GEOFIZIKA VOL. 29 2012

Original scientific paper
UDC 551.511.6

Atmospheric pollution of Russia's cities: Assessment of emissions and immissions based on statistical data

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Received 13 October 2011, in final form 4 May 2012

In Russia, 60 million people live in the cities with high levels of air pollution. Comparative statistical analysis of pollutant emission and immission processes in 1099 cities in the country revealed the role of climate and other environmental factors, fuel mix, and the impact of agglomeration effect on the distribution of pollutants in the cities' atmosphere. In 80% of Russia's cities, air pollution is connected to the levels of anthropogenic emissions; in 5% of the cities, urban pollution levels (pollutants concentration levels according to monitoring (measuring) data) are lower than emissions; and in 15% of the cities, natural conditions amplify the anthropogenic impact. The level of anthropogenic impact in Russia's cities is largely determined by a combination of low efficiency and high power intensity, outdated industrial specialization and inherited transport networks that cannot adequately accommodate current traffic flows. The system of proposed indicators of ecological conditions of the urban environment can be used in assessment of the environmental component of quality of life and its modern processes providing the basis for further ecological and geochemical studies of urban areas.

Keywords: city ecology, anthropogenic impact, indicators, pollution sources, environmental risk, emission, immission, statistical analysis of pollutant

1. Introduction

An urban environment is a complex natural and socio-economic system formed by human and natural components whose analysis provides the basis for understanding its *ecological function*. Urban environmental problems in Russia are associated with excessive anthropogenic load and low stability of natural and anthropogenic ecosystems and the inherited territorial-planning structure formed mainly in the industrial period when production facilities were placed without regard to environmental requirements. Obviously, if the human impact is greater than stability of the environment, its conditions deteriorate.

Methodologically, it is rather difficult to estimate the balance of natural and anthropogenic factors of formation of the modern ecological situation, most pronounced in the urban air basins where pollutant emission[1] and immission processes occur in conjunction. In this paper, we use the term *immissions* to describe the part of emissions that concentrates in the near-surface air layer. Immissions also describe the level at which humans are affected by emissions (Henkel et al., 2009). The effects of emissions on the local air quality may be assessed through immissions that, in turn, may be measured directly or modeled using characteristics of emission sources and local conditions (such as wind or topographic conditions, etc.) as the initial factors (Dry Deposition, 2003). In relation to other components of urban landscapes, the air basin represents a transitional system that consists of gaseous and particulate matter often containing high concentrations of heavy metals and other pollutants (Bezuglaya and Smirnova, 2008; Chubarova et al., 2010; Boubel et al., 1994; Dockery et al., 1993; Dockery and Pope, 1994; Shekhovtsov, 2008). Therefore, comparison of emission and immission parameters is most feasible for urban environments. In the final analyses of immissions, it is also necessary to consider the number of people who live under specific emission levels.

According to the last census in 2010, in Russia, there are 1099 cities where 95.6 million people live (73% of the population). The vast majority (777) are small towns (up to 50 thousand population) that do not have a proper degree of monitoring system of air pollution; only 240 cities have data on air quality. However, almost all cities in Russia have information on pollutant emissions, i.e., an important indicator of the human impact on the atmosphere. Comparative analysis of emission and immission parameters for the cities that have complete information makes it possible to assess potential of applying parameters of impact to monitor conditions in the cities without such measurements. Assessment of urban air quality should consider analysis of the following phenomena:

– *Impact* on the air basin based on information about different types of emissions (from stationary sources, vehicles, total) and on calculation and comparison of absolute and relative emission parameters of air pollutants in urban landscapes (Bityukova, 2009; Bityukova et al., 2010; Chubarova et al., 2010; Kasimov and Perelman, 1993);

– *Change* of an environmental state and air pollution by measuring concentrations of pollutants in the air, using statistical data analysis and comparing

[1] Emission (official statistical data of Rosstat, http://www.gks.ru) – is pollutants inflow into the atmosphere (which makes injurious effect to population health and environment) from stationary sources and vehicles. All pollutants which inflows into the atmosphere after dust – and gas-cleaning machines (because of incomplete trapping and cleaning), and also without cleaning are taken into account. Accounting of emissions is conducted both their state of matter (solid, liquid and gas) and for individual substances (ingredients – inorganic dust, SO_2, NO, NO_2, CO, C_xH_y, other VOCs).

the results with the hygienic standards (IAP, SI, MRR[2], etc.) (Bezuglaya and Smirnova, 2008; Lollar et al., 2003; The World Atlas of Atmospheric Pollution, 2008) or of *changes* in pollutant immissions in urban areas (Boubel et al., 1994; Kosheleva et al., 2010; Shekhovtsov, 2008; Solovyov, 1985);

– *Environmental sustainability* that depends, in urban settings, on natural (Bityukova, 2009; Perelman and Kasimov, 1999) and anthropogenic factors;

– *Consequences* for the environment and the population because pollutants in air and dust contaminate soils, plants, and water and enter human bodies directly through inhaled air and through food chains, reducing the health outcomes and quality of life (Chubarova et al., 2010; Henkel et al., 2009; Kasimov and Perelman, 1993).

