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SPATIAL FEATURES TRANSFORMATION OF EMISSION FROM MOTOR VEHICLES IN MOSCOW

ABSTRACT. The article examines changing volumes of emission from vehicles by administrative and municipal districts of Moscow. In Moscow automobile transport is the general source of pollution, it produces more than 93% of allover, and this is the absolute maximum of impact for Russian cities and regions. In 2011-2017, it was the first time when the growth of motorization was noticed against background of reduce of pollution due to modernization of car park and new quality of petrol. Total gross emission from vehicles decreased four times. Shifts in the factors defining spatial specifics of distribution of pollution from vehicles are revealed. Assessments of air pollution based on information of all Moscow streets provides estimations for 93 thousand low-level city areas. One of the research result revealed a high correlation between changes of pollution density and changes in transport infrastructure including developing of public transportation, modernization of car park structure. Spatial uniformity of pollution from vehicles has become the main trend of recent years. Programs of the new housing construction and large-scale projects aimed at the transformation of the districts increase the transport connectivity of the city. Administrative decisions on the traffic intensity reduction in the central districts decrease territorial differentiation of pollution. Transport and planning structure at the level of the city, the district, and the area is the defining characteristic. An attempt to solve the transport problem through the transformation of the street road network complicates the application of innovative techniques for combatting air pollution in Moscow.

KEY WORDS: Moscow, vehicles, transport networks, emission, ecology, pollution areas, transport modelling, environment

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INTRODUCTION

Greater polarization of society, growing social tension, and emerging territorial segregation have become crucial effects of Post-Soviet economic transformations in Russia in terms of intracity development. The development of Soviet cities based on the aspiration of unifying the space gave way to the development of cities under the market economy, significantly affected by the cost of urban land and real estate. Having first shown in the capital which is at the moment a "modernization outpost", a number of relatively new to Russia social and economic processes (territorial segregation of society, emerging ethnic quarters, gentrification of the center) have started to develop in the cities. This necessitates studying the transforming quality of urban environment in Moscow in order to foresee the development of other cities in the country. The Post-Soviet Moscow has experienced the period of structuring of the space, sharp polarization of the urban environment, new functions of many districts appearing (Vendina 1996).

Research of intracity differences in environmental quality is extremely relevant now and have significant applied value, first of all, in the context of studying trends in the development of real estate market and city lands, analyzing the best options of using city land plots, identifying problem urban areas and designing programs for their development. The environmental situation is a crucial component of urban environmental quality. The urbanized areas are the ones of deeply changed nature. High concentration of various activities in cities disrupts the dynamic balance in nature and deteriorates the ecological living conditions of people.

Vehicles have become the leading source of air pollution over the past decades: transport emissions exceed 50% of gross pollution in half of the regions and in three forth of the cities (Bityukova 2019). Atmospheric emissions from mobile sources account for 44.7% in Russia (2017) and over 93% in Moscow (980 thousand tons, an absolute maximum for Russian cities and regions). Vehicles are the source of highly toxic substances, emissions are localized and they form areas of high pollution density. However, transport is perceived by the population as a mobility factor, rather than a pollution factor and does not affect real estate prices (Bityukova, Makhrova, Sokolova 2007).

RELATED RESEARCH

The research of vehicle problems in the cities is at the intersection of social and natural sciences: geography, sociology, history, ecology, demography, and economics. Most of the environmental transport researches are devoted to technical aspects, i.e. improvement of cleaning system methods, reburning and fuel quality.

Socio-political aspects of development of communications, legal framework and social interpretation are generally viewed in the context of traffic flow optimization in the cities and agglomerations. Modelling of planning systems and assessing of the necessary level of development for roads and streets network in the cities always emphasize a special connection between transport system development and economic and social development (The concept of assessing 2016) with a specific demonstration of the changing role of the city centre falling into decay as city transport started to use long-distance highways which led to the formation of suburbs (case studies of Chicago, Detroit, Los Angeles) (Vuchik 2011). The Soviet town-planning practice, on the contrary, would form transport systems founded on the priority of public transport (Blinkin, Koncheva 2016).

