Use of the Esri’s ArcGis products to create indicators of the integrated characteristics of the WTG placement in the geoecological system on the territories of wind farms

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Abstract. With the development of wind energy in the south of Ukraine, there was a question of the safety of its operation for the ecosystems of the region. The goal of many years of work was the development of methods for geoecological analysis of natural and technical geosystems in the territories of wind farms to assess the impact of wind turbine placement. An integrated approach in carrying out monitoring work and individual methods of analysis, as well as the characteristics of the natural and technical geosystem, using an integral approach, made it possible to synthesize various aspects into a single geoecological system, the analysis of which gives a more complete picture of the relationships and connections of the objects of the territory as a complex natural and technical geosystem. The resulting analysis of the criteria provides a better environmental assessment and selection of means to minimize the negative consequences of the impact on the natural environment.

1. Introduction
With the development of sources of energy-saving systems, wind power plants have become widespread. In the last 20 years, the number of such power generation projects and their importance as a source of renewable energy has been constantly growing. Much attention is paid to the protection and conservation of biological diversity within the borders and adjacent territories to wind farms, both on the part of the state at the level of implementation of legislative acts, and on the part of the public at the level of environmental initiatives.

The south-east of Ukraine (the Azov-Sivash region) since 2000 has been a region for the development of wind energy. A powerful natural and technical geosystem of the regional level has been formed on this territory, including natural landscapes and systems of technical objects, represented by 10 wind farms and a network of power transmission lines. During the construction and development of the wind farms, as well as service roads, the degree of negative technogenic impact on the natural environment reaches its maximum. In addition, enterprises of the food industry, agriculture, transport, and recreational development of the coast are functioning here. When the construction work is completed, the influence is reduced to the functioning of the WF.

When the elements of the technogenic block interact with the components of the natural block, peculiar, still insufficiently studied natural and technical geosystems are formed. In the
case when the components of the environment, natural and modified by man, are studied, it is common to speak about “geosystems”.

Back in the mid 1960s, I. P. Herasymov, L. F. Kunitsyn, V. S. Preobrazhenskyi, A. Yu. Reteyum, K. N. Dyakonov and others developed the concept of geotechnical systems. A geotechnical system is a set of natural objects and engineering structures interconnected and functioning as a single entity [1]. It is an open system that exchanges components with the environment. The geotechnical system also includes a control and management unit. Information about the state of natural objects is an obligatory component of geoecological monitoring. Natural processes in the transformed landscapes are changed by the functioning of geotechnical systems. In this regard, it is relevant to assess the impact of wind farms on natural complexes and their components. Let us evaluate the indicators of wind turbine placement using a complex geoecological analysis.

Geoecological analysis is the identification of signs that characterize the current and expected state of the environment [2,3]. It is based on impact monitoring of the environment. The main purpose of such monitoring is to solve the problem of improving the environmental situation, optimizing the existing nature management. When analyzing a specific system, it is important to assess the level of impact of technological and technical processes within the boundaries of the geosystem and in adjacent territories. The process of changing the natural block of the technogeosystem as a result of economic activity proceeds through specific migration channels: air, land, water. At the same time, when the processes of the impact of technogenic processes are superimposed on natural processes and phenomena, the effect of its impact is enhanced [4]. One of the main tasks of geoecological analysis is to assess the state of the study area as a geosystem of the topological level - the main carrier of ecological and geographical information, on which ecological situations and problems arise [2,5,6]; to evaluate specific violations and ways to eliminate or mitigate them, preventing the development to a higher hierarchical level [7].

The objectives of the environmental assessment (EA) of projects are to determine quantitative criteria for making decisions on the admissibility or inadmissibility of project implementation, to ensure the choice of an option and type of planned economic activity with the lowest environmental and social costs, to obtain quantitative criteria for evaluating the effectiveness of environmental measures planned by the project, to choose an acceptable for society the rate of return in the implementation of the project [8]. Environmental Assessment (EA) accompanies all stages of the monitoring cycle. Natural-economic (geosystem) monitoring is a complex system of observations and assessment that allows you to track the state and changes in natural geosystems and the consequences of their transformation into natural-technical ones, assess the state of the territory where the differences of parameters from the baseline due to intense anthropogenic impacts are recorded, assess qualitative and quantitative content of the studied indicators of geosystems within any region [9].