2. Research methods

The paper proposes an integrated set of indicators for assessment of the environmental impact of pollution sources as well as of potential of landscapes to deposit, transport, and transform pollution. Such impact assessments on the atmosphere are different from assessments of urban air basins that include direct measurements of pollutant concentrations at stationary, fixed-route, and mobile air quality control posts; they also differ from remote sensing methods of research on contaminants content in the atmosphere (National Air Quality, 1997; Saet et al., 1990).

The information base included the sectoral and regional statistics, the database "Passports of Russian Cities – 1994–2011" (Federal State Statistics Service, the Russian Federation), a database for 900 largest industrial facilities, and maps on immissions of sulfur and nitrogen (EMEP, i.e., European Monitoring and Evaluation Program) (Dry Deposition, 2003).

[2] IAP is the Index of Atmospheric Pollution calculated based on mean annual concentrations of several pollutants; it characterizes the level of long-term air pollution. SI is the Standard Index or the greatest measured spot concentration of a pollutant divided by its Maximum Allowable Level (MAL); it characterizes the level of short-term pollution. MRR is the Maximal Repetition Rate (in percent) of the increase of the observed maximal spot concentration of one pollutant over its MAL at all control posts in the territory. The maximum allowable level (MAL) is a document (approved by law hygienic standard) certifying the conformity or nonconformity with the sanitary rules of environmental factors, economic and other activities, products, services, buildings, structures, premises, equipment and other property.

The maximum permissible concentration (MPC) – approved by law hygienic standard – a document certifying the conformity or nonconformity with the sanitary rules of environmental factors, economic and other activities, products, services, buildings, structures, premises, equipment and other property.

3. Results

The *absolute amount of emissions* is a key indicator that describes the ecological situation, i.e., the magnitude and spatial differences in pollution. A high degree of interdependence of ecological and economic processes indicates that, in the absence of modernization, the anthropogenic impact (AI) is the leading factor that determines air quality (Fig. 1).

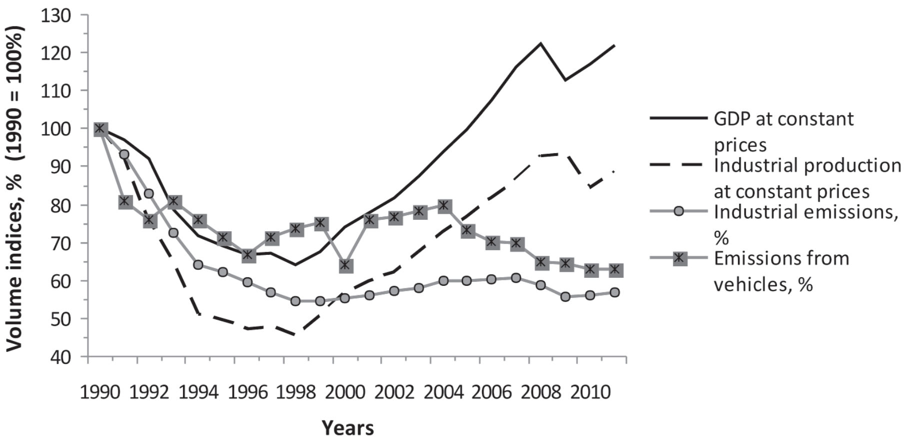

Figure 1. The change in GDP, industrial production, and pollution of the atmosphere in 1990–2011. (1990 = 100%) Source: Federal State Statistics Service.

Table 1. Number of cities with the dynamics of emissions from the stationary sources in Russia's cities during the period of recession (1990–1998) and economic growth (1998–2008).