The strategies of transport accessibility based on the assessment of direct and indirect costs with various planning goals, such as greater safety, unity of community, and environment protection provide maximum overall benefits (Isalou, Litman, Shahmoradi 2014). However, it is admitted that the state alone is able to implement a solution to transport problems of large cities in the context of Cost and Benefit Analysis and based on the need to internalize the outer effects of vehicles (Hovavko 2012). The monetized estimates of external and internal effects from transport show that in Moscow just as in US cities (Litman T. 2002) main potential damage is connected with economic losses due to traffic jams (about 40 billion rub/year) while damage from air pollution, waste and water resources accounts for 15 billion rub/year (Kichendzhi, Katoyama 2011). Therefore, various political and planning reforms are needed, they can help both to increase cost efficiency, justice and to improve ecological situation since a car stuck in a traffic jam emits an average of 30% more pollutants.

Studies of environmental problems of transport are considered in various aspects:

– The impact of noise and pollution on people's health was studied, also health risk assessment for the population connected with functioning of vehicles facilities (Yakushev, Kurolap, Karpovich 2013). Special attention is paid to the impact analysis of solid particles, it is proved that up to 400 million people live under the pronounced impact of PM, transport being a key source of pollution (Revich 2018);

– Impact assessment for individual types of pollution was shown, especially for solid particles, in particular, the correlation coefficient between traffic intensity and concentrations of PM10 and PM2.5 are 0.36 and 0.39 respectively based on Tom-Tom index (Http://www.tomtom.com/en_gb/trafficindex) (Azarov, Kutenev, Stepanov 2012; Parsaev, Malyugin, Teterina 2018);

– Various environmental and geochemical researches were carried out, for example, salinization, pollution with heavy metals and metalloids near highways with various traffic intensity and in the courtyards with parking. All of them have demonstrated a rather uniform pollution of soils and of individual environments (Kosheleva, et al. 2018).

There is a large number of models of distribution and diffusion of emissions from mobile sources. However, there are almost no science works that would consider transformation of territorial structure of emissions from vehicles (Revich, Kuznetsova 2018).

Territorial structure of pollution is a set of orderly structured and interconnected elements making an impact on the environment with inherent spatial coordination and symbiotic relations between them and with other structures – industry, environment, and settlements. Centers of impact with specific types and levels constitute elements of the structure, while impact areas form the network of relations. The territorial structure of pollution has significant methodical value since it is the proximity of areas of anthropogenic impact (AI) to certain natural complexes and population that creates a specific interaction which, at the extreme, turns into a conflict. Both the persistence of AI sources and the variability of areas cause changes in territorial proportions of pollution. Actual areas of impact were identified and used to calculate pollution density and to zone regions and cities, laying the basis for methodical developments in this work.

MATERIALS AND METHODS

The main problem in the research of changing territorial structure of vehicle pollution in Moscow is the development of a unified technique allowing to carry out the analysis of serial observations of transformations in traffic intensity, transport infrastructure and spatial patterns in Moscow transport. Since it is difficult to select one specific indicator reflecting the level of environmental stress to identify territorial differentiation of vehicle air pollution, the method of areas was applied (Bityukova 2019). The ***density of harmful emissions*** (CO, SO_2, NO_x, C, NH_3, CH_4, volatile organic compounds (VOC) other than methane (CH_4) man-made emissions only) (tons/sq.km per year) indicator is calculated for each street and areas with various density of atmospheric emissions are detected in order to assess atmospheric pollution within areas.

There were several steps of the research:

Traffic intensity assessment. A proprietary technique is used to assess the transport load allowing to calculate the intensity for motorways sections without direct measurements of the passing transport. The systems of transport monitoring in Moscow are widely used and problem of

the availability of these data has occurred a long time ago. Real-time monitoring and machine learning methods would make it possible to estimate environmental stress similarly to services of traffic congestion, e.g. Yandex.Probki. Currently, due to limited access to such systems, open data of Google and OSM cartographic services are used.
Transport intensity calculation is based on the formula:

$$G_K = \frac{v_{cp} \cdot t \cdot P}{2 \cdot l_{cp} + D} \cdot k_s \cdot k_r \cdot n$$

units/hour,
where:
V_{cp} – average daily speed of traffic flow, m/sec (based on Google geographic information system);
t – duration of allowing signal of traffic light, sec.;
P – number of allowing signal cycles per 60 minutes, units;
n – number of lanes for a specific section based on OSM API;
k_S – coefficient of distance from the road section to the city centre;
k_r – coefficient of the motor way class and the value of connectivity of the road section;
$2 \cdot l_{cp} + D$ – dynamic gauge – a minimum section of the road in meters required for safe movement in the traffic flow with the assigned speed (dynamic gauge) that includes the doubled average length of the vehicle and "effective distance", i.e. recommended minimum distance between moving cars in meters. Naturally, in reality high traffic intensity during rush hours does not allow this distance to be observed, while low intensity does not provide for the adequate number of moving cars for it to occur. Therefore, this condition is most relevant for the period which is characterized by traffic intensity close to its average daily value.

