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Geo-ecology of surface atmosphere of Tomsk and methodology for the ecological risk calculation

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Abstract
The present study presents new methodological approach of environmental assessment of surface atmosphere layer based on principles of non equilibrium dynamics. The role of natural and technogenic factors in forming areas of dust and airborne pollution is determined. The results of the study of ecological risk from atmosphere chemical pollution of the town are presented.

1. Introduction
The Earth's atmospheric mantle suffers from increasing effects of anthropogenic and technogenic factors in global, regional and local scale. The situation is particularly critical in natural and technogenic ecosystems and urban areas of Western Siberia. The limits of atmosphere self-purification and self-regeneration from a wide range of toxicants are exceeded several dozen of times, and according to macro-components many times, which is accompanied by the ecological risk increase.

The international community, concerned about the state of the environment, is making efforts to improve the current ecological situation. Most states issued the concept of sustainable development, which is implemented in their long-term plans. It provides for the prevention of further destruction of the natural environment by prioritizing environmental and social requirements over economic ones.

In the sustainable development policy of Tomsk the following sustainable development criteria have been developed: 1) the level of air pollution; 2) drinking water quality; 3) the level of waste management; 4) morbidity of respiratory system; 5) morbidity of digestive system; 6) infectious and parasitic diseases.

One of the most important hygiene problems in Tomsk is atmospheric pollution. According to the data from the Center for Hydrometeorology and Monitoring of Tomsk Region, the index of atmospheric pollution (IAP) in Tomsk is the highest in the region.

The territory of Tomsk is confined to the joint of two large geological and, correspondingly, hydrogeological complexes. The lower one is represented by Paleozoic metamorphic stales, which are folded and broken by deep tectonic faults into horst-keystone blocks. The upper (Mesozoic-Cenozoic) complex is represented by sedimentary rocks of the platform cover. After considering the results of drilling, geophysical measurements and satellite image interpretation, the cover rocks on the northwestern slope overlap the submerged surface of the basement rocks and have a slightly inclined monoclinal folding with angle up to 5°. At the same time, a large number of disjunctive dislocations have been revealed in the cover rocks with the absence of characteristics of plicative tectonics. They are recorded by geological and geophysical data, and become clearly obvious in the landscape, and by the sharp difference in hypsometric marks of stand-alone formations. The system of large tectonic fractures of the east-north-east extension prevails, which include diabase dikes the right tributary valley of the river Tom, the paleochannels and geoactive linear zones adjacent to the foundation block boundaries and deep faults. Another leading characteristic of disjunctive tectonics is the embedded nature of valleys and river terraces.

As a result, a peculiar landscape with several hills and lowland areas was formed within the limits of the town. There are showings of numerous springs and even lakes on both types of landscapes within the platform cover. And lacustrine-boggy sediments predominate in the lowland areas. So the natural
The landscape of the territory was formed in the geological history. Eventually, the landscape and the river network played a leading role in the development of the town's structure. They were the main limiting factors in the development of urban systems, including residential areas, industrial sites, traffic arteries and recreational areas.

The complex of factors responsible for the specific features of atmospheric pollution within the town includes natural weather and climatic conditions as well as features of architectural solutions and the spatially functional structure of the town.

Tomsk has a wide range of industries (with nested and mostly impregnated structure in residential areas), in contrast to the predominantly mono-profile neighbour towns (Kemerovo, Novokuznetsk, etc.). There are several thousand stationary sources of atmospheric pollution, which belong to industrial enterprises, in the town. Some areas of Tomsk possess a long-outdated street and road network and a low traffic capacity. The study of natural and technogenic factors, mechanisms of direct communications and feedback between them for ecologically significant sources of pollution allows us to reveal general patterns of the atmospheric air state and to work out measures for environment and human protection.

Thus, the density of uneven distribution of atmospheric pollution largely depends on the landscape, the location of industrial facilities and their hazard category, the density and number of stores in buildings and structures, microclimatic parameters, and so on.