Index dynamics of air emissions 2008 / 1998 (1998 = 100%)	Total number of cities with emission index 2008 / 1998 (1998 = 100%)	Including centers with a volume of emissions, tons, 2008						Total number of cities with emission index 1998 / 1990 (1990 = 100%)
		300–399.9	100–299.9	50–99.9	30–49.9	10–29.9	< 10	
> 150	**239**	1	5	6	10	28	189	72
100–150	156		6	7	11	21	111	**66**
80–100	**110**	4	3	5	6	16	76	**41**
60–80	115		3	6	9	11	86	**109**
< 60	283			2	5	19	257	**615**
total	903	5	17	26	41	95	719	903

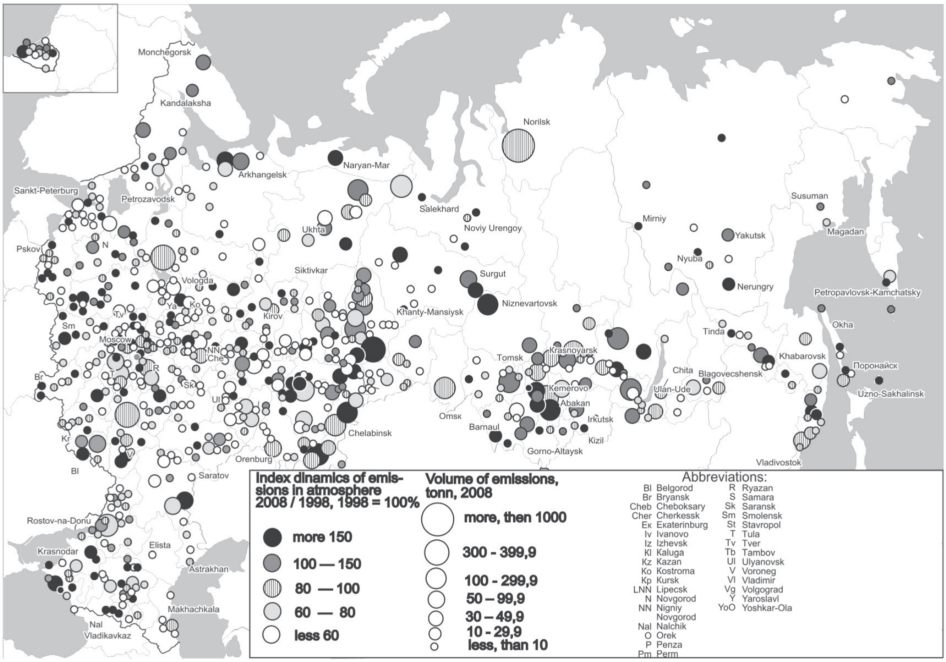

Figure 2. The dynamics of emissions from the stationary sources in Russia's cities during the economic crisis (1998–2008).

Since the beginning of the industrial recession in 1990, emissions of pollutants from industrial facilities in the vast majority of the cities were continuously declining. Economic growth in 1999–2007 has led to an increase in pollution by 2003 in 39% of the cities, and by 2008 – in 43% of the cities (Tab. 1, Fig. 2). As the industry remains a major factor that currently defines the ecological conditions of the cities in Russia (Bityukova, 2009), the crisis of 2008 has led to a further reduction in air pollution. *During ten years of economic growth, the territorial structure of pollution is practically back to the structure of 1990* (Fig. 3).

During 20 years, fuel burning accounted for the largest share in the total emissions from the stationary sources; up to 90% in the northern and eastern cities with a long heating season and the predominance of coal or heating fuel oil in the fuel mix, as well as in the centers of large thermal power plants (Bityukova and Sokolova, 2008). Motor vehicle emissions, since 1990, were growing more slowly than the number of cars (that, during this period, increased by more than two times) due to both technological (the restructuring of the fleet and fuel quality) and planning (construction of new roads, bridges, etc.) factors. In many cities of Russia, the contribution of vehicles to the total emissions is more than 90%.

Measurements of the intensity of AI in relative terms are necessary for environmental monitoring of the atmosphere in the cities and for a comparison