Reliable modelling of traffic load for roads of minimum and intraquarter significance is difficult which constitutes a disadvantage of this technique.

Calculation of atmospheric emissions. Running exhaust emissions from vehicles have reduced by 6 grams per km over the five years (2011-2017) and constitute 21 grams per km now (State Standard (GOST) 56162-2014, 2014).
Pollutant emission (g/sec) of moving vehicles flow on a motor way (or its section) with a fixed length of L (km) is determined by the formula:

$$M_{L_i} = \frac{L - L_0}{3600} \sum_{1}^{K} M^{\Pi}_{K.i} \cdot G_K \cdot k_C \cdot r_{V_{K.i}}$$

g/sec,
where:
$M^{\Pi}_{K.i}$ – specific running exhaust emission of i th harmful substance by K th group of cars for city service conditions, g/km
K – number of groups of cars;
G_K – average daily traffic intensity, i.e. the car number of each of K groups passing through the fixed section of the chosen part of the motorway per hour in both directions on all lanes, units/h;
K_C – correction factor taking into account climatic systems of the car, road conditions and gripping;
$r_{V_{k.i}}$ – correction factor taking into account average speed of traffic flow (V, km/h) on the chosen section of the motorway;
1/3600 – conversion coefficient (hours into seconds);
L – length of the section of the motorway, km;
L_0 – line of cars at a red light and length of the corresponding zone of the intersection, km.

Calculation of impact areas for vehicles. The most important proposed method component is the calculation of the surface area of pollution. It is necessary to take into account transport specificity and planning structure of the studied area which significantly impacts on territorial distribution of emission density around the city. For the most part, the planning is designed for the traffic of the mid 1980s and still has not undergone any significant changes. Therefore, problems connected with imperfect city planning exacerbate the impact of pollution from transport.

OND-86 (All-Union regulatory document) technique is quite suitable for visualization and interpretation of results. This technique identifies the fields of concentration equivalent to maximum allowable concentration – fields of concentration (fig. 1).

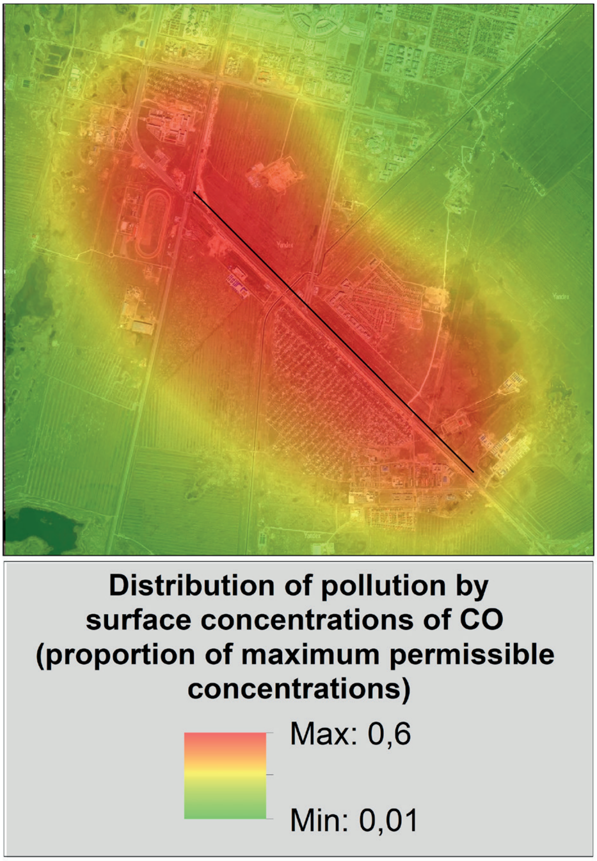

Fig. 1. An example of calculated area of pollution by surface concentrations of CO formed by automobile transport, exceeding the maximum permissible concentrations

Impact area for highways with traffic intensity of 10 thousand cars per day accounts for up to 400 meters, with the gas contamination and dust content showing up at a distance of up to 1-2 km downwind from the route in dry and clear weather. A persistent area of chemical impact (radius of 400 m) which is shown in continuously exceeded maximum allowable concentration is formed by large highways with traffic intensity of about 50 thousand cars per day.