The surface atmosphere of Tomsk differs by exceeding the maximum permissible concentration (MPC) of dust in 2 times, carbon monoxide in 1.4 times and nitrogen dioxide by 1.5 times. The exceedings in the deposit media (in snow blanket) in relation to the background values are the following: dust from 5 to 100 times, toxic metals from 20 to 10000 times. In recent years, the environmental characteristics are significantly worsen by increasing pollution with formaldehyde, phenol, ammonia, methanol. The number of motor transport and the volume of pollutants from mobile sources is rapidly growing (more than 5% per year), their proportion in Tomsk exceeds 78%. Concentration factor of lead along transport lines and their intercrossing areas is 5-6 MPC.

The implementation of the concept of sustainable development (SUSTAINABLE DEVELOPMENT), approved at Heads-of-government conference in December 1992 in Rio de Janeiro, stimulated searching for new approaches in methodology and interpretation of environmental data. The statutory environmental requirements are established in legislative and regulatory documents and are aimed at ensuring environment conservancy, environmental rehabilitation and human health protection.

Russian standards for environmental requirements and environmental certification conform to international standards of ISO14000 series according to environmental management systems and are called GOST-R ISO 14000-98. Various criteria for the integral assessment of the environment within urban areas were developed taking into account these requirements [1, 2].

Numerous mathematical models and computer technologies for accounting aerosol transfer and the surface atmosphere quality assessment were created. As a rule, they are used under different conditions and oriented towards assessment of the damage caused or prevented. The ranking methods considering the degradation factors of ecological systems and combinatorial methods got widespread use [3, 4].

A special breakthrough of atmosphere ecology research is associated with the implementation of nonlinear dynamics principles, especially those devoted to the study of chaos in determinate systems. The promising direction described in the present article suggests a comprehensive approach with the participation of meteorologists and geologists-geochemists. It allows to obtain the most complete and timely information about the state of the surface atmosphere layer, taking into account climate dynamics, meteorological conditions and sources of pollution in warm and cold seasons, as well as geomorphological and town-planning features of the area. Under comprehensive approach all changes in the surface atmosphere quality in all time scales must be considered. Whereas even a single emission of pollutants may cause serious negative effects on people and the environment.

2. Results and its discussion

We performed the postcasting of the surface atmosphere quality for the last 25 years on the stationary hydrometeorological facilities of the natural and technogenic geosystem of Tomsk. It made it possible to us
establish a complex, periodically (from diurnal and circadian to perennial) recurring spatiotemporal dynamics of the internal distribution structure of macro- and microimpurities of the surface atmosphere. Time-series trends of the surface atmosphere quality being studied, the long-term trend indicating a change trend of the surface atmosphere quality and the frequency of these changes, is calculated. We chose a linear polynomial as a function approximating a long-term trend. It allows us to optimize the process of searching for new empirical facts of changing the operating modes of the system generating the time series.

The variability of the surface atmosphere quality and the risk of pollution is determined by the combined effects of synoptic, weather and climate conditions and the emission regime, with the emission regime having a stronger effect. The repeatability of pollutant concentrations above MPC_{с.с.} was calculated for various types of synoptic processes: anticyclone, cyclone, intermediate field, low-gradient field with increased pressure, low-gradient field with reduced pressure, contrast zone. We found that the maximum number of pollutions occur in cold seasons with anticyclones, but with their rapid displacement the content of impurities does not rise significantly.

The ratio of multi-temporal cycles depends on the location of posts, landscape and geomorphological conditions of different zones of the natural and technogenic geosystem. Practically, diurnal and intra-monthly cycles have the greatest variability for all impurities and at all survey points. However, their contribution depends heavily on the type of pollutant and geomorphological conditions. Mean values and dispersion of pollutants are calculated. The ratio of the maximum concentrations to the mean values varies according to the type of impurity and the natural and technogenic geosystem zone in wide range from 6.2 to 548.1. We found that the content of dust and main aerosol-gaseous impurities ranges from zero to values exceeding the MPC_{с.с.} in 7-8 times.