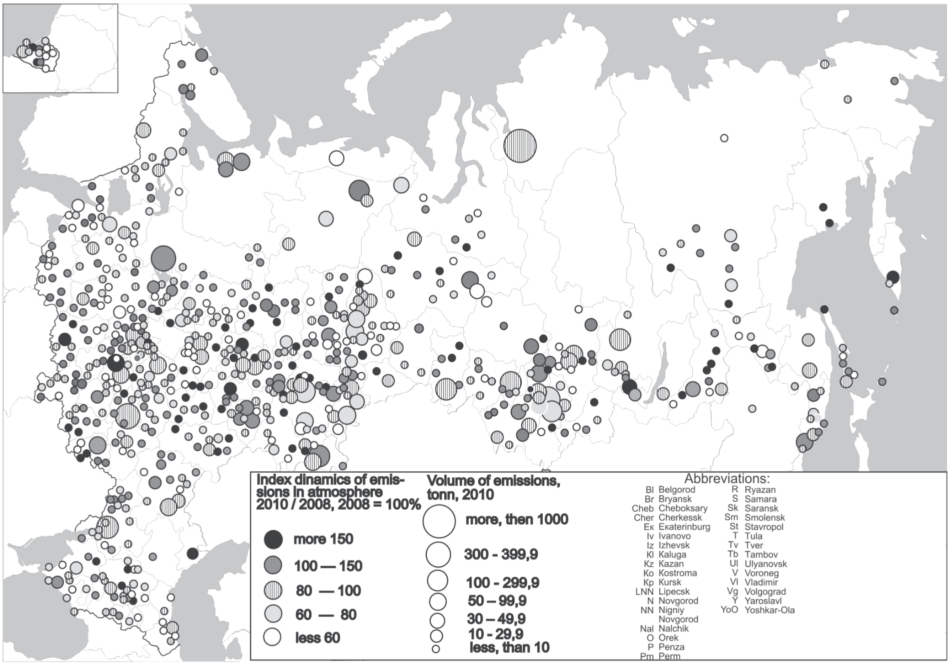

Figure 3. The dynamics of emissions from the stationary sources in Russia's cities during the economic crisis (2008–2010).

with other relative indicators adopted in international research programs for assessment of sustainable development, of human development index, etc. (Human Development Report, 2010; Seinfeld, 1989). The authors have evaluated the significance of the proposed indicators and have suggested a number of new indicators of atmospheric pollution of the urban environment.

Various parameters that characterize intensity of pollution are used in assessments of the environmental situation of Russia's cities. Here, we will focus on the *density of emissions* of pollutants from industry (P_{ind}) and motor vehicles (P_v) as the key indicators of pollution intensity. In most cases, the *density of emissions Q* (Bityukova et al., 2010) was calculated for the area of a municipality $Q_{total} = P_{ind} / S_{total}$, where S_{total} is the area of the municipality (km^2) or, if the area of a municipality is large, for a built-up area (S_{built}), i.e., $Q_{built} = P_{ind} / S_{built}$.

The impact of the stationary sources. The extremely high density of emissions was found in 16 cities with about 800 thousand people. These are basically areas of concentration of the largest coal-fired thermal stations. It is particularly important that the Q_{built} identifies the most problematic cities of smelting of nonferrous metals that use obsolete technologies (Norilsk, etc.) and of emerging oil production facilities and gas-compressor stations, which points to a poor environmental compatibility of the fuel industry (Tab. 2).

Table 2. Distribution of cities: the density of air emissions from the stationary sources, 2010.

Distribution of cities	The density of air emissions from the stationary sources (t/km^2 per year)						
	50–250	20–50	10–20	1–10	0.5–1	0.1–0.5	0.01–0.1
Total population in the groups of cities, thousands people	778	2289	4075	24774	16773	37454	1592
Percent of population in the groups of cities	0.9	2.6	4.6	28.2	19.1	42.7	1.8
Number of cities	16	31	40	229	157	396	63
Including centers of large business	7	14	18	39	20	29	2
Cities which are region centers		1	3	25	20	25	

A quarter of the cities with major business[3] are characterized by high and very high emission loads from industry, i.e., most of the points of growth, with inherited or resource competitive advantages, continue to have a poor environmental quality of this growth. Among the regional capitals, the cities of medium or low density of industrial pollution dominate, but there are no cities with low density of pollution. *The environmental feature characteristic of Russian urbanization, usually based on the industrial development, is the increase in emissions with population growth.*

The impact of motor vehicles was estimated by two parameters: the *density of motor vehicle emissions* $Q_v = P_v / S_v$; where P_v is the emissions, in tons per year; S_v is the area of the road network (km^2) and the *linear emissions density* $Q_{lv} = P_v / L_v$; where L_v is the length of the road network, km. The highest values of Q_v are characteristic mainly for the regional centers, major ports, and resort locations (Sochi, etc.). Among the cities with low and very low Q_v values, there are small and medium-sized metallurgy centers with a low ratio of vehicle emissions to the total emissions, as well as some regional centers (Astrakhan, Bryansk, Penza, etc.).

The *linear emissions density* is proportional to the growth of the automobile fleet, reaching maximum values in the cities with over one million population (the correlation coefficient between Q_{lv} and the population of the city is 0.99); it is proportional to fuel consumption in the northern cities.

[3] The cities of major business include 178 cities where at least 40% of the industrial production is associated with enterprises that are part of an integral business-group or a company that is structured in accordance with accepted international practices, is an equal partner in large-scale integral transactions, and is actively using resources of the world's financial market, i.e., that has features of an entity of the global economy.