2. Material and methods
Geoecological research methodology allows at a higher scientific level to approach the assessment of the impact of technogenic processes, namely the placement of wind turbine generators (WTG) and the formation of the wind power plant (WPP) site, on the state of the components of the environment – avifauna and chiropterofauna, which are considered as one of the important bioindicators of the ecosystem state.

The validity of ecological conclusions is significantly increased when using geocological analysis, which is increasingly being introduced into theoretical and practical ecology. Its use is especially effective in the assessment of natural and technical geosystems. To date, there is no single methodology for the ecological and geographical analysis of geosystems, and an individual approach is used for each type of natural and technical geosystem.

Geoecological analysis within the limits of the natural and technical geosystem, a component
of which is the ecological system, with the dependence between the initial and its constituent changes, makes it possible to model the ecological situation on the basis of computer technologies using modern software and hardware. As a result, a geographic information system (GIS) is being created. In a broader sense, it is a geo-environmental information and cartographic support for the studies carried out, as a set of environmental information and cartographic material about the processes, phenomena, events, objects inherent in the geosystem under study.

When processing information data and preparing for mapping, as the main product of the analysis, GIS technologies were used, namely Esri’s ArcGis software products (satellite images for geographical analysis of the territory, a set of program functions for information processing).

Work on assessing the impact of wind farms on biological complexes and their components has been carried out for many years at the sites of wind farms in the Azov-Black Sea region. As a result, various approaches and methods of analysis were developed, new technologies and software were implemented, which were tested in practice and developed into a huge methodological material with an integrated approach. Thus, the Biodiversity Research and Training Centre developed and implemented the WebBirds Web application [10], designed analytical and information databases of bird census and migrations [11], developed research methods at wind farm sites [12], and also considered the features of using new technologies when carrying out monitoring studies at WPP sites [13, 14]. The accumulated methodological experience allows us to talk not only about the analysis of the territory of the wind farm, but also a complex regional assessment that is due to the growth of the wind farm network in the south of Ukraine, and the cumulative impact on each other.

The developed methods of geoecological analysis were carried out on the basis of the functionality of the ArcGis 10.4 – ESRI software complex for the WPP sites. Complex analysis is achieved by superimposing information layers, existing and developed by the team of the Biodiversity Research and Training Centre, and author’s methods of analysis on the cartographic material.

According to the requirements of the project documentation, when carrying out research for each territory, complex monitoring work was carried out, during which lists of discovered species of animals and plants and their belonging to international conservation lists were compiled, their habitats were mapped, quantitative and qualitative parameters of populations were taken into account, and critical significant habitats were determined. As a result of the work carried out, detailed maps were obtained in the studied and adjacent territories, which made it possible to conduct a complex analysis during the operation of wind farms, and at the early stages of design to correct the installation sites of wind turbines to free up territories valuable for natural significance.

Let us consider the method of analysis using the example of the Overianivka and Novotroitsk wind farm, located in the Kherson Region near the Sivash, with monitoring data over 10 years of research.

3. Methodology

1. **To analyse the territory, it is first necessary to determine the boundaries.** That’s why it is necessary to know the geolocation of the wind turbines that form the WPP site (figures 1–19).

   In larger wind farms, the turbines are usually arranged in groups or in a line perpendicular to the prevailing wind direction, or are located along the contour of hills where the wind speed is higher.

2. **The formation of the boundaries of the WPP site is based on 500 m buffer zones around the WPP, the zones of potential impact.** According to international requirements, the boundaries of the site are at a distance of 500 m from the extreme wind turbines (figure 3).
3. When assessing the impact, the main zones of impact around the WPP are identified. These are buffer zones of 500 m, 250 m and 140 m (150 m).

Each of the buffer zones characterizes the impact of certain processes.

