Application of GIS-technologies to visualize the results of monitoring the snow cover of an industrial city

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Abstract. Snow cover monitoring is a part of the environmental monitoring system, the pollution of which is a reflection of the degree of anthropogenic impact in view of the fact that the snow cover is an effective accumulator of aerosol pollutants falling out of the atmospheric air. Carrying out a complete study of atmospheric air, scientific assessment of the dynamics of the state of urban air and computer modeling is not possible without analysis and statistical processing of the data obtained using special software. This article is an example of the use of GIS technologies in order to visualize and interpret the results obtained in the analysis of the snow cover of an industrial city (in case of the Sterlitamak city), in particular, the Kriging method used makes it possible to obtain representative schematic maps of urban pollution.

A geographic information system (GIS) can be characterized as an information and analytical system, which is supposed to process large volumes of cartographic information, use effective methods of data analysis, visualize statistical and analytical data that change in space and time, using maps and their combinations [1].

The integrative nature of geographic information systems makes it possible to create on their basis a powerful tool for collecting, storing, organizing, analyzing and presenting information. GIS have such characteristics that rightfully allow this technology to be considered the main one for the processing and management of monitoring information [2].

The use of GIS technologies is possible in MapInfo Professional, Surfer, MapInfo Proviewe, Zulu 7.0. GIS tools far exceed the capabilities of conventional cartographic systems, although, of course, they include all the basic functions of obtaining high-quality maps and site plans. The very concept of GIS provides comprehensive opportunities for collecting, integrating and analyzing any data distributed in space or tied to a specific location. If necessary, visualize the available information in the form of a map with graphs or diagrams, create, supplement or modify a database of spatial objects, integrate it with other databases.

The use of the Surfer 8 geographic information system was developed based on the results of monitoring the snow cover of an industrialized city (in case of the Sterlitamak city).

Snow cover was chosen as a natural indicator - a collector of atmospheric pollution.

Geochemical and hygienic studies have established links between the content of impurities in the atmospheric air and their fallout on the territory of cities, which are recorded in the form of anomalies in the soil and snow cover - natural environments that deposit pollution and are easily accessible for study at any predetermined network of sampling points [3]. This makes it possible, based on the results
of the study of soils and snow cover, to carry out an approximate hygienic assessment of air pollution [4].

The study of the distribution of pollution in the snow cover makes it possible to identify sources of pollution, to differentiate the zones of their detection according to the intensity of the impact and the range of propagation of emissions. The existing air pollution is reflected in the snow cover [5].

In winter, the elemental composition of aerosol contamination of the snow cover was investigated; 22 samples were taken to determine the characteristic dynamics of the concentrations of chemical elements contained in the snow [6]. Sampling was carried out before the beginning of snow melting in early March in order to determine the integral composition of aerosols and to reveal the complex pollution of the snow cover during the entire winter season. Location of sampling points was determined on the basis of functional and city zoning (table 1).

Table 1. The location of sampling points.

| Sample numbers | Location                                |
|----------------|-----------------------------------------|
| 1              | Sanitary protection zone of N-StTEC     |
| 2              | Sanitary protection zone of OAO “Kaustik” |
| 3              | Near the industrial enterprises “Kauchuk”, “TEC”, “SNKhZ” |
| 4              | SPZ OAO “Soda”                          |
| 5              | Ufimskaya street, Pervomaisky village   |
| 6              | Furmanov Street                         |
| 7              | Kol’tsoAvtovokzal                       |
| 8              | Dom svyazy                               |
| 9              | Artem Street                            |
| 10             | Dom Radio                               |
| 11             | Kol’tsoVechnyiogon’                     |
| 12             | Chernomorskaya Street                   |
| 13             | Elevatornaya Street (1 m from the road) |
| 14             | Elevatornaya Street (50 m from the road) |
| 15             | Tukaev street (Soda district)           |
| 16             | Gorgaz                                  |
| 17             | Mira Street (district of the Staryigorod) |
| 18             | Gogol’ Street                           |
| 19             | Stepnaya Street (VTS district)          |
| 20             | Along the Rayevsky tract (10 km to the north-west) |
| 21             | Zaashkadary’e (10 km to the east)       |
| 22             | 40 km to the north of Sterlitamak        |

Sampling to determine the contamination of snow was carried out within the sanitary protection zones of the main pollutant enterprises, in residential areas, at the crossroads of streets with the busiest traffic (figure 1). Plots 10 and 40 km from the Sterlitamak city were selected as background points. The point located 40 km from the city (No. 22) is influenced by minimal anthropogenic impact, therefore the concentrations of chemical elements at this point were taken as background concentrations for the territory.

1. Sampling points were unevenly distributed throughout the territory, so all points were plotted on an electronic map of the city with an accurate geographic reference.
In the study of the chemical composition of snow, the techniques used for the analysis of natural waters were used [7].

To analyze the state of the city’s snow cover, the following indicators were measured:

- pH value,
- the content of sulfate ions,
- concentration of nitrate ions,
- the content of chloride ions,
- the amount of solid particles,
- COD indicator.

Chemical indication of snow cover pollution is based primarily on comparing the concentrations of pollutants in urban snow samples with the corresponding values of their background analogue.