The *total impact density* $Q = (P_{ind} + P_v) / S_{total}$ emphasizes that, despite the growth of the fleet and deindustrialization, the stationary sources of impact are leading in many cities. The highest Q values are characteristic of the cities with less than 10% contribution of vehicles, which host the largest coal-fired thermal power plants of the Urals: Reftinskaya and Troitskaya. Inefficiency of the old thermal power plants leads to high levels of pollution: in 2006, with the increase in electricity consumption by 4.2% and production at thermal power plants by 5.2%, compared with 2005, the absolute amount of emissions grew by 11%. High Q levels are associated with metal plants, particularly with poorly located, in relation to the residential area, the world's largest Cherepovets plant "Severstal" and the very old Tula iron foundry. The Q levels decrease in the centers of location of tube-rolling and semi-integrated facilities or in the centers of actually idle plants (Petrovsk-Transbaikalskyi).

In 92 cities (out of 214 cities studied, accounting for 40% of the country's emissions), industry remains the leading (over 60%) source of pollution; in 76 cities, the dominant source of pollution is transport. Industry (mainly ferrous and nonferrous metallurgy, coal energy) is the leading source of pollution in 56% of the cities with high emissions (over 100 tons/year) and in 100% of the cities with the highest levels of impact density. In the cities with a population of 500–1 500 thousand, the sources of pollution are equally industry and transport (Novosibirsk, Chelyabinsk, Ufa, Krasnoyarsk, Omsk, Barnaul, Orenburg, Khabarovsk, Yaroslavl, Kemerovo, Ryazan, and Volgograd). In 46 cities, the prevailing source of pollution was not identified. These are the cities with consistently growing vehicle fleet and developing industry (e.g., the center of gas production Salekhard and Procter & Gamble facilities in Novomoskovsk) and the cities that have experienced a decline in production or a closure of the main source of pollution (e.g., a coal mining center Cheremkhovo in the Baikal region).

The assessment of the AI presented herein has revealed negative changes in the environmental conditions in the urban areas and has identified necessary measures and strategies for sustainable urban development. Because basic processes and power intensity remain the main pollution factors in the industrial sector, it is necessary to modernize or replace the most outdated assets in order to achieve decrease in the maximal levels of pollution. The crisis of 2008 presented the Russian energy sector with a second chance to remove the most outdated and "dirty" equipment, because the first opportunity in the industrial sector has been utilized only poorly. *The main directions of the strategy to enhance the ecological situation should come down largely to creation of stimuli and providing support for facilities' initiatives aimed at their greening and modernization*, because investments into the atmospheric air protection are 99% financed through their own funds.

Assessment of the ecological situation is based on objective measurements of concentrations of pollutants in the air (i.e., IAP [see footnote 2]). The main disadvantages of this approach include a limited number of monitored cities (no more than 240), the number of control stations, the range of monitored air pollutants, and a failure to accurately identify the source of contamination. However, a comparison of indicators AI and IAP allows one to identify the role of natural conditions and planning structure in creating sustainable urban environment. The role of these factors is important: out of 37 cities with the highest IAP, only six had high ($\geq$ 10 t/km^2) values of the areal emission density (Q), and the vast majority were characterized by an average (3–10 t/km^2) values of Q.

Dispersing and accumulating ability of air of urban landscapes depends on meteorological factors, e.g., air temperature in the surface layer and at a certain altitude; temperature inversion; its height relative to the source of discharge; wind speed and direction; amount, intensity and nature of precipitation; fog; the number of cloudless days; and the amount of solar radiation coming into the near-surface layers of the atmosphere (Bezuglaya and Smirnova, 2008). Low potential of atmospheric pollution (PAP) contributes to the situation when even a high level of emissions density does not lead to high levels of pollution. In contrast, high PAP in most of the eastern cities of the country located in the intermountain basins causes even low values of emissions to produce high levels of pollutants in the atmosphere.

Planning factors. Industrial pollution is mainly determined by the basic technologies, the nature of resource and fuel usage, treatment systems, and, to a lesser extent, by the location of industrial facilities and environmental conditions. For the transport sector, the geographical distribution of pollution in the urban environment have the same (if not more) importance as the number of vehicles, the structure of flow, and the type of fuel. The relief and the presence of green areas and water bodies, of natural and man-made barriers in the transport

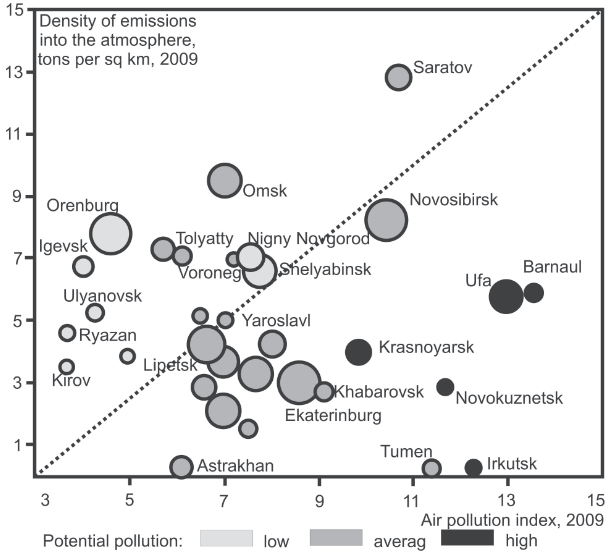

Figure 4. The distribution of the cities depending on the density of air emissions and IAP, 2009. Symbols' diameters are proportional to the cities' population; the color indicates PAP.

