REGIONAL GEOGRAPHIC INFORMATION SYSTEMS OF HEALTH AND ENVIRONMENTAL MONITORING

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Submitted on August 22, 2016.

doi: 10.5922/2079-8555-2016-4-10

The article describes a new scientific and methodological approach to designing geographic information systems of health and environmental monitoring for urban areas. Geographic information systems (GIS) are analytical tools of the regional health and environmental monitoring; they are used for an integrated assessment of the environmental status of a large industrial centre or a part of it. The authors analyse the environmental situation in Voronezh, a major industrial city, located in the Central Black Earth Region with a population of more than 1 million people. The proposed research methodology is based on modern approaches to the assessment of health risks caused by adverse environmental conditions. The research work was implemented using a GIS and multicriteria probabilistic and statistical evaluation to identify cause-and-effect links, a combination of action and reaction, in the dichotomy 'environmental factors — public health'. The analysis of the obtained statistical data confirmed an increase in childhood diseases in some areas of the city. Environmentally induced diseases include congenital malformations, tumors, endocrine and urogenital pathologies. The main factors having an adverse impact on health are emissions of carcinogens into the atmosphere and the negative impact of transport on the environment. The authors identify and characterize environmentally vulnerable parts of the city and developed principles of creating an automated system of health monitoring and control of environmental risks. The article offers a number of measures aimed at the reduction of environmental risks, better protection of public health and a more efficient environmental monitoring.

Key words: geographical information technologies, environmental risks, integrated assessment, monitoring of public health

Creating regional systems of medical and environmental monitoring with a focus on the impact of adverse environmental factors on public health is the principal activity of regional environment agencies. The efficiency of creating such systems is often augmented by current geographic information technology, which offers adequate tools for information collection and analysis, forecast production, and informed decision-making in order to minimise environmental risks to public health [1; 21].

The methodology for creating IT-based regional medical and environmental monitoring systems derives primarily from the works of Russian and international experts in the following fields:

geochemistry, bioindication, and anthropogenic pollution monitoring (N. S. Kasimov et al. [10; 27], M. G. Opekunov [20], Yu. E. Saet, B. A. Revich et al. [5; 23], F.R. Burden et al. [32], GIS for Green Government… [33], P. A. Longley et al. [34]);

urboecology (V. A. Vladimirov [3], V. S. Khomich [6], Regions and Cities of Russia... [24]);

human ecology and public health risk assessment (S. L. Avaliani et al. [1], G. G. Onishchenko et al. [21], B. B. Prokhorov [22]);

technology for multi-criteria assessment, and geoecological and geographic information mapping (V. S. Tikunov et al. [4], I. K. Lurie [13], S. M. Malkhazova et al. [16], V. Z. Makarov et al. [15], V. V., Dmitriev, N. V. Kaledin [8], V. I. Sturman [25]);

practical applications of geographic information systems to support administrative decision-making in healthcare and spatial planning in Northwestern and Central Russia, Siberia, and other regions of the world (I. V. Arkhipova. V. G. Vedukhina [2], I. A. Krasilnikov et al. [12], N. P. Melville, S. M. Ross [35]).

A specific feature of this methodology (the risk-based approach) is that the ‘health’ of the environment is estimated using not only ecosystem and population parameters but also indices describing the conditions of various depositional environments and living organisms. The level of public health depends on risk factors, primarily, the presence of potentially hazardous chemical substances in the environment, as well as other adverse environmental factors. Public health and the condition of the environment and bioindicator species — which can be estimated based on different diagnostic parameters and using alternative and complementary methods — are forms of response to human impact. This response can be used as a criterion for assessing the quality or ‘health’ of the environment [1].

The system of medical and environment monitoring rests on the information obtained in the course of continuous systematic observations. It should include arrays of data on stationary and mobile sources of anthropogenic pollution, the level of contamination of key depositional (water and soil) and transitional (atmosphere, snow cover) environments, biotic reaction parameters (for instance, in woody plants), and public health criteria as indicators of the environmental condition.

Mapping combined with computer-assisted information processing is an effective method for synthesising diverse data. The above requirements are met by geographic information systems, for instance, ArcGIS, MapInfo Professional, and Karta GIS. Using GIS to control the complex anthropogenic impact on the environment requires developing geographic information and analysis packages to support regional environmental monitoring. Such an approach to solving the problem of integrating data from different Russian regional environmental and healthcare bodies has been employed by A. A. Tigeev [26], N. O. Guseynov et al. [7], S. F. Mazurov [14], and A. A. Yamashkin [31].

