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Ecological aspects of zoning the territory of the Saratov region by the risk level of formation of West Nile fever foci

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Abstract. The modern period is characterized by the expansion of the areas of a number of dangerous infectious diseases, previously endemic only for the countries with tropical climate. As a result of Palearctic climate warming and humidification and under the influence of anthropogenic factors, foci of a new transmissible arboviral zoonosis – West Nile fever (WNF) – have been formed in the Saratov region. On the territory of Russia, the circulation of the West Nile virus (WNV) has been recorded since 1963, and cases of human infection have been detected since 1967. In the studied region, the circulation of the virus has been known since the mid-90s of the last century, and epidemic complications – since 2012. 142 cases of the disease were reported in 2012–2020. The ecological prerequisites for a wide circulation of WNV are associated with the increase in the number of birds – carriers, and arthropods – blood-sucking vectors, the longer activity period of mosquitoes and ticks owing to the reduced frosty season of the year. As a result of landscape mapping with the use of modern methods for decoding images of satellite maps and remote sensing of the Earth (ERS), data have been obtained that served as the basis for epidemiological WNF zoning. There are three types of potential WNF foci on the territory of the region, namely: natural, natural-anthropourgic, and anthropourgic ones. The total area of biocenoses has been established, where natural, natural-anthropourgic and anthropourgic WNF foci could be formed: 6619.94 km^2, 1484.62 km^2, and 70.4 km^2, respectively. Cluster analysis of the environmental conditions in 38 administrative districts of the region has distinguished four groups differing in the risk level of infection of the population with West Nile fever. The data obtained are used for planning, substantiating and conducting surveys and preventive measures, and form the basis for predicting the epidemiological situation in the region.
Keywords: West Nile fever, landscape mapping, epidemiological zoning, remote Earth sensing, Saratov region

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INTRODUCTION

The modern doctrine of the natural focality of infectious diseases is based on a complex of knowledge that appeared at the junction of several sciences – medicine, geography, ecology and biology (Shoshin, 1961; Baroyan, 1967; Avtsyn, 1972; Lebedev, 1974; Lederberg et al., 1992; Stozharov, 2007; Fornace et al., 2014; Morozova et al., 2017).

One of the global threats of our time is the incidence of infectious and parasitic diseases that cause great social and economic damage to humanity (Sergiev et al., 2000; Giesecke, 2004; Lobzin, 2012). The problem of infectious pathology not only retains its relevance, but is increasingly exacerbated in connection with climate changes, abiotic and biotic environmental factors, an increase in anthropogenic load on natural ecosystems, the expansion of transport links, human development of new territories and environments, side effects of genetic engineering in research in the field of medical microbiology, bioterrorism (Pokrovsky et al., 2003; Korenberg, 2004; Sergiev, Filatov, 2006; Grigoriev, 2014; Gray, Webb, 2014; Franclinos et al., 2019). Currently, new opportunities have emerged that make it possible to accelerate the acquisition of relevant and reliable information for epidemiologists on large areas using GIS tools, satellite mapping, Earth remote sensing (ERS) methods, ecological inspection of territories, epidemiological zoning (Morozova et al., 2017).

Currently, in various spheres of human activity, ERS methods are increasingly being used, the data of which are obtained using artificial Earth satellites, manned and unmanned aerial vehicles. These methods are also used in environmental monitoring of natural foci of infectious diseases (Arnberger, 1983; Barnes, Peck, 1994).

One of the main sections of epidemiological surveillance in natural foci of infectious diseases is the zoning of a territory in order to differentiate it by the level of risk of human infection. The main tasks are the typification of foci, the creation of forecast maps necessary in the development of measures for the prevention of diseases. When studying the natural foci, a search and selection of a convenient and meaningful basis for creating thematic maps of medical and environmental purposes is carried out. As a rule, landscape and zoological maps (distribution and number of carriers and vectors of infections), schematic maps of the results of epizootic monitoring, location of foci types, population size, etc. are created as intermediate products.

