us to obtain thresholds at each stage of analysis for each contamination type.

There is another factor that significantly influences the change in ecological status, and which should be taken into account in the comprehensive assessment of the current ecological status, as well as in predicting its likely changes. It is shown that the change of ecological status is affected by the number of non-canalized settlements located near the border. This is due to the fact that the majority of small settlements and the private development areas within cities and towns do not have centralized household wastewater drainage. For the purpose of sewage disposal, cesspools are equipped within the private construction framework, from which sewage pumping by suction machines is carried. That means there is a great risk of the GPS getting into the surface and groundwater when flooding the area during floods.

4. DETERMINING THE TREND OF ECOLOGICAL STATUS CHANGES OF UKRAINE-POLAND BORDER TERRITORIES

4.1. Modeling of pollution movement timing and estimation of its influence on the ecological status changes of the Western Bug river basin transboundary territories

According to the described methodology, the authors

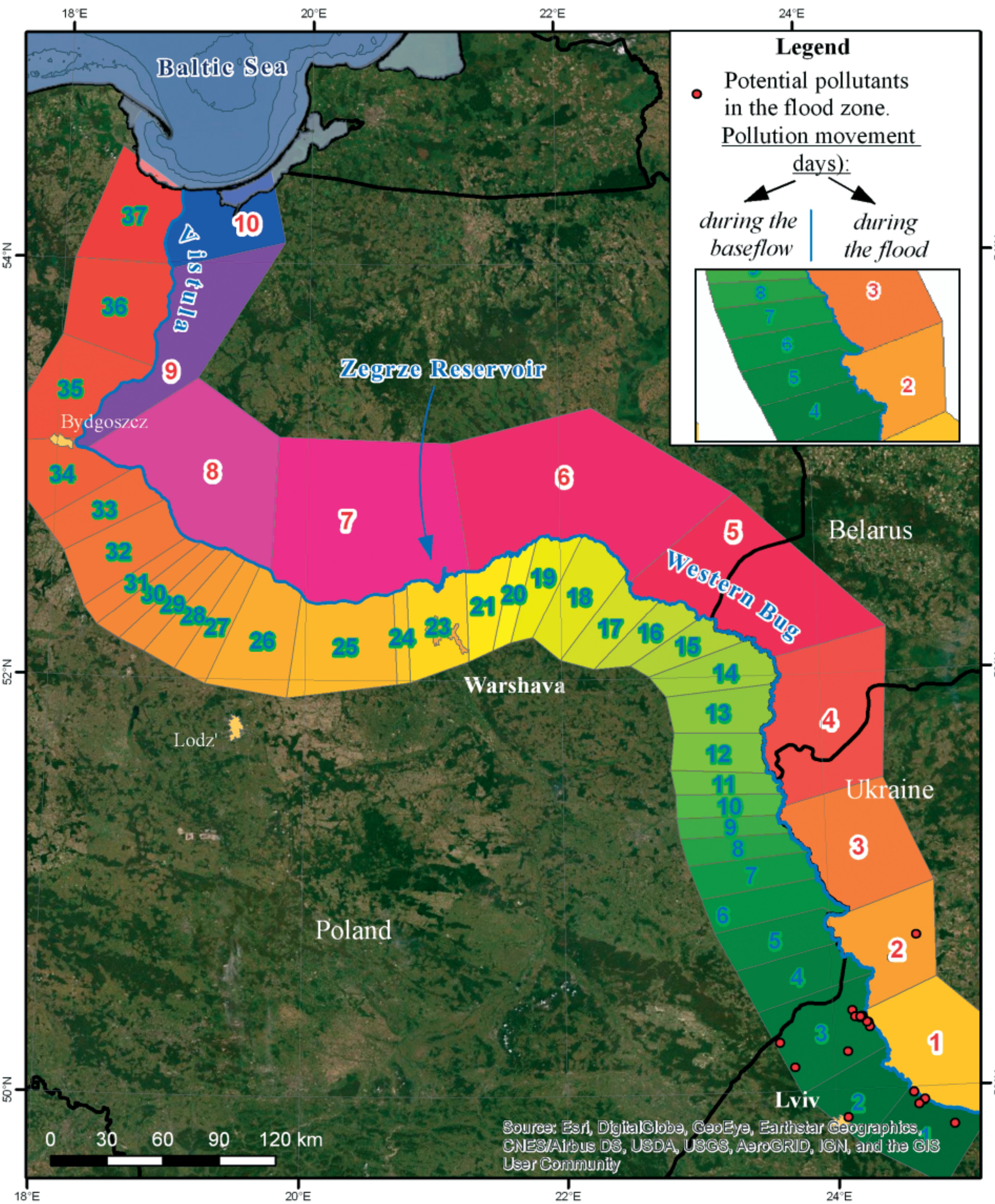

Figure 5.
Cartographic model of the pollution movement time from the source of the Western Bug river to the Baltic Sea under different hydrometeorological conditions

constructed a cartographic model of pollution movement from the Western Bug river source to the Baltic Sea under different hydrometeorological conditions (Fig. 5).

The analysis of the modeling results made it possible to identify the following main trends in the environmental status of the border areas of Poland and Ukraine:

According to the first "Static" geomodel, the chemical composition of water in the Western Bug and Vistula basins will correspond to modern indicators with a gradual tendency to further increase pollution. Exceedance of the limiting values for such components as phenols, petroleum products, surfactants, and ammonia nitrogen will be closely observed.

According to the "Dynamic" geomodel, there is a significant likelihood of a large number of dangerous substances entering the Western Bug river basin, Vistula and the Baltic Sea. A significant excess of regulatory values for heavy metals (mercury, cadmium, chromium, zinc, copper, etc.), possible bacteriological contamination with complete damage to all sources of water supply, as well as other components will be temporarily observed in the water supply.

According to the "Emergency" geomodel, significant volumes of pollutants are dumped into the river systems. For example, in the case of an accident at the Lviv treatment plants, sewage drains will fall into the river waters, which exceed the norms of organic and nitrogenous compounds, phosphates, etc., but the greatest danger lies in the bacterial contamination of the river system with the temporary inability to use it for drinking water.