Each urban territory has its own regional features affecting the environmental condition and public health. Geoecological studies conducted earlier on the territory of the Voronezh region produced an integrated assessment of the quality of urban environment. It identified atmospheric air pollution, which varies considerably across the territory and shows differences in the levels of environmental risk to public health, as a major problem [9; 11; 18; 29].

Regional geographic information system in medical and environmental monitoring of an urbanised territory

Using general systemic approaches, the authors created a geographic information and analysis system for medical and environmental monitoring in a large city (EKOGIS, Voronezh). It includes subsystems for storing environmental/geochemical and medical/geographical data and software for assessing environmental risks. The basic interval for evaluating the quality of urban environment was seven years (2009—2015). Three information generalisation levels represented operational territorial units:

1) functional planning urban zones (six zones and control — seven territorial units);

2) catchment areas of children's outpatient clinics (12 units);

3) urban monitoring sites (75 facilities, including stationary and mobile air control stations of the hydrometeorological service and public health service, as well as other stations selected for an even coverage of the city).

The MapBasic programming language was used to create algorithms for assessing risks to public health caused by air pollution. Software was developed to calculate levels of risk to public health in accordance with regulation R 2.1.10.1920-04 titled 'Guidelines for assessing public health risks associated with chemical pollutants' [21].

The initial data for EKOGIS Voronezh were either obtained through field experiments or provided by regional environmental and monitoring bodies. The structure of the GIS is shown in fig. 1 and the sites of collecting atmosphere, snow cover, and soils samples in fig. 2. The GIS is the foundation of a practicing ecologist's workstation. It combines analytical and administrative elements of a unified system for medical and environmental monitoring.