Arbovirus infections, previously endemic only for tropical latitudes, are becoming more and more widespread in the world. Their reservoirs are birds and blood-sucking arthropods. One of the most dangerous diseases is West Nile Fever (WNF), a vector-borne zoonotic disease, which, in accordance with the International Health Regulations (2008), which entered into force in Russia in 2007, requires international control. Currently, the epidemiological significance of this infection is increasing due to the expansion of its nosoareal, the risk of occurring outbreaks with a severe course of the disease with damage to the nervous tissue, a high specific gravity of deaths, the lack of specific treatment and prevention means, an increase in the number of anthropourgic foci, the presence of a large number of latent forms with viremia (Lvov, 2000, 2009; Petersen, Roehrig, 2001; Calistri et al., 2010). Most researchers find the main causes of WNF nosoareal expansion in climate warming and humidification, which leads to an increase

in the number of carriers and vectors of the virus, prolongation of the infection period (Haines, 1998; Wittmann, Baylis, 2000; Izrael et al., 2001; Jaenisch, Patz, 2002; Zell, 2004; Platonov, 2006; Dubinina, 2017).

On the territory of the Saratov Region, the circulation of the West Nile virus (WNV) in natural ecosystems was detected in the 1990s, and in the subsequent period was repeatedly confirmed by the results of epizootiological monitoring (Lyapin et al., 1996; Shcherbakova et al., 2009). Since 2012, the epidemic manifestations of WNF began to be recorded, which indicated the formation of WNF foci in the region (Krasovskaya et al., 2013; Matrosov et al., 2013; Zakharov et al., 2016; Kazorina et al., 2017).

The main purpose of the study was the epidemiological zoning of the territory of the Saratov Region according to the level of risk of infection of the population with West Nile fever.

MATERIAL AND METHODS

The studies were carried out on the territory of the Saratov Region in 2010–2020. Investigation of the formation of natural WNF foci was carried out using ecological, zoological, epizootiological, epidemiological, geographical and statistical research methods. For the purposes of epidemiological zoning, the method of development and analysis of cartographic models was applied, which is highly informative and illustrative. Such maps make it possible to characterize the territory by a whole range of features and indicators, while reflecting the medico-ecological characteristics (Morozova et al., 2017).

The electronic Database (DB) “Carriers and vectors of West Nile virus in the Saratov Region” was used for the analysis, which made it possible to systematize the information received, facilitated its processing and analysis. When creating a database, we used a layer-by-layer organization of spatial data. Its attributive structure includes 30 thematic sets, which contain 113 classes of objects. For the analysis of the landscape allocation of the natural WNF foci, a specialized thematic layer was created, describing 27 subtypes of geobotanical zones. It contains information on the geographical coordinates of the survey point, the date of material collection, the number of animals caught by species (birds, small mammals, mosquitoes, ticks).

Currently, the main methods of medical-geographical research are comparative-geographical and logical-epidemiological ones. Based on them, medico-geographical forecasting is carried out, which is used to obtain maps of epidemiological zoning of territories (Malkhazova, 2001; Morozova et al., 2017).

When typing and mapping natural, natural-anthropourgic and anthropourgic foci of West Nile fever (WNF) in the Saratov region, the Earth remote sensing method (ERS) was deployed. In our case, we worked with color space satellite images (in the visible spectrum of radiation) of the Saratov Region of medium and high resolution. Map images were obtained from publicly available sources of the Bing Maps geo-service. We used ERS materials obtained using the complex for aerial photography from an unmanned aerial vehicle (UAV) “GEOSCAN-101” to refine the reference images necessary for deciphering the foci of WNF.

The primary input of geo-information and the creation of thematic data layers were carried out in the SASPlanet 07.16.07 software. Further, relying on an external database, as well as standards of typical images, the analysis and interpretation of ERS materials were performed. Thematic layers were subsequently edited and spatially analyzed in ArcGIS Desktop 10.1 using core platform applications ArcMap, ArcCatalog and ArcToolbox from ESRI CIS. The programs used were adjusted to work in the WGS 84 coordinate system. Area calculations were conducted using the Albers equal-area conic projection for the European part of the Russian Federation.