To neutralize the consequences of blade separation, the following set of measures is applied:

A safe distance is determined; wind farms are designed and placed in such a way that there were no buildings or settlements in the possible directions and within the possible spread zones of the blades. It is unlikely that such a safety distance will exceed 300 meters, although it may vary depending on the size, shape, weight and speed of the wind turbine, as well as the height of the wind turbine [15,16].

The main factor determining the distance between the turbines in a wind farm is the speed and turbulence of the air flow. As a general rule of thumb, the distance between adjacent turbines located in the direction of the wind is equal to 5-7 rotor diameters. The size of the site required to place a wind farm depends on the planned number of turbines; however, the actual area of land disturbed by the location of the wind farm (for example, the area required for turbines and access roads) is significantly less than the total area of land occupied by the project. For example, a typical wind farm with 20 turbines may be located on a 1 square kilometer site, but most likely only 1 percent of that land will be actually used [17].

Wind turbines are placed at specific intervals to maximize the potential of wind power while using minimal space. The main factors in determining the distance between the turbines are the speed and turbulence of the air flow. As a rule, the distance between wind turbines is from 3 to 5 rotor diameters perpendicular to the prevailing wind direction, and along the prevailing wind direction – from 5 to 7 rotor diameters [17]. In some countries and territories, the minimum recommended distance between wind turbines is 200 meters, so as not to interfere with the passage of birds between the turbines [18]. If the distance between the turbines along the prevailing wind direction is less than 5 rotor diameters, significant energy losses due to the formation of a turbulent wake are very likely [19].

So, on the example of the Overianivka and Novotroitsk wind farm, where the rotor diameter is approximately equal to 125 m, the minimum distance equal to 3 rotor diameters is 375 m, the maximum distance is 7 rotor diameters, or 875 m, at least 5 diameters is the optimal distance in order to avoid energy loss and is equal to 625 m. After analyzing the technical characteristics of the wind turbine, in which the diameter of the rotor can vary from 90 to 150 m, the indicators were averaged and the optimal buffer zone around the wind turbine was selected that meets the technical requirements of the wind farm in order to avoid energy loss, and a comfortable zone, which should not be less than 500 m between the wind turbines and meets international requirements. For biological objects and the formation of comfortable movement corridors, as well as for choosing the route of census and the VPs, 500 m buffer zones are used, the overlay of which shows the zones of attention for biological objects (figure 4).

Formation of 140 m buffer zones around the WTG is a risk zone (125 m is the maximum diameter of the rotor plus about 7 m for vortex flows that can impact on insects, birds and bats) (figure 5).

To neutralize the consequences of ice breaking and other physical impacts, a zone of direct influence was chosen, for which the following set of measures is applied [20]:

- During the formation of ice, the operation of wind turbines stops;
- Warning signs are installed within a radius of at least 150 meters from the wind turbine;
  Outside these zones, one can observe free space for the formation of movement corridors and migration of animals.

4. Analysis of the ratio of risks and free zones of movement. The methods of mathematical analysis to assess the actual impact and its percentage are used. Knowing the technical characteristics of the wind turbines that are being built on the site and mathematical
methods, it is possible to calculate the amount of space occupied by the wind turbine and, accordingly, the percentage ratio attributable to the risk zones on the entire wind farm site. This is a rather rough estimate, but it gives an opportunity to understand the spatial representation of the degree of interference. Using the main physical characteristics of wind turbines (figure 6), it is possible to calculate the share attributable to technical structures at the wind farm site, which is the actual impact on the environment.

5. Characteristics of the density of the WTG placement as an element of the formation of barrier risks. Considering the 500 m buffer zones around wind turbines as a component of the site for ecosystem objects, it is possible to identify areas that are under the influence of more than one wind turbine. In such territories, there is an imposition of 500 m buffer zones of several wind turbines, on the other hand, this territory is free from the direct physical influence of wind turbines, along which ecosystem objects move. The overlay of buffer zones shows the density of the wind turbines and the nature of the free space between them (figure 7-8). It can be seen from the illustrations that the fewer overlaps, the more comfortable the site is, especially for birds and bats.

If we consider the area with a radius of 500 m between the wind turbines as comfortable, then the area attributable to this site is 78.5 hectares. Accordingly, the area attributable to one wind turbine should not be less than this value.