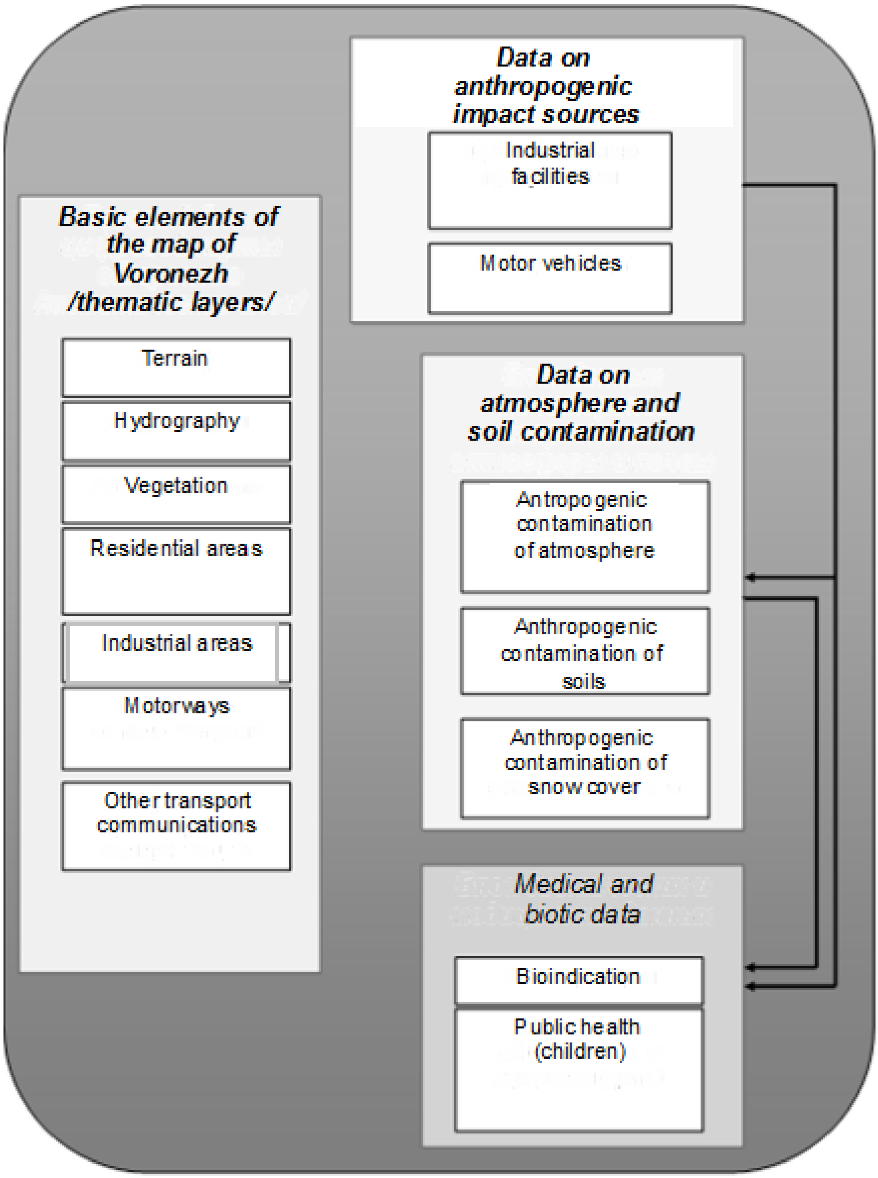

Fig. 1. Structure of a database for an integrated assessment of geographic information software for medical and environmental monitoring

Fig. 2. Sites of collecting atmosphere, snow cover, and soil samples in Voronezh

The digital basis — a map of Voronezh — was divided into six major thematic layers:

1) vegetation (urban and suburban forests, parks, and garden squares comprising the greenbelt of the agglomeration);

2) hydrography (the Voronezh reservoir, perennial and intermittent rivers);

3) residential areas divided into three functional subareas: a) historical centre, including low and high-rise public and business buildings and the ‘old’ five-storey housing erected in the 1950s—70s (HC); b) modern high-rise housing (nine storeys and higher) (MH) built in the 1980s — 2000s, and c) primarily low-rise privately owned housing (PH).

Creating the initial database and introducing analysis algorithms made it possible to develop a GIS software package that ensures systemic collection and evaluation of different environmental and medical data and cohesion with the current environmental control system. Other benefits are the automation of data analysis and environmental risk calculation procedures and the possibility of prompt geographic information mapping [9; 11; 28; 29].

Methodology for assessing air-borne anthropogenic pollution to environment and public health

Based on the registry of industrial and traffic contributors to atmospheric pollution in Voronezh (199 companies, 152 major streets), the authors developed an original methodology for assessing air-borne anthropogenic pollution sources. The methodology consists of the following stages:

— evaluating a potential industrial contributor (pollutant hazard indices were calculated for each industrial facility);

— compiling a hazard class 1 pollutant index (percent of the city's total emission of hazard class 1 pollutants);

— compiling indices for class 2, 3, and 4 pollutants and total emission by company.

Thus, four class-specific pollutant hazard indices and a total impact index were compiled — $I_{cl1,}$ $I_{cl2,}$ I_{cl3}, I_{cl4}, I_{sum});

— compiling a weighted average environmental hazard index by company (I_{ind}) in view of the weighted hazard coefficients of pollutants of different classes [9] used to calculated the total atmosphere contamination index CI_{atm}:

$$CI_{atm} = \left(\frac{C_1}{N_1 * TC_{C_1}} + \frac{C_2}{N_2 * TC_{C_2}} + \frac{C_n}{N_n * TC_{Cn}} \right) * t,$$

where *C_i stands for the average annual concentration of substance I, TC — for the average daily threshold concentration of substance i; N_i — for the constant assuming the values of 1; 1,5; 2; 4 for substances of hazard classes 1, 2, 3, 4 respectively; $t = P / P_o$, where P is the average annual frequency of calm,%; $P_o = 12.5$ %.*

Concentrations of pollutants in the atmospheric air change rapidly in time and space; they depend on many factors. Given a normal sample distribution, periods of one year and longer require using the arithmetic mean of concentration. Thus, the average weighted index of environmental hazard was chosen as the most representative characteristic.