When processing the data necessary to summarize the received information and carry out the epidemiological zoning of the Saratov region by WNF, the method of cluster analysis was used. When choosing standard cell area, we used the territories of municipal districts of the region, within the boundaries of which all information was collected and processed. The information was presented in tabular form, which reflected the ranked manifestations of signs by regions. As criteria for differentiating the territory of the region, the following features were identified: population density, areas of potential WNF foci-natural, natural-anthropourgic and anthropourgic, fauna and number of carriers and vectors of infection, findings of WNV markers in populations of birds, small mammals and mosquitoes, presence and the level of the immune layer in the population and farm animals (horses), as well as registered cases of WNF. All signs were evaluated on a four-point scale – from 1 (minimum criterion value) to 4 (maximum criterion value). In the absence of indicators for a certain area, zero was put down. When conducting cluster analysis, Jaccard's coefficient of community was used according to the "nearest neighbor" method. To select an acceptable degree of fragmentation of the obtained clusters, the criterion of "significant similarity" was used. The latter is calculated as the upper 95% confidence limit of the average similarity between districts. Subsequently, the principles of extrapolation and interpolation of data obtained in neighboring territories were used in the epidemiological zoning of the entire territory according to the risk of WNF.

Statistical data processing was performed in the software packages MS Exel 2000 (Microsoft Corp.), PAST 2.17 c (Hammer et al., 2001) and Statistica 6.0 (Statsoft Inc., OK, USA).

RESULTS AND DISCUSSION

142 cases of West Nile fever among the population were registered in the Saratov Region in 2012–2018. During the same period, according to the epizootic monitoring data, persistent circulation of West Nile virus (WNV) in natural and residential biotopes was noted in the region. In a study of 69 bird species, WNV markers were found in 15: great cormorant (*Phalacrocorax carbo* Linnaeus, 1758), gray heron (*Ardea cinerea* Linnaeus, 1758), common gull (*Larus canus* Linnaeus, 1758), silver gull (*Larus argentatus* Pontoppidan, 1763) and black-headed gull (*Larus ridibundus* Linnaeus, 1766), common (*Sterna hirundo* Linnaeus, 1758) and small (*Sterna albifrons* Pallas, 1764) terns, rook (Corvus frugilegus Linnaeus, 1758), hooded crow (*Corvus cornix* Linnaeus, 1758), jackdaw (*Coloeus monedula* Linnaeus, 1758), magpie (*Pica pica* Linnaeus, 1758), common starling (*Sturnus vulgaris* Linnaeus, 1758), sparrowhawk (*Accipiter nisus* Linnaeus,

1758), bluethroat (*Luscinia svecica* Linnaeus, 1758), great tit (*Parus major* Linnaeus, 1758). Of the 23 species of small mammals studied, positive results were obtained for 5 species of rodents: house (*Mus musculus* Linnaeus, 1758) and small wood (*Apodemus uralensis* Pallas, 1811) mice, common (*Microtus arvalis* Pallas, 1778), social (*Microtus socialis* Pallas, 1773) and bank voles (*Myodes glareolus* Schreber, 1780). In the study of 24 mosquito species, markers were found only in *Culex pipiens* Linnaeus, 1758 and *Ochlerotatus* (*Ae*) *caspius* Pallas, 1771.

The differentiation of the territory of the Saratov Region according to the level of epidemiological hazard with its subsequent zoning was carried out by the example of WNF foci – a new dangerous arbovirus infectious disease for the region. To study the foci of West Nile fever in the Saratov Region, we used the methods of large-scale epizootiological mapping. The capabilities of Earth remote sensing methods using modern cartographic GIS applications greatly facilitated the task of identifying the contours and calculating the sizes of decoded landscape elements (polygons).

The main deciphering features were dimensions, configuration (geometry), structure, pattern, color scale and tonality of images. The most recognizable images on satellite and aerial images are large-scale and linear objects: settlements, buildings, city blocks, roads, rivers, structures, agrocenoses (gardens, vegetable gardens, fields, arable lands, etc.), as well as the boundaries of plant associations, well distinguishable in color photographic images (forests, meadows, coastal water vegetation, forest belts, green areas of cities and towns, etc.).