6. Construction of Thiessen polygons and their analysis to determine areas of barrier risks. Thiessen polygons are an important component of spatial analysis concepts such as assessment of the nearest neighbour and proximity. The Thiessen polygons, named after the American meteorologist Alfred H. Thiessen, are a more specific application of the Voronoi diagram in meteorology and geophysics [21].

An important characteristic of the site is the nature of the placement of wind turbines and the assessment of placement using Thiessen (Voronoi-Thiessen) polygons. This approach makes it possible to determine the zones of impact of each wind turbine. Critical characteristics of the site forms barrier zones and risk zones.

The Thiessen polygons have the unique property that each polygon contains only one input point, and any location within that polygon is closer to its associated point than to any other polygon point. The Thiessen polygons can be used to subdivide a point coverage into regions (zones of impact), known as the Thiessen polygons or Voronoi diagrams. Each zone (region) contains only one coverage input point. Each region has a unique property, the essence of which is that any location within the region is closer to the point of the region than to the point of any other region (figure 1). In other words, wherever an object is located inside the polygon, the nearest point of the region to it will be a point inside the polygon (the polygon is the zone of impact of the point of the region for any object), thus, the limits of impact are formed (figure 10).

**Figure 1.** Thiessen polygons from point features (for object A, the nearest point of impact will be 2, for B it will be 4, for C it will be 6).

Let us consider the nature of the location of wind turbines (point objects), using the Thiessen polygon function, which allows you to divide the area where the wind farm is located into the
zones of each wind turbine impact. The territory is divided into polygons, inside which there is only one wind turbine, and any object located inside the polygon, the nearest wind turbine for it will be a wind turbine from the same polygon (that is we can talk about the zone of impact of a wind turbine) and the formation of boundaries of this impact. Having the boundaries of impact zones, it is possible to estimate their area. Knowing the acceptable values of areal characteristics, which corresponds to a 500 m buffer zone around the wind turbine and is equal to 78.5 ha, it is possible to build a gradation of values. In this gradation, we can distinguish risk zones (the sites with an area of less than 78.5-80 ha), border territories (80-100 ha), satisfactory sites (100-130 ha) and comfortable ones (with an area of more than 130 ha) (figure 10).

**Assessment of the wind farm impact on the components of wildlife**

The greatest number of questions is caused by the impact of wind farms on the avifauna. Indeed, wind farms, as vertical structures with moving elements, pose a certain risk to birds. As the main factors of the impact of wind turbines on the avifauna, one can single out: physical impact in a collision with turbines, blades and towers; habitat disturbance; violation of the bird migration route. Possible indirect effects on birds include those caused by changes in the habitat and the presence of a disturbance factor in the territory of the wind farm, quantitative and qualitative changes in the species composition of animals that are prey for predatory birds, changes in the nature and number of places for bird breeding and resting due to natural changes in the habitat, as well as the use of wind turbines by birds as seats. Impacts on birds and bats depend on the scope of the project and other factors, including technological aspects (e.g. a tower size and a turbine design), wind turbine lighting and a wind farm layout. In addition, the impact may be affected by the characteristics of the wind farm area, including its relief and topographical and biotopic characteristics (for example, proximity to large concentrations of birds, bats or prey species), the number of birds and bats flying through the territory of the wind farm, the features of their behaviour that put them at particular risk (for example, bird soaring heights and migration routes of bats), as well as meteorological aspects.

The assessment of the wind farm impact depends on many factors starting from the location of the wind farm (relief, location of wind turbines on the site), meteorological factors, species diversity, etc. It should be noted that careful planning of the location of wind farms in cooperation with expert ornithologists, in order to minimize the impact on the avifauna, allows achieving a relatively low level of mortality of birds and bats.

When carrying out such research work, one inevitably encounters natural factors of dynamic variability, which should be separated from the impact of wind farms on natural components. For example, in the same time periods, monitoring data may differ depending on temperature indicators, the level of water and anthropogenic transformation of the territory, etc.