Using weight constants, the authors employed the following formula:

$$I_{ind} = \frac{I_{cl1}}{N_1} + \frac{I_{cl2}}{N_2} + \frac{I_{cl3}}{N_3} + \frac{I_{cl4}}{N_4}.$$

— calculating the carcinogenic emission hazard index (CR) — total emission of substances with proven carcinogenic effect,% of the total city emission (I_{CR}). Carcinogens were interpreted as substances classed as group 1, 2A, and 2B according to the IARC classification published in the *Guidelines for assessing…* [21];

— evaluating the potential hazard of motor vehicle contributors. At first, the average traffic intensity was identified for each major street according to its category [30]. Further indices of potential motor vehicle emission hazard were compiled using a street guide:

— index of potential motor car emission hazard index (I_{car}) — a ranking based on traffic intensity in streets of different categories;

— indices of potential lorry/bus emission hazard index (I_{lor} and I_{bus}) and the total traffic impact index based on the total traffic intensity for a street of a given category (I_{ti});

— calculating a total index of the industrial and traffic infrastructure impact on urban environment ($I_{\sum}$) for any operational territorial unit in view of the weight significance of the three basic indices of hazard associated with pollutant emissions from stationary and mobile sources into the atmosphere (for instance, in the catchment area of a children's outpatient clinic) using the following formula:

$$I_{\sum} = \sum_{i=1}^{n} (I_{ind} + I_{CR} + I_{ti}),$$

where i...n stands for the number of objects (industrial facilities, streets) within a given territorial unit;

— producing digital maps of hazards associated with anthropogenic impact on the urban environment. This is conducted through spatial interpolation of environmental hazard indices compiled for industrial and motor vehicle contributors, using the isoline method. The authors calculated the *area indices* of pollutant emission and traffic intensity by residential complex. These include:

1) *coefficients of pollutant emission impact* associated with stationary sources, t/year per 1 km^2 of a district's area by hazard classes, including carcinogen substances;

2) *traffic impact coefficients*: the number of motor vehicles per hour per 1 km^2 of a district's area by vehicle type and in total;

3) *total industrial and traffic impact index* ($I_{\sum}$ stands for the sum of standardised values of I_{ind}, I_{CR}, I_{ti}).

The maps were produced using the standard MapInfo tools through the IDW interpolation method and drawing isolines with the help of the Surfaces module. Note that MapInfo uses two interpolation methods — inverse distance weighting (IWD) and triangulated irregular network (TIN). Based on the experience of drawing thematic surfaces, the authors established that maps based on discrete values (relatively independent and located at a significant distance, and having no direct influence on each other) required the use of the IDW method.

Analysing the formation of urban anthropogenic pollution zones

ECOGIS Voronezh made it possible to analyse the formation of anthropogenic pollution zones in an urban environment. The analysis included the following elements:

1) evaluating the dependence of pollutant concentration in the atmosphere on the seasonal factor and pollutant dispersion;

2) assessing the statistical effect of industrial and traffic impact parameters on pollutant concentration in the atmosphere, snow, and soil;

3) analysing the link between soil and snow cover contamination through comparing relevant contamination indices at the most representative monitoring sites.

The analysis of air contamination took into account the vertical stratification of the atmospheric condition, which affects pollution in different seasons. It was established that the minimum values of atmosphere contamination index (ACI) are observed in spring and autumn. The maximum ICA values are characterised by a distinct annual course with a minimum during the cold period and a monotonic increase until July, when the pollutant concentration is twice the threshold level.

A comparison of data on the maximum ACI values and the vertical temperature gradient makes it possible to state an increase in the ACI values during major surface inversions reaching an altitude of 3.0 m. In all residential complexes, the situation deteriorates in warm periods, when the maximum ACI values are attained due to the stable stratification of the atmosphere.

The analysis of the formation of anthropogenic contamination zones in the urban environment took into account the stratification of the atmosphere, convection conditions, and the frequency of inversion affecting atmospheric pollution in different seasons. Monthly atmospheric contamination indices were calculated.

The analysis of correlations within the ‘pollution source — transitional environment — depositional abiotic environments’ system showed a rather logical pattern. The total array of correlations is dominated by significant positive coefficients (55—84 % of cases). The most stable connections are observed in the cases of massive emissions of hazard substances belonging to class 3 and 4, carcinogens and substantial industrial and traffic emissions and the weighted contribution of carcinogens found in the emissions from stationary sources.

The ranking of ‘responses’ from geochemical indicators to industrial and traffic impact showed that they were stronger in the atmosphere and soil and weaker in snow. High-priority geochemical indicators are soot and formaldehyde in the atmosphere, nitrogen compounds in snow, and the total heavy metal contamination index in soils. These indicators show a stable positive correlation with the industrial and traffic impact parameters in 75 % of the cases.