Determination of the timing of pollution advancement by river waters was made from the leakage, dependent on the flow velocity in separate river sections at the baseflow and at a constant speed (1.5 m/s) during flood or waterfill. According to calculations, pollution from leakage will reach the Ukraine-Poland border in 42 hours when flooding, and 104.7 hours at baseflow. The flow of contaminants into the Zegrzyn reservoir, which is a source of drinking water for the Warsaw agglomeration, is 6.4–22.6 days under different weather conditions. Pollutants will reach the Baltic Sea in the period from 9.5 to 36.3 days.

Thus it can be concluded that the space monitoring of pollution of the Ukrainian part of the Western Bug river basin allows timely decisions to be taken to prevent the negative effects of border area contamination and does not require constant availability of new contact measurements. The time between them may be increased.

4.2. Assessment of environmental degradation impact on human health

Identifying new, unaccounted pollution sources from space monitoring data allows to more accurately analyze the likely negative effects of environmental degradation on the Ukraine-Poland border areas. Taking into account the statistics obtained by medical institutions, an analysis was carried out on the impact on human health of all contamination detected in the observed territory [29–31]. The effects of pollutants on human health are shown in Table 3.

At the next stage, all types of contaminants presented in the table were classified with an analysis of their concentration level and three groups of the most dangerous substances were identified (Fig. 6).

Impact analysis of these components on the occurrence of different morbidity types in people has led to the conclusion that despite the positive trend in statistics on the level of general population morbidity, the mortality rate does not decrease, the largest num-

Table 3.
Impact of pollutants on the development of different types of diseases according to Maltseva I.G. [32]

Component	Disease type
Arsenic	seizures, hyperkeratosis, skin cancer, lungs, bladder, diabetes, etc.
Manganese	anemia, diseases of the musculoskeletal, urogenital, nervous system, skin
Copper	disorders of the movement apparatus
Zinc	heart disease, blood, cancer
Cadmium	hypertension, coronary artery disease, renal failure
Cobalt	lung sclerosis, cardiomyopathy, dermatitis, thyroid disease, hypertension,
Lead	anemia, kidney disease, nervous system
Nickel	kidney diseases, lungs, cancers
Nitrates	hypoxia, impaired endocrine, May, cardiovascular, nervous system, gastric cancer
Chrome	allergy, asthma, cancer
Mercury	nervous system damage,
Beryllium	sarcoidosis, fibrosis, heart disease, liver, cancer
Iron	liver disease, immune system, cardiovascular disease, allergy, infertility
Sulphates	bile and urolithiasis, cardiovascular disease,
PAV	immune system degradation, allergies, brain damage, liver, kidneys, lungs.
Petroleum products	cardiovascular system diseases
Phenols	nervous and respiratory system lesions, liver, heart, blood, brain, cancer