Having the technical characteristics of the site and the data of the territory as a geoeological system makes it possible to conduct an associated analysis of heterogeneous spatially coordinated data (vegetation, the presence of the NRF objects and eco-networks, agricultural use, monitoring data on flora and fauna objects and species diversity). Special attention was paid to the analysis of territories for the presence of objects of the natural reserve fund of Ukraine, territories promising for inclusion in the list in the NRF, objects proposed for inclusion in the ecological network, territories of the forest and wetland fund of Ukraine, as well as territories of natural significance.

To obtain data on the state of geoeological nature for the implementation of a complex analysis, the work was carried out due to the specifics of their implementation, namely, the need to accurately indicate the contours and locations of objects on the ground, which often, by their nature, do not have clear boundaries and move in space.

**7. Allocation of natural areas.** Using satellite imagery data, as well as analysis of the territory, monitoring of the main groups of animals and plants, complex information is collected and put on cartographic material. Then analysis and calculation of assessment criteria are
8. **Emerald Ecological Network.** Particular attention is paid to the territories of the NRF, which are within the boundaries of the WPP or are located in its buffer zones (figure 11b, figure 12).

9. **Analysis of biotopic and species diversity** in the assessment of the impact area, as an integrated approach to the study and analysis of the WPP territory (figure 13).

10. **Particular attention is paid to ornithological census.** The data of monitoring census of birds and other animals are considered within the site and 500 m zones of impact, so we have an integrated approach to the natural and technical geosystem. This gives us the opportunity to analyze in space the degree of risk for migratory and settled birds within 500 m of buffer zones (figure 14).

11. Using the characteristics of the barrier effect and monitoring data of migrations, **zones of tension** where the density indicators of wind turbines are critical and large flows of bird movement at dangerous heights are indentified. The use of such an analysis clearly shows areas requiring additional attention during mass migrations (figure 15).

12. **Analysis of breeding complexes taking into account risk zones.** Let us consider the location of the main breeding complexes and their quantitative characteristics taking into account 500 m zones and barrier risks (figure 16).

13. **Analysis of bird density.** Using the density of gatherings and migrations with superimposition of layers of natural sites to identify zones of maximum biodiversity and increased abundance, identify corridors, take into account barrier areas to implement measures to minimize the impact of WPP. The analysis of bird density shows the main places of bird concentrations and areas that require special attention (figure 17).

Similar mechanisms have been worked out for bats, with individual assessment parameters, which made it possible to analyze the situation and identify places that require additional attention (figure 18).

14. After analyzing the territory of the WPP and the objects under study, with a complex comparison of all the information received, **risk zones were identified.** They were places with the highest concentration and species diversity of wildlife objects. Recommendations and mechanisms have been developed to minimize the impact of wind turbines on the biological components of the geosystem (figure 19).

4. **Results**

The application of this metod of geoecological analysis gave us the following results:

1. Placement of point data for the location of wind turbines (figure 2).
2. Formation of the boundaries of the WPP site based on 500 m buffer zones around the WTG or zones of potential impact (figure 3).
3. Formation of impact zones (figures 4 and 5).
4. Analysis of the ratio of risk volumes and free movement zones (figure 6).

The number of wind turbines at the WPP site is 40, the area of the WPP site is 4304 ha = 43*10^6 m^2.

If we talk about the volume of the obstacle in the section of the WPP site, then we can discuss the volume of all towers and their share relative to the rest of the space (figure 7). The volume of one tower outside the rotation area \( V_1 = 1060 \text{ m}^3 \). As there are 40 towers, then \( V_2 = 42.4 \times 10^3 \text{ m}^3 \) is the volume of all towers in the WPP site which is a static obstacle. The volume of space with a height of 54 m above the ground of the WPP site is \( V_3 = 23.2 \times 10^8 \text{ m}^3 \) (figure 8). Scheme of volumes attributable to the wind turbine rotors. The volume of towers from the entire space is 0.002%, the percentage of a static obstacle at a height of up to 54 m from the ground (refers to insects and species of birds and bats that live or hunt at these heights).
As a result of the blade rotation, a plane of rotation is formed, which also rotates in space depending on the wind direction. As a result of rotation, there is a sphere – a ball (figure 8). The sphere volume $V_4=1 \times 10^6 \text{ m}^3$ is an obstacle volume for one WTG which is a dynamic obstacle. Reasoning further, we can talk about the volume of the rotational element and its share in space. The volume of all elements in space is $V_5 = 40 \times 10^6 \text{ m}^3$ of the volume of space in which the rotational elements are located. $V_6=5.4 \times 10^9 \text{ m}^3$ is the site volume. Accordingly, the percentage of spatial dynamic risk is 0.74% of the total space at the height of 54 m to 180 m.