The highest contamination level was observed in the industrial and traffic zones. There is a strong positive correlation between the integrated atmosphere and soil contamination indices, which is indicative of the considerable contribution of air-borne pollutants to soil contamination ($r = 0.77$).

Evaluating responses of biota to anthropogenic pollution

To evaluate the responses of biota to anthropogenic pollution, the authors employed bioindication methods. The silver birch (*Betula pendula Roth.*) and the black poplar (*Populus pyramidalis Borkh.*) were selected as the most widespread bioindicator woody species. The analysis of leaf samples through the established methods of leaf fluctuating asymmetry (FA) using the Zakharov scale [17] made it possible to calculate the integrated index of development stability. Morphometric parameters of the lamina of the above species growing in different functional zones were used as bioindication criteria.

The zones characterised by the most unfavourable conditions (4 points) are those of industrial facilities, motorways and areas adjoining to them. The most favourable situation (1—2 points) was observed in recreational and residential zones (in particular, in the low-rise residential subzone). Most of the city's territory demonstrated an average level of deviations from the 'norm' — a moderate degree of anthropogenic contamination of the urban environment. In most cases, these are modern high-rise residential complexes.

The correlation of bioindicator parameters by functional zones is shown in the chart below (fig. 3).

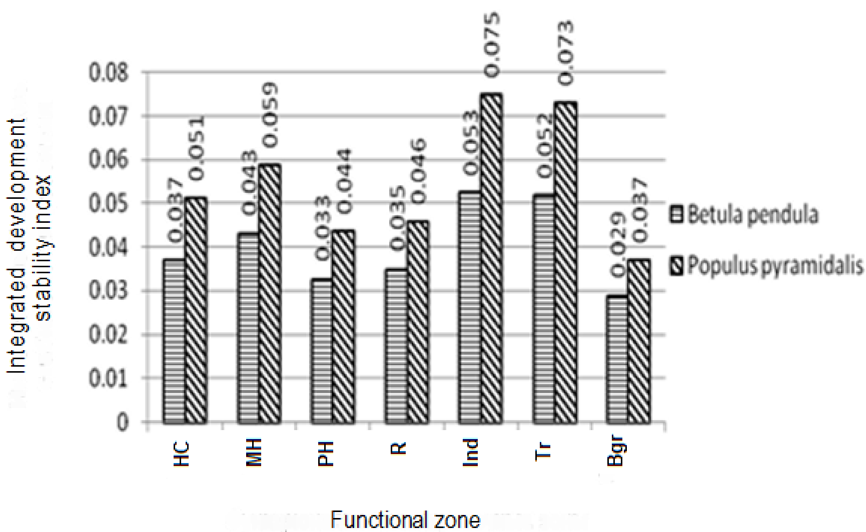

Fig. 3. Integrated development stability index for the silver birch (Betula pendula) and the black poplar (Populus pyramidalis); territorial zones: HC stands for the historical centre, MH — for the modern high-rise housing, PH — for the private housing, R — for the recreational zone, Ind — industrial zone, Tr — transport zone, and Bgr — background

Overall, the degree of deviation of the integrated development stability index from the physiological norm is significantly high in the industrial left-bank area, which is explained by the significant number of industrial facilities and the features of low terrain preventing the atmosphere from self-purification. The sampling statistical analysis of bioindication parameters leads to a conclusion that the data on the environment quality obtained through the FA calculation agree with the available information on pollutant concentration in the atmospheric air and the layout of major industrial pollution sources.

Assessing anthropogenic contamination effect on children's health

The analysis of the effect of anthropogenic pollution factors on children's health was based on a quantitative assessment of industrial and traffic impact on the urban environment and the ecogeochemical characteristics of the atmosphere, snow, and soil. Overall, the prevalent significant positive correlations (approximately 60 % of the cases) confirm an increase in the disease incidence rate in children living in areas under strong anthropogenic pressure. Priority health risk factors — which were identified based on significant positive correlations — include the coefficient of carcinogen emission impact and motor vehicle impact index. In residential complexes contiguous with motorways and industrial facilities emitting carcinogenic pollutants, children demonstrate a higher rate of incidence of four disease classes — congenital disorders, neoplasms, endocrine diseases, and diseases of the genitourinary system. The incidence rate in zones exposed to anthropogenic pollution is 1.8 times that in recreational residential complexes.