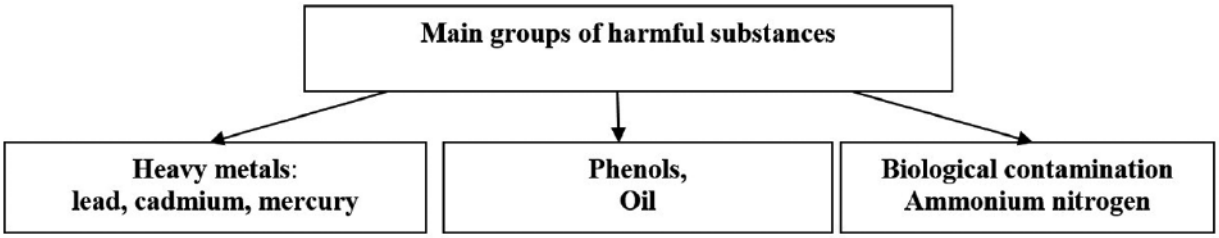

Figure 6.
The most dangerous substances

ber in the morbidity structure – respiratory diseases. The number of tumors in the studied area is increasing [10, 11]. This is a very dangerous trend. That is, we can conclude that all of the above indicators are very poisonous and dangerous to human health. To prevent these consequences, some recommendations regarding preventive action may be appropriate. But the key is to constantly monitor the environmental status to prevent the negative effects of its deterioration.

5. CONCLUSIONS

1. Available sources of information on the assessment of the current state do not allow to objectively evaluate all pollution types with determination of their quantitative characteristics and need to be supplemented by their space monitoring data. This is especially true for unauthorized landfills, non-sanitary buildings and others.
2. The analysis of potential pollution sources from space imagery showed that the monitoring methods did not take into account 22 landfills, 21 waste heaps, 2 settling tanks, 1 ash dump, 7 food tanks and 1 dump of Khimvolokna factory.
3. Comprehensive analysis of statistical and space monitoring of the Earth data has allowed to determine a significant excess concentration of very dangerous substances for human health in filtrate: ammonium exceeds the maximum permissible concentration (MPC) by 1000 times, phenols by 400 times, petroleum by 150 times, chlorides by 30 times, heavy metals (lead, cadmium, copper, zinc, nickel, chrome, manganese, etc.) by 10–60 times. The concentration of iron and mercury may exceed the MPC by 2500 times.
4. Assessment of the influence of waste heaps and sedimentation plants of the coal mining industry on the Western Bug river basin, which are located within the basin, allowed to calculate the volume of heaps and the content of heavy metals (2475.9 tonnes), using the ERS data and its impact on the environment.
5. The research revealed the expediency of taking into account the environmental impact of the mining, energy, food industry and the number of non-canalized settlements.
6. According to the modelling results, the lack of operational decisions to prevent the negative effects of environmental degradation can lead to the significant amount of pollutants and bacterial contamination from the source of the Western Bug river to the Zhegzhin reservoir in 6.4 days during flood and 22.6 days during floods, 22.6 days during baseflow, and to the Baltic Sea water area in 9.5 and 36.3 days, respectively.
7. Environmental changes in the Western Bug basin pose a direct threat to residents and the environment of Poland, Ukraine, Belarus, as well as the Baltic countries. Only continuous monitoring of the border area environmental status, an interdisciplinary approach to the obtained data processing (not limited to obtaining current assessments and conclusions), and the development of a support system for making prompt decisions to prevent the negative effects of environmental degradation will overcome this problem. However, to improve the estimates accuracy and further forecasts, it is necessary to have prompt and objective a priori information from both Ukraine and Poland.

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