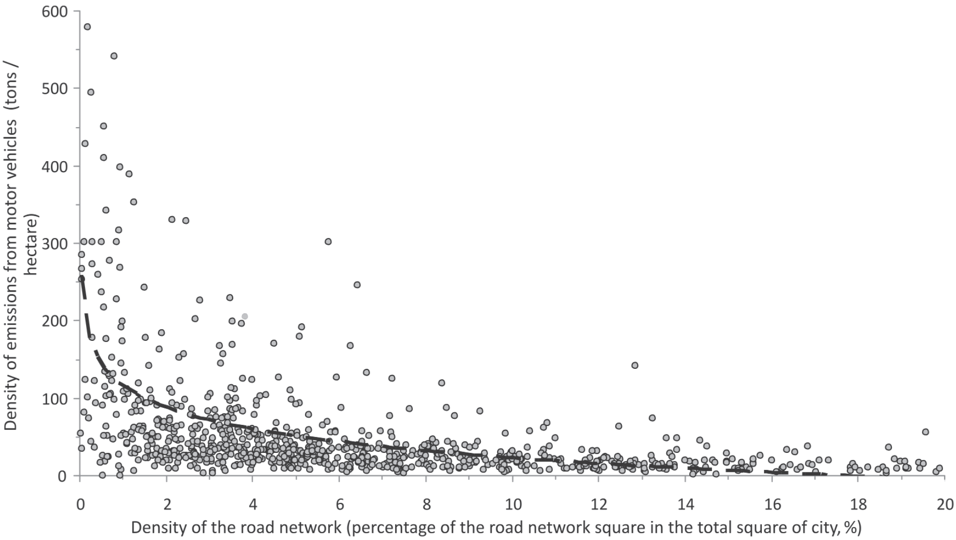

Figure 5. Dependency between the density of emissions from motor vehicles and the density of the road network in Russia's cities.

network, and its topology, to a large extent, determine the flow in the cities; thus, congestion reduces the flow velocity to 20 km/hr, which leads to a 1.3-fold increase in emissions. The density of emissions from transport decreases with increasing density of the transport network (Fig. 5), indicating *a major area of improvement of ecological situation in big cities, i.e., expanding the road network*. In the Far East cities with a low density of the network, pollution is low, apparently, due to a high share of Japanese vehicles in the fleet structure.

Agglomeration factors were identified by comparing the levels of emissions and immissions in the cities. The air system in many cities, especially those located within large urban agglomerations, is subjected to external influence. The EMEP website has data on deposition (immissions) of sulfur and nitrogen for various years (Dry Deposition, 2003), which are calculated in the EMEP model for 50 km by 50 km cells; they can be used as the average values of dry deposition and wet precipitation for cities and surrounding suburbs. In calculating dry deposition, the concentration of substances in the air, meteorological data (wind speed, surface temperature and air, and some of the parameters of atmospheric turbulence), leaf area index, diffusion of molecules (from the surface), as well as gas exchange between the atmosphere and the leaves (leaf temperature, vapor pressure deficit in the "leaf-to-air" system, etc.), and precipitation are accounted for. Wet precipitation considers the concentration of substances in the air, the intensity of rainfall, and some indicators that depend on a pollutant (the factors that express the ability of clouds to remove pollutants and the degree of scavenging).

Table 3 Immission factors (IF) for SO_2 in Russia's cities in 2009.*

IF_{SO_2}	Density of emissions SO_2 (t/km^2 per year)	Density of SO_2 depositions (t/km^2 per year) the average for the group of cities	Cities
> 1.0	1.101	1.5	Stavropol, Nalchik
0.75–1.0	1.209	1.01	Novorossiysk
0.50–0.75	2.702	2.0	Ekaterinburg
0.25–0.50	3.319	1.14	Yoshkar-Ola, Kazan, Krasnodar, Krasnoyarsk, Lesosibirsk, Maikop, Makhachkala, Mezhdurechensk, Rostov-on-Don, Ulyanovsk
0.10–0.25	6.14	0.91	25 towns, Moscow, Saint-Petersburg, Oryel, Belgorod, Astrakhan, Tomsk, Kursk, Bryansk
< 0.10	21.63	0.82	57 towns, Arkhangelsk, Tula, Tambov, Samara, Chelyabinsk, Sochi, Barnaul, Kaluga, Saransk

*Note: $IF_{SO_2} = 0.75$ means that 75% of emissions is immitted.