The proposed methodology also includes the calculation of ecological risk, including a carcinogenic risk of the area within the geocology of the natural and technogenic geosystem. The risk assessments, in particular, along with the system of integrated environmental monitoring, are currently the main content of the problem of ensuring environmental safety.

The WHO references define risk as "the expected frequency of adverse effects arising from a specified pollutant effects". According to the US Environmental Protection Agency's (US EPA) Glossary, risk is "the probability of injury, disease or death in certain circumstances. Quantitatively, the risk is expressed by values from zero (no harm will be done) to one (reflecting the certainty that the harm will be done)." The methodology of risk assessment is the universally recognized and most important tool for characterizing the effects of environmental factors on the population health and making management decisions [9]. There is a large number of studies on the health risk assessment with chronic (long-term) exposures of atmosphere pollutions, as well as those belonging to the authors of the present study [10-15].

As for research and practical application, the main task of risk assessment is to obtain and summarize the information on the possible effect of human habitat factors (in the present study - atmosphere pollution) on his health. The risk assessment is a key element of the risk analysis procedure. The general scheme of risk assessment includes several stages:
1. hazard identification;
2. assessment of dose-response relationship;
3. exposure assessment;
4. risk profile.

3. Hazard identification
Hazard identification is the first stage of health risk assessment. The following blocks are important for hazard identification:
- finding the sources of hazardous substances emissions into the environment;
- defining the hazardous emission;
- identification of all potentially hazardous factors;
- listing of priority (the most dangerous) factors.
One of the important activities at the stage of hazard identification is the determination of the chemicals toxicity. This indicator is the key in further study of the peculiarities of the substance distribution in the environment and risk assessment of its health effect.

4. Assessment of dose-response relationships

The dose-response relationship assessment is the relation between the exposing dose (the amount of chemical effecting the body), the order, the duration of the exposure and the intensity, the prevalence of the studied adverse effect in the exposed population.

Characteristics defining the dose-response relationship:
- Carcinogens
  - carcinogenic potential factor (slope factor), SF (mg / kg-day) -1;
  - a single risk, UR, (mkg / m³)⁻¹, (mkg / l)⁻¹.
- Non-carcinogens
  - reference dose (RID), mg / kg;
  - reference concentration (RIC), mg / m³

Carcinogenic potential (carcinogenic potential factor, SF) is a measure of additional individual carcinogenic risk or the degree of carcinogenesis increase under carcinogen exposure.

The reference dose is the daily lifetime exposure of a chemical, which is defined by taking into account all available up-to-date research data and probably does not result in an unacceptable health risk for sensitive population groups.

5. Exposure assessment

The exposure (effect) is the contact of a body (receptor) with chemical, physical or biological agents.

The exposure can be expressed as the total amount of substance in the environment (in units of mass, for example, mg); as the exposure value, that is the mass of the substance, referred to a unit of time (for example, mg / day); the exposure value standardized with account of the body weight (mg / kg-day). Quantitative exposure assessment can be obtained on the basis of the exposure concentrations assessment during the exposure period, as well as the calculation of the intake.

In assessing the risk of inhalation exposure the pollutant exposure concentrations are used, compared with the limit concentration for continuous exposure (inhalation concentration, units of measurement are mg of pollutant per m³ of air).

It provides controlled concentration for inhalation exposures, the units of measurement are mg of pollutant per m³ of air.

The average daily lifetime dose with inhalation exposure should be calculated by the formula:

\[ \text{LADD} = \frac{C \times CR \times ED \times EF \times BW \times AT \times 365}{BW \times AT \times 365} \]

where \( \text{LADD} \) is a daily lifetime dose, mg/(kg×day);
\( C \) is a substance concentration in air, mg/m³;
\( CR \) is air intake rate 20 m³/day;
\( ED \) is an exposure duration, 70 years;
\( EF \) is an exposure frequency – 365 days per year;
\( BW \) is a body weight, 70 kg;
\( AT \) is an averaging period of exposure – 70 years (average human life expectancy);
365 is a number of days per year.