The research results allowed us to map potential pathobiocenoses where the West Nile virus can circulate in the Saratov region settings. Inability to fully cover the natural and anthropogenic biocenoses by field research led to the use of methods for probabilistic assessment of their epizootiological and epidemiological significance. In this regard, the level of risk of WNF foci formation of three types: natural, natural-anthropourgic, and anthropourgic, was used as a criterion.

The identified types of foci differ in age, the nature of epizootic manifestations, biocenotic and spatial structure, stability, and epidemiological significance. Their allocation to certain ecotopes: natural landscape structures of various ranks, various types of sites transformed as a result of human activity (pastures, agrocenoses, park zones, settlements, industrial zones, hydraulic structures, etc.), made it possible to identify such foci on the ground and on maps.

Images of multi-storey buildings in cities and urban-type settlements were used as the main deciphering signs of potential anthropourgic foci of WNF. Their contouring was carried out using color satellite images, where such buildings were clearly distinguished by their geometric pattern, configuration, size of objects, shadows and other features. Based on remote sensing data, all rural settlements, agrocenoses, as well as the territories of gardening associations and dacha cooperatives were identified with great accuracy. These are the most significant potential WNF foci. Thus, anthropourgic and natural-anthropourgic foci have linear boundaries (Fig. 1–3).

It is known that the main difficulty in using the data of epidemiological statistics is associated with their organization according to the administrative-territorial principle, when data on the incidence among the population cannot be reconciled with landscape

structures of one rank or another (Lebedev, 1974). To eliminate this drawback, we carried out landscape differentiation within the boundaries of 38 administrative districts of the Saratov Region, on the basis of which natural, natural-anthropourgic and anthropourgic WNF foci were identified with subsequent quantitative analysis.

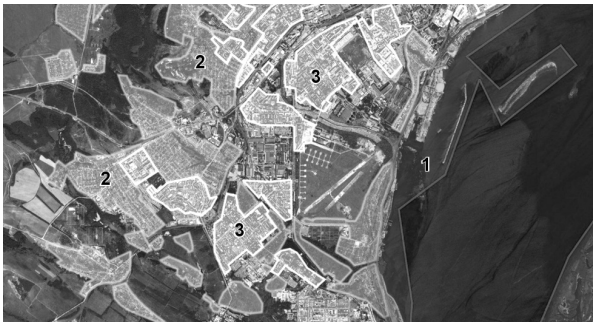

Fig. 1. A fragment of the decoding cartogram of West Nile fever foci in the city of Saratov: *1* – natural foci (intra-zonal floodplains of the Volga and other rivers); *2* – natural-anthropourgic foci (private building areas in the suburbs); *3* – anthropourgic foci (high-rise apartment blocks)

The situation was somewhat more complicated with the delineation of natural foci – near-water biocenoses, where the boundary is a strip of indefinite (different) width. Based on the location of plant communities and the limiting scattering distances of blood-sucking mosquitoes – potential vectors and reservoirs of WNV, the linear boundary was drawn five hundred meters outside those intrazonal facies.

Taking into account the high level of risk of human infection in anthropourgic and natural-anthropourgic foci in the districts of the Region, where there is a large proportion of areas with potential foci of this type, we can assume the occurrence of epidemiological complications.

Mapping metric data allow comparing indicators for all administrative districts of the Region, which can be used to create application maps to assess the risks of infection of the population with this dangerous fever. Naturally, in all districts of the Saratov Region, there is a high probability of the formation of natural foci, occupying large areas of near-water plots, where nesting and forage areas for birds are located, the concentration of blood-sucking mosquitoes and Ixodidae ticks.

Fig. 2. A fragment of the cartogram for deciphering West Nile fever foci on the territory of Engels city (the legend as in Fig. 1)

The obtained cartographic data on the location of 3 types of foci, differing in the level of potential risk of human infection, formed the basis for the zoning of the region by WNF (Table). In most of the administrative districts, the conditions for the formation of anthropourgic foci are not created, while natural-anthropourgic and natural foci can arise elsewhere.