To assess the relationship between emissions and immissions we suggest using the *immission factor* $IF = D / Q$ (where D is the amount of pollutant's immissions (t/km^2 per year); Q is the density of emissions from all sources (t/km^2 per year). *IF* shows the share of immissions in the volume of emissions. SO_2 was chosen as an example because of its large share in the total emissions of the cities and the negative impacts on natural geosystems (acid precipitation, soil acidification, etc.).

The highest values of Q_{SO2} are characteristic for the cities with a high proportion of heating oil or coal in the fuel mix and with a high share of electric power (Arkhangelsk, Murmansk, etc.), specializing in industries technologically emitting sulfur compounds, i.e., in nonferrous and ferrous metallurgy. Out of 97 cities, in only two (Stavropol and Nalchik), the *IF* values exceed 1, which is explained by additional pollutants from the outside or by large areas of the municipalities, similar to the case with the parameter Q described above (Tab. 3).

4. Discussion

Thus, each of the proposed indicators reflects some facet of the ecological state of natural and man-made landscapes of the cities, whose functioning is characterized by dynamic, open, and complex internal and external relationships. AI on the atmosphere remains the most important ecological problem of urban development. The parameters for the industrial and motor vehicle sectors reflect the territorial structure and dynamics of the pollution and identify not only the increasing contribution of transport to the pollution, but also the dependence of the level of the industrial impact on the scale of production. The less modernized enterprise, the greater the dependence of the emissions from the production, and the driving factor here is the size of the city.

The density of emissions shows the intensity of AI on the atmosphere. The density of the motor vehicle emissions (per area or length of the road network) (Q_v), isolates cities with significant traffic flows, with defects of the transport network, and with the increased cost of fuel, but does not assess the role of individual factors. Using the areal density of emissions (Q) showed that, contrary to a traditionally identified trend for the increase in the motor vehicle pollution, a key differentiating spatial factor is industry. The high density of pollution from industry has a long-term stagnant character, reaching maximal values in the centers of coal state district power plants (GRES) and facilities producing commodities in demand on the international market, i.e., copper and nickel (Norilsk, Zapolyarnyi, Karabash), oil (Strezhevoy of Tomsk Oblast), gas (Myshkin, Polysayevo), etc. The influence of industry in many ways continues to define the urban environmental issues in Russia.

The density of immissions is useful for evaluating the effect of trans-regional transport and inflow of pollutants from the atmosphere into the underlying surface. IAP, based on data from objective measurements, reflects actual urban air quality, but does not reveal the source of contamination. IF can be used in estimating the magnitude and direction of the global and regional migration of pollutants, e.g., of nitrogen and sulfur oxides. Comparison of urban emissions and immissions reveals the role of individual factors, in particular, of hidden, for municipal governments, agglomeration effects of pollution, when the level of pollution immissions is higher than the level of their emissions by urban sources.

5. Conclusion

The parameters discussed in this paper are mostly informative when used dynamically (they reflect processes) or in comparison with each other for individual cities. Their combined use allowed the authors to overcome limitations of individual indicators and to use multivariate statistical procedure of cluster analysis, essentially dividing the pool of various environmental situations for 240 cities studied into three types (Fig. 6):

The cities where atmospheric pollution corresponds to the level of impact. Most Russian cities fall into this category:

– The largest metallurgical centers (Novokuznetsk, Magnitogorsk, Nizhny Tagil, Krasnoyarsk, Chelyabinsk, Norilsk, Bratsk) and Moscow, where one-fifth of urban population lives; they have the highest AI levels and, regardless of their population, city layout, and environmental conditions create the maximal levels of air and soil pollution;