6. Risk profile

The risk profile is the final part of the risk assessment and the initial stage of risk management.

The method of comparison of the received dose / concentration with the reference dose (safe dose / concentration) is used to characterize the non-carcinogenic risk, that is the calculation of the hazard quotient (HQ);
Hazard quotient (HQ) is the ratio of the exposure dose (or concentration) of a chemical to its safe dose (reference level of exposure). The calculation of the hazard quotient is carried out according to the following formula:

$$ HQ = \frac{A_D}{R_f D} \tag{2} $$

where $HQ$ is a hazard quotient; $A_D$ is an average dose (mg/kg-day); $R_f D$ is a reference (safe) dose (mg/kg-day).

The carcinogenic risk profile is based on the assessment of an additional number of cancerous diseases throughout the lifetime resulted from carcinogen exposure. The amount of the individual carcinogenic risk is determined by the formula:

$$ CR = LADD \times SF \tag{3} $$

where $CR$ is the individual carcinogenic risk; $LADD$ is a lifetime average daily dose, mg/(kg x day); $SF$ is the carcinogenic potential factor, reference data are used, (mg/(kg x day))⁻¹.

The laboratory data of air environment in Tomsk regularly conducted by the hydrometeorological service at stationary sites were analyzed during the study. This allows us to obtain reliable information about the actual conditions of atmospheric air pollution throughout the town. Based on these data, the daily, annual average and maximum concentrations of the main air pollutants were calculated for the years 1993-2014.

To assess the ecological risk in the territory of Tomsk conditioned by chemical pollution of the surface atmosphere layer, the normative documents of the Sanitary and Epidemiological Supervision Center of the Ministry of Health of the Russian Federation "Guidelines for the population health risk assessment from pollutant exposure" [5], the software EPA US [6], the software system "RISK ASSISTANT" [7] were used. In the present study, we consider the ecological risk of harmful substances intake through the respiratory tract (inhalation exposure). A group of people exposed was examined (an "average inhabitant" weighing 70 kg, being 70 years old and with the 30 years exposure experience was selected). It is accepted that Tomsk is his permanent residence, except for 2 weeks a year, and the exposure lasts 3 hours a week.

Carcinogenic risk calculation is carried out according to the formula:

$$ CR = 1 - \exp(-SF \times LADD) \tag{4} $$

where $CR$ is an individual carcinogenic risk; $LADD$ is a lifetime average daily dose throughout lifetime, mg/(kg x day); $SF$ is the cancerogenic potential factor (mg/(kg x day))⁻¹, (the software uses the database of substance cancerogenic properties http://www.epa.gov/iris/subst/).

These assessments represent a theoretical over-background carcinogenic risk. For example, if the calculated risk is one per 1,000,000, it means that a person has a chance of a million to get cancer due to this chemical exposure, in addition to his chances of getting cancer for other reasons.

The ecological risk assessment was carried out for all ingredients controlled at Tomsk stationary sites: dust, sulfur oxide, nitric oxide, carbon monoxide, hydrogen sulphide, phenol, formaldehyde, ammonia, hydrogen chloride. The individual carcinogenic risks of chemicals, with the exception of formaldehyde, were less than $1 \times 10^{-6}$. According to the classification of risk levels given in [5-7], the individual lifetime risk, equal to or less than $1 \times 10^{-6}$, corresponds to one additional case of serious disease or death per 1 million exhibited persons; it characterizes such levels of risk that are perceived as negligible. Such risks do not require additional measures to reduce them, but their levels are subject to periodic monitoring.