When assessing the location of natural foci, attention is drawn to their confinement to water bodies: the Volgograd and Saratov reservoirs (Volga river), as well as small rivers of the Volga, Don and Kamysh-Samara drainless basins, and in some cases to ponds and lakes of natural or artificial origin. The total area of biocenoses, where natural foci of WNF can occur in the Saratov region, is 6619.94 km^2 (6.6%). They occupy the largest area in Balakovsky, Engelssky, Marksovsky, Dukhovnitsky districts of the Left Bank, as well as Saratovsky, Volsky, Voskresensky districts of the Right Bank.

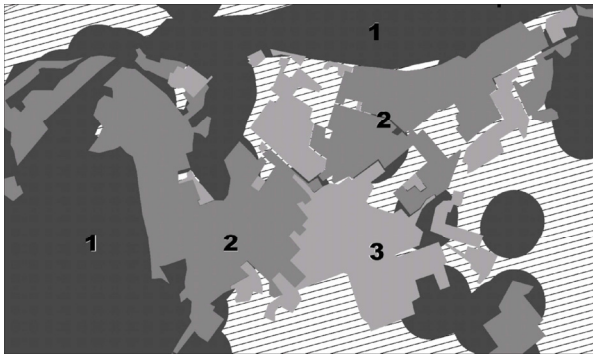

Fig. 3. A fragment of the resulting overlay of polygons for assessing the area of the West Nile fever foci in the territory of Engels city (the legend as in Fig. 1)

There are almost no differences in the cartometric indices of the natural anthropourgic foci of the WNF on both banks of the Volga. The total area of these foci was 1484.62 km^2 (1.5%). There is a large share of such foci around the regional center and other large cities: in Balashovsky, Volsky, Saratovsky, Rtishchevsky, Tatishchevsky, Balakovsky and Engelssky districts.

Table. Characteristics of the risk levels of West Nile fever (WNF) foci formation of different types in the Saratov Region

Score points and proportion of areas (%) of foci of different types						Total sum of points	Risk levels of WNF foci formation
Natural		Natural-anthropourgic		Anthropourgic			
Points	%	Points	%	Points	%		
1	≤ 1.0	1	≤ 1.0	0	0.0	< 5	Low
2	1.0–5.0	2	1.0–2.0	1	0.01–0.1	5–6	Medium
3	5.0–10.0	3	2.0–5.0	2	0.1–1.0	7–8	High
4	≥ 10.0	4	≥ 5.0	3	≥ 1.0	> 8	Very high

Anthropourgic WNF foci are detected in 23 out of 38 districts. The total area of elements of this type of foci was only 70.4 km^2 (0.07%). Naturally, in the left-bank part of the Region, the number of such mini-foci and their total area turned out to be half as much as on the right bank, where the regional center and large cities with an abundance of multi-storey buildings with warm basements are located.

The resulting cartometric indicators on the ratio of WNF foci of different types, as well as other features of epizootic and epidemiological significance, were used to differentiate the territory of the Saratov Region by the risk of human infection with WNV. Based on the results of the data processing, a cluster analysis of administrative districts was carried out using the Jaccard's coefficient according to the "nearest neighbor" method (Fig. 4).

The cartometric data we have obtained allow us to compare indicators for all administrative districts of the Saratov Region, which can be used to create application maps to assess the risks of infection of the population with this dangerous fever. The choice of the territories is driven by the logistics of medical service and observation in the regions of Russia. Cluster analysis of information on administrative districts by various indicators, such as: cartometric data on the types of WNF foci, population size, infection of carriers and vectors of WNV, results of laboratory studies of blood sera from donors and horses, data on the incidence of the population, as well as the use of cartographic extrapolation and interpolation resulted in zoning of the Saratov Region according to the level of potential epidemiological hazard.