Integrated environmental assessment of urban environment

An integrated assessment of the environmental condition in the catchment areas of children's outpatient clinics was carried out using the above parameters of anthropogenic contamination, incidence rate in children, and the 'response' from woody species. Two statistical methods — weighted scoring method (table 1) and cluster analysis (table 2) — were used to perform comparison.

The *weighted scoring method* is convenient for unifying a significant number of environmental characteristics and for territory classification, when there is a need to examine only one factor — the incidence rate. Coefficients, based on the correlations between other parameters (risk factors) and the factor in question, are used to calculate corrections to the significance of parameters. Finally, the integrated score — a hypothetical factor — is computed based on the average weighted score defining the intensity of the process in question, for instance, the degree of medical and environmental tension through a combination of individual environmental and public health parameters. The results are shown in table 1.

This method helped to identify the degree of medical and environmental tension for the catchment areas of each outpatient clinic. The highest medical and environmental tension is observed in the right-bank area and its three clinics, whereas the industrial and heavy-traffic left-bank area has seven children's outpatient clinics. The most environmentally safe territories are two periphery commuter districts — the Agricultural University area (AUA) and the Southwestern periphery.

Table 1

Voronezh territory types by the risk of environmentally related diseased in children (based on the weighted scoring method)

Catchment area	Medical and environmental tension criteria*							Risk index***
	X1	X2	X3	X4	X5	X6	Y	
1	0.96	1662	0.52	131.6	29.6	0.053	977.6	3.66
2	0.24	3197	0.70	136.1	29.2	0.041	1227.5	5.06
3	3.18	2228	0.76	152.5	44.8	0.048	1535.0	8.33
4	0.001	1001	0.50	113.0	16.1	0.046	868.5	1.27
5	1.10	1395	0.75	118.4	59.5	0.049	1491.0	5.87
6	2.63	595	1.13	118.9	52.8	0.043	1441.6	5.23
7	5.46	1643	0.86	116.2	57.2	0.056	1546.1	8.33
8	2.44	1592	0.94	142.0	50.2	0.063	1295.2	7.42
9	5.18	1226	0.77	117.9	39.4	0.059	926.3	4.26
10	1.15	2588	0.72	120.1	52.1	0.054	1050.2	6.21
11	0.04	1943	0.89	121.4	38.3	0.044	1506.4	8.20
1-AUA	0.00	359	0.38	113.6	13.3	0.033	821.1	0.60

calculation parameters for the weighted significance of variables **

Correlation coefficients (r)	0.30	0.27	0.73	0.34	0.73	0.10	1.00	R = 0.89
Statistical weights (P)	0.41	0.37	1.00	0.46	1.00	0.14	1.36	

*) *X1 is the coefficient of carcinogen emission impact (t/year per 1 km*^{2}*); X2 is total traffic intensity (vehicle/hour per 1 km*^{2}*); X3 is the integrated atmosphere contamination index (*C_{atm}*); X4 is the snow cover mineralisation index (mg/l); X5 is the integrated index of soil contamination by heavy metals (SHM); X6 is average species development stability (for the silver birch and the black poplar); Y is the key criterion (general incidence rate in children).*

**) *r is correlation with the key factor; P is the ratio of the calculation correlation coefficient to the maximum coefficient in terms of the risk factor (0.73); R is the coefficient of multiple correlation between Y and (X1…X6).*

***) *Medical and environmental risk index calculated using the formula, where X1…X6 and Y are expressed in rank values for each variable: 1 is the minimum, 12 the maximum.*

$Y = 0.143\cdot(0.41\cdot X1 + 0.37\cdot X2 + X3 + 0.46\cdot X4 + X5 + 0.14\cdot X6 + 1.36\cdot Y).$

Cluster analysis made it possible to classify catchment areas by similarities in the manifestations of such anthropogenic pollution factors as biotic, medical, and environmental criteria. The classification results are shown in table 2.

Based on a cluster analysis of similarity parameters of functional zones, the authors identified three cluster groups: a) industrial and transport zones (the highest level of anthropogenic contamination); b) residential area including high-rise and low-rise subzones and the historical centre; c) residential and recreational area and control (the safest and most comfortable zones). Probably, the future urban planning objectives should include decentralisation and isolation of recreational and recreational areas form industrial and heavy-traffic ones. Today, these types of zones are densely concentrated and they alternate with each other creating local foci of unfavourable environment for the biota and population.