The analysis of spatial distributions to the snow cover in the area of influence of a large industrial center showed the unevenness of the content of pollutants due to the impact of anthropogenic sources. The territorial distribution of impurities in the snow cover is presented in Table 2.
Table 2. Content of pollutants in the snow cover of Sterlitamak city.

| Name of substances | No 1 | No 2 | No 3 | No 4 | No 5 | No 6 | No 7 | No 8 | No 9 | No 10 | No 11 |
|--------------------|------|------|------|------|------|------|------|------|------|-------|-------|
| Suspended substances, mg/l | 700 | 400 | 900 | 700 | 800 | 200 | 1200 | 720 | 800 | 600 | 1130 |
| Sulphates, mg/l | 36.1 | 35.2 | 11.2 | 38.9 | 19.4 | 11.9 | 22.1 | 19.6 | 16.2 | 26.5 | 18.9 |
| Nitrates, mg/l | 34.5 | 30.3 | 9 | 3.6 | 26.2 | 17.1 | 18 | 14.8 | 15.6 | 12.4 | 34 |
| Chlorides, mg/l | 6.5 | 11 | 3 | 4.5 | 7.5 | 8.3 | 15 | 4.5 | 4.5 | 4.5 | 2.6 |
| COD (mg/l) | 420 | 540 | 480 | 120 | 262 | 200 | 160 | 80 | 90 | 180 | 230 |
| pH | 8.2 | 7.7 | 8.3 | 8.1 | 8.0 | 8.5 | 8.3 | 7.1 | 8.2 | 8.35 |
| Suspended substances, mg/l | 900 | 1500 | 900 | 1500 | 1600 | 990 | 850 | 800 | 250 | 650 | 130 |
| Sulphates, mg/l | 36.1 | 32.1 | 21.9 | 21.2 | 31.7 | 34.1 | 23.3 | 18.9 | 0.01 | 6.1 | 0.015 |
| Nitrates, mg/l | 23.2 | 56 | 13.4 | 8.4 | 8 | 6 | 13.5 | 12 | 1.5 | 2.4 | 0.7 |
| Chlorides, mg/l | 6 | 12 | 7.2 | 10.5 | 14 | 5.3 | 9 | 7 | 0.08 | 2 | 0.15 |
| COD (mg/l) | 220 | 130 | 240 | 210 | 240 | 320 | 200 | 200 | 40 | 40 | 10 |
| pH | 8.2 | 8.5 | 8.4 | 7.9 | 8.8 | 8.8 | 8.5 | 7.2 | 7.6 | 6.7 | 7.8 |

To interpret the results obtained, the contour maps of the distribution of chemical substances in the Surfer 8.0 information package were constructed using the Kriging method. This method allows us to create accurate surface models from point data that are randomly distributed in space [8].

Based on the aggregate data on the concentrations of substances in the snow cover, given in Table 2, for all sampling points plotted on the city, maps of the city’s atmosphere pollution were built for a specific indicator i (pH, concentration of suspended solids, sulfate ions, etc.). Each snow sampling point was assigned certain coordinates relative to the urban system (X_i, Y_i), then the data tied to the coordinates of the points of the city map are entered into the computer. As the Z coordinate is the value of the index i at a certain point of sampling [9].

The Kriging method consists in linear interpolation of data: from several known values of indicators at some points, values in unknown points between them are determined. After finding the functional dependence \( Z = Z(X; Y) \), spatial curves or variograms are constructed. An example of one of the constructed variograms (in case of nitrate ions) is shown in figure 2.

The numerical representation of the spatial data structure, known as variograms construction, makes it possible to select the appropriate optimal spatial dependence model for the original data. When the original data is unevenly distributed, the variograms value is calculated separately for points offset from each other by the same distance.

Hereafter, the obtained isolines are combined with the map of Sterlitamak, performing an exact reference to the coordinate system of the city, and we designate the points of sampling of the snow cover. As a result, we obtained a map of the pollution of the snow cover with nitrate ions (figure 4(a)).

Based on the obtained snow monitoring data, 6 schematic maps were constructed for all the studied parameters (figure 4).

For a better graphic interpretation, the software package displays areas with different contamination in different colours using the constructed variograms (figure 3).
(points № 11, 12, 13), with the highest concentration maxima occurring in the triangle Prospect Oktyabrya - Chernomorskaya - Elevatornaya, as well as in the Gorgaz district.

**Figure 2.** Variogram of the distribution of nitrate ions in the snow cover in the city.

**Figure 3.** Constructed isoline of the content of nitrate ions in the snow cover
Figure 4. Schematic maps of snow cover pollution in Sterlitamak: a) nitrate ions, b) suspended solids, c) sulfate ions, d) chloride ions, e) COD, f) pH.
It can be assumed that the long idle running time of car engines leads to significant pollution of the surrounding area with nitrogen oxides. The presence of increased concentrations of nitrates (to 17.1 mg/l) in the residential area (points № 8-10 and 18, 19) indicates a wide technogenic area of dispersion of nitrogen oxides in the air basin of the city. The minimum concentration of nitrates is observed in the area of the Staryigorod (6 mg/l).

Thus, the study showed that the use of GIS technologies and geostatistical methods makes it possible to identify areas of territories with varying degrees of snow cover pollution. The results of spatial analysis can be used to construct monitoring schemes for areas where the pollution index significantly exceeds the norm, i.e. the results obtained make it possible to identify the main sources of atmospheric pollution.

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