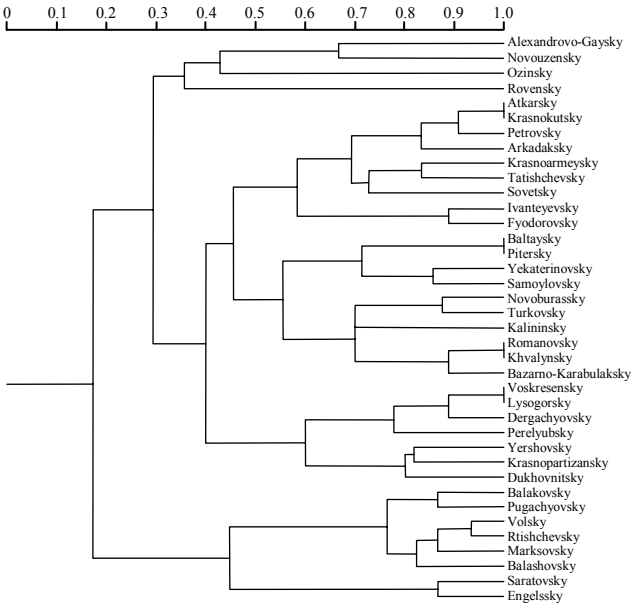

Fig. 4. Results of the cluster analysis of administrative districts in the Saratov Region

The procedure was carried out with the ranking of administrative districts using a point scale for their assessment. We identified 4 groups (clusters) that differ in the level of risk of human infection with WNF (Fig. 5). Thus, the risk levels for the formation of certain types of WNF foci as a whole in the region depended on the size, number of elements, and the proportion of areas of the three types of foci. At the same time, the results of the epizootiological survey were also taken into account: the findings of WNV markers in samples from birds, small mammals and blood-sucking arthropods, as well as the results of tests of blood sera from the population and horses.

Characteristics of the risk levels of human infection in the foci of WNF by the administrative districts of the Saratov Region are given below:

- low: the population is less than the average, there are no anthropourgic foci, the shares of the areas of natural-anthropourgic and natural foci are small; there are no findings of WNV markers in samples from carriers and vectors in blood sera from the population and horses; no human cases of the disease;

- medium: the population is below or at the level of the average, there are anthropourgic foci, but they cover a small area; the share of areas of natural-anthropourgic and natural foci is at the average level; findings of WNV markers are sporadic or absent, there are no human cases of the disease;

- high: the population size is medium or high; the proportions of the areas of anthropourgic and natural-anthropourgic foci are large; findings of WNV markers are registered in samples from birds, rodents, mosquitoes, as well as in blood sera of humans and in samples from horses; human cases are not reported or there are only isolated cases of the disease;

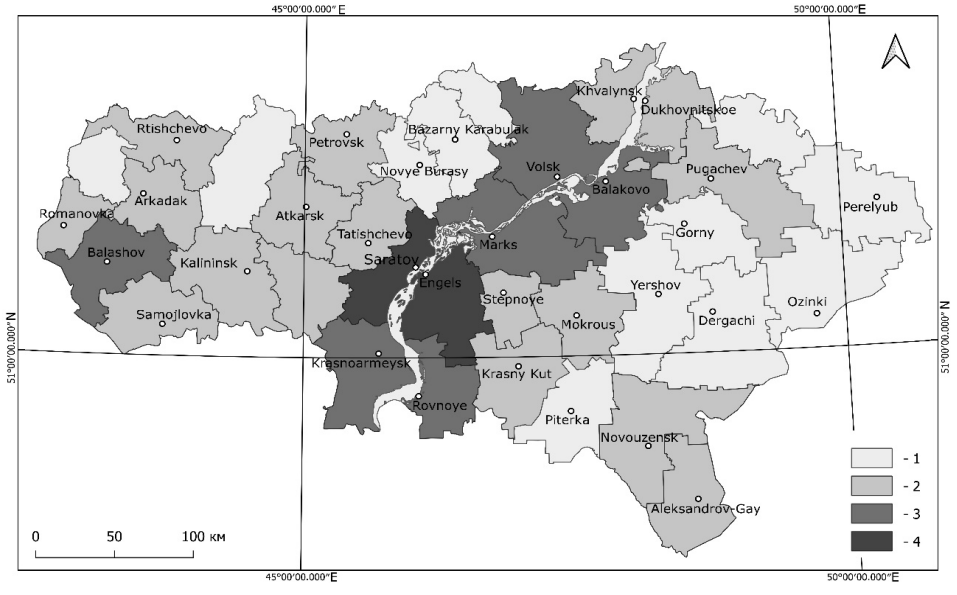

Fig. 5. Differentiation of the administrative districts of the Saratov region by the potential epidemic hazard level of West Nile fever: Levels: *1* – low; *2* – medium; *3* – high; *4* – very high

- very high: high population levels, the urban population predominates: the shares of anthropourgic and natural-anthropourgic foci are large; findings of WNV markers in samples from birds, rodents, and mosquitoes are numerous; WNV markers are found in the blood sera of donors and in horses; human infections are numerous, recorded almost annually.