Table 2

Results of cluster classification of catchment areas

Cluster	Object (outpatient clinic)	General characteristics of cluster group
(average intra-cluster distance = 2.90)		
1	4*, 1-AUA	the reference clean zone (safest for the urban biota and population) — a low risk area
2	1, 2*, 5, 9, 10	a territory with typical urban infrastructure, dominated by residential housing; a moderate level of contamination; low incidence rate in children and a weak biotic response in woody plants — a moderate risk area
3	8*	an industrial heavy-traffic zone characterised by maximum anthropogenic impact on the airshed and soil; the most unfavourable area for woody plants; slightly increased incidence rate in children — a high risk area
4	3, 6, 7, 11*	an area characterised by a high level of anthropogenic contamination, increased carcinogenic risks, a high incidence rate in children, and a weak biotic response in woody plants — a high risk zone

* The most typical element of the group.

Using this method, the authors identified four groups of areas characterised by different combinations of diagnostic characteristics — the reference clean zone, a typical mixed-type urban infrastructure zone (moderate risk), and two zone characterised by a high anthropogenic contamination level (high risk areas). The two most contaminated zones demonstrate different combinations of industrial and traffic pollution factors and different responses from the biota and population. Table 3 shows qualitative and quantitative differences in the characteristics of these zones.

Table 3

Average values of risk criteria, state of biota, and incidence rate in children by catchment area group*

Cluster	X1	X2	X3	X4	X5	X6	Y	Risk index
1	0.0003	680	0.44	113.3	14.7	0.040	844.8	0.94
2	1.73	2013	0.69	124.8	41.9	0.051	1134.5	5.01
3	2.44	1592	0.94	142.0	50.2	0.063	1295.2	7.42
4	2.83	1602	0.91	127.3	48.3	0.048	1507.3	7.52

* See comments to table 1.

The final element of the integrated assessment was the production of a map showing gradient differences in environmental risk indices accompanied by processed data from the most representative environmental monitoring sites (fig. 4). According to the map, there is an approximately three-fold difference in risk indices between environmentally safe periphery residential complexes, on the one hand, and the centre and industrial and heavy traffic zones, on the other.