5. Characteristics of the density of the WTG placement as an element of the formation of barrier risks (figure 9).

In the presented examples, we can see the density of the wind turbine placement according
to 500 m buffer zones around each wind turbine, which allows us to draw certain conclusions about the density of wind turbines at the wind farm site, the comfort of their placement and the

Figure 4. Buffer zones of 500 m and 250 m around wind turbines.

Figure 5. 140 m buffer zones around wind turbines.
Wind turbine parameters
(Vestas V150-4.0/4.2 MW turbines)
1 – Blade rotation diameter 126 m (d)
2 – Area of blade rotation S=12462.7 m²
3 – Blade 63m (R)
4 – Tower (height) 117 m (h)
5 – Distance from the rotation area to the ground 54 m (h1)
6 – Blade bend 5 m (Z)
7 – Tower radius 2.5 m (r)

Total height of the wind turbine 180 m

Figure 6. Scheme of towers in space.

Figure 7. Scheme of towers in space.

Figure 8. Scheme of volumes attributable to the wind turbine rotors.

criterion for interference and disturbance for environmental components already at the initial stage.
6. Construction of the Thiessen polygons and their analysis to determine areas of barrier risks (figure 10).
As a result of the performed analysis, we can see a site divided into polygons, the colour gradation of which corresponds to the value of the area of the site. Risk zones are highlighted in dark (which are recommended to be avoided at the design stages), brown colour are border areas. Research, management and impact minimization work is recommended for these two types of territories. Beige and yellow colours are satisfactory and comfortable zones, respectively, they
require surveys and analysis of additional factors (where these sites are located: natural or anthropogenic biotopes, territories of the NRF, habitats of rare and red book species, etc.).

The use of information layers on technical characteristics in combination with layers of geoecological nature will provide more complete information about the interaction of technogenic and environmental components.

7. Identification of natural areas (figure 11a).
8. Emerald Ecological Network (figure 11b).

An integrated approach was used in assessing the territory of the emerald network within the boundaries of the WPP and 500 m buffer zones (figure 12). The territory of the emerald network was considered in detail: which parts of it are natural and which are anthropogenic. Particular attention was paid to natural areas and their location relative to the 500 m zones of impact.

Estimated characteristics based on the cartographic analysis are presented in table 1.

Using the information layers of the Emerald Network, natural areas, 500 m buffer zones around the wind turbine, there is made an analysis of the territory that fell into the impact zone of the wind turbine, its qualitative and quantitative characteristics, i.e. what territory it is, natural or anthropogenic, in what percentage in what zone is it located, etc., which makes it possible to analyze the impact of wind turbines in the NRF.

9. Analysis of biotopic and species diversity in the assessment of the impact area as an integrated approach to the study and analysis of the territory, using the example of vegetation and bird census (figure 13).
Figure 11. Placement of natural and reserve areas within the WPP site.

Figure 12. Analysis of the emerald network sites that fell into the 500 m buffer zone.

10. Spatial analysis taking into account 500 m buffer zones (figure 14).
11. Analysis of migrations at dangerous heights taking into account barrier risks (figure 15).
In this case, the map shows areas (in dark colour) where the wind turbines are located more
Table 1. Assessment characteristics of natural areas within the boundaries of the WPP site.

| Area within the boundaries of the WPP | Area (ha) | Percentage |
|--------------------------------------|-----------|------------|
| The Overianivka and Novotroitsk WPP (the entire site) | 4304 | 100 |
| The Overianivka and Novotroitsk WPP (within the Emerald Network) | 2921 | 67,9 |
| Natural areas that are within the WPP | 1155 | 26,8 |
| Natural areas within the 500 m risk zone | 539 | 12,5 |

Figure 13. Types of analysis on the territory of the WPP.

densely and make a certain risk zone for mass migrations at dangerous heights.