CONCLUSION

Based on the results of processing the data on climate change, information on the outcomes of ecological and epizootiological survey, epidemiological monitoring of public health, landscape mapping of the Saratov Region in 2010–2020, the differentiation of administrative districts by the level of potential epidemiological hazard of human infection in the foci of WNF was carried out. All districts differ in environmental conditions, population size and features of economic activity, which determine the factors, territories, terms and contingents of the risk of WNF infection. Modern research methods using GIS tools allow to collect, organize, process, and analyze the received information with greater reliability and in a shorter time. A very high level of risk of human infection with

West Nile fever is noted only in the Saratovsky and Engelssky districts. Seven administrative districts with a high level of risk are located mainly in the valley of the river Volga: Volsky, Voskresensky, Krasnoarmeysky, Rovensky, Marksovsky, Balakovsky, as well as Balashovsky districts. Territories with medium level of risk of human infection cover 17 districts, with a low – 12 administrative districts.

Thus, the differentiation of the territory of the Saratov Region in terms of the risk of infection of the population with WNF is the basis for epidemiological forecasting, which is necessary for planning, organizing and conducting more targeted epidemiological surveillance over the development of the epidemiological situation; choosing and justifying the scope, volumes and territories of preventive measures. The lessons learned from the epidemiological zoning of the region's territory by WNF can be used to obtain predictive cartographic models for other relevant infections.

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ECOLOGICAL ASPECTS OF ZONING THE TERRITORY OF THE SARATOV REGION

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ЭКОЛОГИЧЕСКИЕ АСПЕКТЫ РАЙОНИРОВАНИЯ ТЕРРИТОРИИ САРАТОВСКОЙ ОБЛАСТИ ПО УРОВНЮ РИСКА ФОРМИРОВАНИЯ ОЧАГОВ ЛИХОРАДКИ ЗАПАДНОГО НИЛА

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Аннотация. Современный период характеризуется расширением ареалов целого ряда опасных инфекционных болезней, ранее эндемичных только для стран тропического климата. В результате потепления и увлажнения климата и под действием антропогенных факторов на территории Саратовской области сформировались очаги нового трансмиссивного арбовирусного зооноза – лихорадки Западного Нила (ЛЗН). На территории России циркуляция вируса Западного Нила (ВЗН) регистрируется с 1963 г., случаи заболеваний населения выявляются с 1967 г. В изучаемом регионе циркуляция вируса известна с середины 90-х гг. прошлого столетия, эпидемические осложнения – с 2012 г. В 2012–2020 гг. отмечено 142 случая заболевания населения ЛЗН. Экологические предпосылки широкой циркуляции ВЗН связаны с ростом численности птиц – носителей и членистоногих кровососущих – переносчиков, увеличением периода активности комаров и клещей в результате сокращения морозного периода года. В результате ландшафтного картографирования с применением современных методов дешифрирования изображений спутниковых карт и дистанционного зондирования Земли (ДЗЗ) получены данные, которые были положены в основу эпидемиологического районирования по ЛЗН. На территории области выделяют три типа потенциальных очагов ЛЗН: природные, природно-антропоургические и антропоургические. Установлена общая площадь биоценозов, где могут формироваться природные очаги ЛЗН – 6619.94 км^2, природно-антропоургические – 1484.62 км^2, антропоургические – 70.4 км^2. В результате кластерного анализа экологических условий в 38 административных районах области выделены четыре группы, различающиеся по уровню риска инфицирования населения лихорадкой Западного Нила. Полученные данные используются для планирования, обоснования и проведения обследовательских и профилактических мероприятий, кладутся в основу прогнозирования эпидемиологической обстановки в регионе.

Ключевые слова: лихорадка Западного Нила, ландшафтное картографирование, эпидемиологическое районирование, дистанционное зондирование Земли, Саратовская область

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