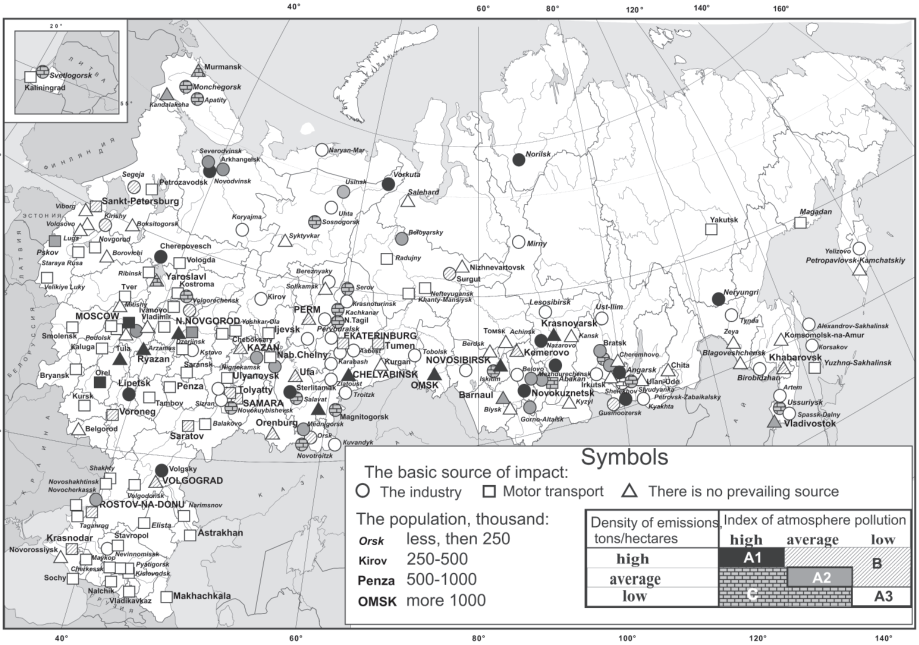

Figure 6. Typology of Russia's cities based on the parity of the levels of AI and air pollution.

– Medium and large cities (6% of the population), where the influence of industry, energy, and transport in cold climates (Omsk, Novosibirsk, Achinsk, Nazarov, etc.) leads to high AI levels and generates high levels of pollution;

– Large number of cities (74.46% of the population) where the average AI levels determine the average IAP levels;

– Cities with low AI levels – mostly small towns and recreational centers (Kislovodsk, Pyatigorsk, Sochi).

The level of pollution of the atmosphere above the level of impact. This category includes the cities with poor conditions of pollutant dispersion: natural (Tyumen, Minusinsk, Blagoveschensk, Zima, Cheremhovo, Irkutsk, Barnaul) or topological features of the transportation network inherited from the previous era of development and inadequate to today's transportation needs (Balakovo, Saratov, Ekaterinburg).

The level of pollution of the atmosphere below the level of impact. This category mainly includes the centers of the largest power stations (Dzerzhinskyi, Gusinoozersk, Troitsk, Asbest, Volgorechensk, Kirishi, Novocherkassk) where 0.5% of the urban population lives. The high AI level does not form significant pollution of the air basin, because the height of emission sources creates low density of pollution and location, as a rule, on the banks of rivers or water reservoirs contributes to pollution decline.

Thus, the ecological situation of the atmosphere of Russia's cities is largely determined by a combination of factors: industry specialization, the level of energy efficiency and power intensity, the fuel mix of the energy and utilities sectors, modernization of fixed assets and transport networks, as well as by natural conditions. Further research should involve a more holistic assessment of the ecological status of Russia's cities using data on pollution of depositing media, i.e., soils, plants, water, and bottom sediments.

Acknowledgements – This study was conducted under the support of the Russian Geographic Society's Grant №38/08/2011; of the Federal Target-Oriented Program "Research and Development for Priority Directions of the Scientific-Technical Complex of Russia for 2007–2013" the Ministry of Education and Science of the Russian Federation; and of the Program for Development of Moscow State University.

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SAŽETAK

Atmosfersko onečišćenje ruskih gradova: procjena emisija i imisija na temelju statističkih podataka

Victoriya R. Bityukova i Nikolay S. Kasimov

U Rusiji gotovo 60 milijuna ljudi živi u gradovima s najvišim razinama onečišćenja u zraku. Komparativna statistička analiza procesa emisije i imisije onečišćujućih tvari u 1099 gradova u zemlji otkrila je ulogu klime i drugih čimbenika okoliša, mješavine goriva i utjecaja aglomeracije na raspodjelu onečišćujućih tvari u urbanoj atmosferi. U 80% ruskih gradova onečišćenje zraka je povezano s razinama antropogenih emisija; u 5% gradova urbane razine onečišćenja (koncentracije onečišćujućih tvari određene na temelju mjerenja ili monitoringa) niže su od emisija, a u 15% gradova prirodni uvjeti pojačavaju antropogeni utjecaj. Razina antropogenog utjecaja u ruskim gradovima u velikoj je mjeri određena odnosom niske efikasnosti i visokog utroška energije, zastarjele industrije i naslijeđene prometne infrastructure, koja ne može adekvatno podnijeti trenutnu gustoću prometa. Sustav predloženih pokazatelja ekoloških uvjeta urbanog okoliša može se koristiti pri procjeni ekološke komponente kvalitete života te može poslužiti kao osnova za daljnja ekološka i geokemijska istraživanja urbanih područja.

Ključne riječi: ekologija grada, antropogeni utjecaj, indikatori, izvori onečišćenja, rizik okoliša, emisije, imisije, statistička analiza onečišćujućih tvari

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