12. Analysis of breeding complexes in risk zones.

The results of census data for the breeding period of 2021 are presented in figure 16 and table 2, where areal indicators are considered.

Table 2. Characteristics of breeding complexes within the boundaries and buffer zones of the WPP site.

| Locations of breeding gatherings | Area (ha) | % |
|---------------------------------|-----------|---|
| Total area of breeding gatherings | 3483 | 100 |
| Within the WPP | 643 | 18,46109676 |
| Outside the WPP | 2840 | 81,53890324 |
| Water breeding gatherings | 2352 | 67,52799311 |
| Ground breeding gatherings | 1131 | 32,47200689 |

After analyzing the locations of breeding gatherings and their numbers, it is possible to identify areas that require special attention and measures to minimize the impact of wind farms.
Figure 14. Spatial analysis of birds getting into the 500 m zone and their percentage.

| Migrations          | Number | %  |
|---------------------|--------|----|
| Total               | 24503  | 100|
| Outside the WPP     | 14120  | 57.63|
| The WPP             | 10383  | 42.37|
| 500 m zone around the WTG | 7560  | 30.8 |

Figure 15. Analysis of bird movements at dangerous heights and their percentage (March 5, 2021. Spring migrations).

| Within 500 m at the height of 50-200 m | Number | Altitude |
|---------------------------------------|--------|----------|
| Anser albiros                         | 486    | 90       |
| Branta ruficollis                     | 90     | 90       |
| Branta ruficollis                     | 140    | 120      |
| Grus grus                            | 22     | 200      |
| Total                                | 738    |          |
| % of total migratory birds            | 3.01   |          |

during the breeding period.

13. Analysis of the population density

   Analysis of the placement density for the most vulnerable species of animals (birds and bats) (figures 17, 18).

   Analysis of the abundance and location of their concentrations makes it possible to identify areas of large bird gatherings taking into account barrier risk zones, to analyze the ornithological situation at the wind farm site.

14. Allocation of zones for the implementation of mechanisms to minimize the impact of wind turbines on geocological systems (figure 19).
5. Conclusions

Particular attention is paid to ecogeographic mapping and the scheme of its implementation based on GIS technologies, the purpose of which is to prevent, reduce and compensate for environmental damage.

Geoecological analysis made it possible to compare various spatial information with each other and present the results of the analysis in a convenient form for perception. Work made for geoecological analysis and assessment of the state of the study area and its mapping made it possible to move to a geoinformation system as the basis of geoecological information and cartographic support for research.

The results obtained when performing system monitoring and geoecological analysis showed that there were zones of local “stress” in the study area, which is typical to some extent for natural and technical geosystems. And it is necessary to carry out specific work and implement some means to minimize the environmental load. Numerous kinds of work have made it possible to develop a methodology of geoecological analysis for wind farm sites based on GIS technologies. This makes the geoinformation system an indispensable tool for analyzing information on the state of natural and technical geosystems.

Geoecological analysis contributed to a complex assessment of the ecological state of the WPP site and the development of recommendations for minimizing the impact of the WPP on the natural environment and its components. Based on the data obtained, recommendations and justifications were made on the possibility (or impossibility) of building a wind farm and its infrastructure, on limiting the impact on individual biocomplexes, on minimizing damage to flora and fauna during the construction and operation of a wind farm for the entire site as a whole and its individual parts. There were made expected impacts on ecosystems. The main advantages of this analysis are mobility, georeferencing accuracy, further use of data in the design and monitoring work, compatibility with subsequent geoinformation data for subsequent analysis, convenience in visualization, ease of perception and clarity of thematic maps.

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Figure 17. Distribution of the density of bird gatherings and migrations for 2021.
Figure 18. Analysis of the density and places of bat concentrations for 2021.

Figure 19. After analyzing the technical component of the site, as well as the location of the main biocomponents, with an analysis of their life and places of concentration, areas of special attention were identified. In these territories, there were recommended the means of minimizing the impact of wind turbines and controlling the environmental situation.

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