However, atmospheric air in Tomsk is polluted with formaldehyde, its content may exceed MPCсс in 4 to 6 times. It is crucial to note that formaldehyde is also the only controlled chemical pollutant inducing individual carcinogenic risk. In this context, a hygienic assessment of the additional carcinogenic risk of atmosphere pollution in the residential areas of Tomsk was performed. The term "additional carcinogenic risk" means an addition to the risk that some person has already possessed, getting cancer caused by other reasons.
According to the performed study, the greatest contribution to levels of carcinogenic risk in this area is made by formaldehyde after atmosphere pollution. On average, across the city the individual carcinogenic risk caused by formaldehyde atmosphere pollution is $2 \cdot 10^{-5}$ and it annually adds 1 case of malignancy to the general morbidity in the town.

The ranking of individual carcinogenic risk levels for 2014 is shown in Table 1. The minimum level of risk is observed at Stationary site-11 (crossing of st. Proletarskaya and st. Baranchukovsky), Stationary site-5 (st. Herzen, 68), Stationary site-13 (st. Vershinin) and Stationary site-14 (st. Lazo), due to the data for 2002. According to the risk classification, such risk is characterized as low. The individual risk throughout the lifetime is in the range of less than $1 \cdot 10^{-4}$ more $1 \cdot 10^{-6}$ and corresponds to the area of conditionally acceptable (permissible) risk; the majority of foreign and sanitary-hygienic standards recommended by international organizations for the population in general are established at the same level.

The maximum risk level is observed at Stationary site-2 (Lenin Square) and at Stationary site-12 (sett. Svetliy). According to the current regulations, it is characterized as average, and is acceptable for occupational areas pollution and exceeding for residential areas; the administrative and technological and sanitary-hygienic measures should be taken to reduce such risk and develop curative measures.

The average level of risk in the town is $7.7 \cdot 10^{-5}$. It means that within seven decades, seven additional cases of cancer among population of 100,000 people exposed to formaldehyde inhalation exposure may occur. A low level of risk with the values of $8 \cdot 10^{-5}$ and $9 \cdot 10^{-5}$ is noted in the districts of st. Herzen and st. Lazo, respectively, and it is characterized as minimal, due to the lack of significant stationary technogenic sources of atmosphere pollution.

### Table 1. The individual carcinogenic risk levels ranking for 2014.

| Stationary site # | Address | Individual lifetime carcinogenic risk | Risk level |
|------------------|---------|--------------------------------------|------------|
| Stationary site 2 | Lenin square | 2e-004 | Average |
| Stationary site 5 | st. 68, Herzen | 8e-005 | Low |
| Stationary site 11 | crossing of st. Proletarskaya and st. Baranchukovsky | 1e-004 | Low |
| Stationary site 12 | settl. Svetliy | 2e-004 | Average |
| Stationary site 13 | st. Vershinin | 1e-004 | Low |
| Stationary site 14 | st. Lazo | 9e-005 | Low |

According to the research results the individual risk value $2 \cdot 10^{-4}$ makes possible two additional cases of cancer among population of 10,000 people within 70 years. Such risk is observed in the center of the town on Lenin Square, as well as in the Svetliy settlement. In accordance with the classification of risk levels, such individual lifetime carcinogenic risk has an average level and is unacceptable to the population. Similar studies were carried out in St. Petersburg [8]. Their results showed that the values of carcinogenic risk in 20 districts of the city are in the range from $4.9 \cdot 10^{-5}$ to $11.2 \cdot 10^{-5}$. This results approximate to our data for Tomsk, except for the areas with the average risk level. We may presume...
that the level of individual carcinogenic risk from formaldehyde defined in the present study is typical and peculiar for urban areas with a high technogenic load.

7. Conclusion

Thus, owing to the development of the methodical base following the principles of nonlinear dynamics, including the assessment of individual ecological risks, we could zone the town according to the carcinogenic risk level, predict the possible health consequences for the population by comparing quantitative risk levels over a long period of observations, under different scenarios for the development of industrial production, motor transport and economic activities.

At the same time, it is clear that a direct extension of foreign methods prevents us from giving a reliable assessment. Therefore, it is necessary to find a hygienic and epidemiological justification of the risk assessment techniques application in a specific region, taking into account climatic, physical, geographical and social conditions.

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