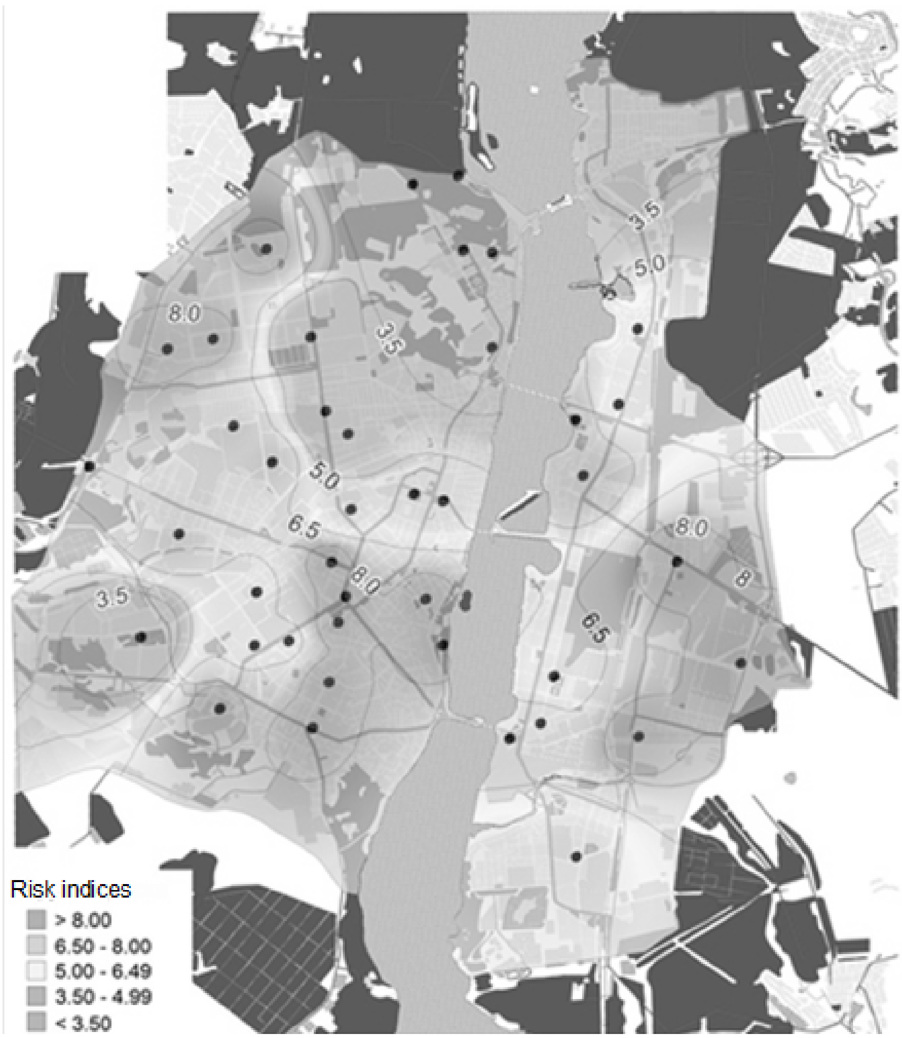

Fig. 4. Integrated assessment of environmental condition of Voronezh (IDW interpolation)

Conclusions

The above suggests the following conclusions.

1) Anthropogenic pollution is affected by the natural and environmental factors, in particular, seasonality and atmospheric stratification, as well as by infrastructure, industrial facilities, and traffic organisation. 2) The atmosphere and soil have a stronger response to the industrial and traffic impact, whereas snow is a weaker geochemical indicator. 3) In the left bank area, the growing conditions of woody plants deteriorate significantly. The development stability index values of the silver birch and the black poplar growing in the industrial and heavy-traffic zones are twice the background level. 4) The incidence rate of congenital disorders, neoplasms, and endocrine and genitourinary system diseases in children in contaminated zones is 1.8 times as high as that in recreational and residential areas. The major risks to health are the coefficient of carcinogen emission impact and the traffic impact indices 5) In Voronezh, the industrial zone is the ‘leader’ in terms of integrated air contamination index and the transport zone in terms of soil and snow cover contamination.

The results of the study made it possible to develop a medical and environmental monitoring plan based on the application of geographical information technology as a fundamental element of an urban environmental policy. Its key principles are as follows:

— *compliance with the unified public system for environmental monitoring* [19];

— *systematic organisation of information describing on the condition of the environment, the biota, and public health* (the priority indicators are the atmosphere, snow cover, soil, and the biota — i.e. the parameters of plant growth — and the criteria of public health with a focus on the health of children);

— *comprehensive environmental monitoring coverage of the city's territory;*

— *unification of environmental monitoring criteria used within the environmental regulation system.* In some cases, compliance with regulations does not guarantee the safety of unfavourable factors' impact on the biota. For instance, woody plants are very sensitive to a number of toxicants — nitrogen oxides, sulphur, and lead. Adverse effects are observed at concentrations below threshold values. This holds true for Voronezh, where woody plants' response to negative impacts does not always correspond to changes in the incidence rate;

— *synchronisation of the surveillance systems of different environmental bodies.* There is a need for creating a common information field for environmental monitoring through converging information from different environmental services and healthcare statistics. Another objective is developing common approaches to calculating risks to human health.

Among the initiatives aimed to reduce environmental risks in Voronezh, three were identified as priority ones. These initiatives focus on minimising the concentration of pollutants, products of the city's anthropogenic pressure, in the atmosphere:

— *modernisation of the city's transport networks* through increasing their capacity, improving the road surface, and optimising the average traffic speed;

— *technology modernisation* and a reduction in atmospheric emissions from thermal energy and other industrial facilities to ensure an admissible level of the airshed pollution;

— *development and restructuring of urban and suburban forestry systems* to create an environmental infrastructure.

A major strategic goal is reinventing the development pattern to segment the vast zone of increased anthropogenic pressure, which is associated with increasing risks to public health. There is a need to introduce green spaces — parks and recreational microzones — to reduce the environmental risk and make the urban environment more comfortable.

This work was supported by a grant from the Russian Basic Research Foundation No. 14-05-00722.

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To cite this article:

Kurolap, S. A., Klepikov, O. V., Vinogradov, P. M., Gritsenko, V. A. 2016, regional Geographic Information Systems of Health and Environmental Monitoring, Balt. reg., Vol. 8, no 4, p. 108—124. doi: 10.5922/2079-8555-2016-4-10.