Calculated data of specific running exhaust emissions of harmful substances for vehicles of various ecological classes and types of engine based on the fuel consumed is used to reflect emissions from different cars. These indicators are coincided with the current EMEP air pollutant emission inventory guidebook taking into account specific features of the structure and modes of vehicle movement.

Spatial impacts of traffic flows in the context of urban development is calculated as the product of the length of the road section multiplied by the impact area size (in sq.km). Thus, the impact area of vehicles flows *(S)* is calculated as the sum of products of the area of a rectangle (one side is equal to the length of the impact area interval (L_i), the other one is equal to the impact area (*2r*)) and the circle with the radius equal to the impact radius of *r*.

$$P = (V_i \bullet L_i \bullet 365 \bullet K) / (L_i 2^2_{\pi r})$$

where

P – total value of emission density for vehicles flow in its impact area;
L_i – length of the calculated transport section (km);
V_i – a car traffic in the calculated section;
r – impact radius for vehicles flow on the adjacent territory (km);

K – emission volume for one car per 1 km per year (i.e. motor emission volume per year divided by total mileage for the whole city).
Thus, the coefficient of impact for vehicle flows on the adjacent territory allowed defining and describing the total index of density of vehicle emission for the researched areas, the total number of which, as we allocated, was more than 93 thousand.

RESULTS AND DISCUSSION

Dynamics of air pollution from vehicles and its territorial proportions is the result of both *transformational* and *inherited factors*. Among the transformational factors are the intensify, for example the number of automobiles and the reduction of the anthropogenic impact such as fuels and engine improvement. *Inherited* conditions of development play a great role in the formation of areas with high emission density from vehicles: the planning structure, road network connectivity, the width of the roads, a number of bridges, relief features, the green belt and so on.

Impact level factors include the inherited technical quality of domestic cars. However, the majority of inherited development aspects boil down to *motor emission distribution across the territory:* the terrain, planning structure, bridges, road width, topology of the road network, low connectivity of the network, increased role of transit functions, etc.

The analysis of possible dependence of emissions volumes on vehicles and its dynamics showed that none of the indicators can be included in the equation of multiple linear regression. There are two main reasons for the absence of correlation between them. *First*, the static nature of the initial variables estimating only the registered population and the size of vehicle fleet. At the same time, the actual population and vehicle fleet are much more important for modern large cities with their strong daily, weekly and seasonal rhythmic. The use of indicators of the registered population and vehicle fleet lead to significant underestimation for the central districts of the city and possible overestimation for residential areas in the daytime. Second, the various nature of independent and dependent parameters. The population, vehicle fleet size, parameters of planning structure of the territory, the housing stock are endogenous characteristics of the respective municipal districts. The emissions from vehicles today are much stronger connected with conditionally exogenous characteristics – first of all with transport geographical location, transit intensity of the district, capacity of the main highways crossing the district.

Since there are two groups of opposite factors, exacerbating air pollution and reducing it, no clear impact of the ***growing automobilization*** is observed. This trend had already been detected for Moscow earlier (Bityukova, 2008). Growing automobilization level became an important characteristic of the Post-Soviet period, Moscow became a leader in this process (second after Primorye and Sakhalin). Today Moscow concentrates 10% of the Russian vehicle fleet, over 4 million cars. Maximum annual increase in the number of cars (19.1%) was observed in the early 1990s, then the situation was more or less stable until the growth started to slow down in 1996. 2011-2013 saw an average annual decrease in vehicle fleet increase rates of 2-5% reflecting market saturation, and due to the fall in real income personal vehicle fleet reduced by 8%, and vehicle fleet of organizations by 6% after 2014 (fig. 2).

Until the mid-1980s atmospheric emission volume was growing at about the same rate as the automobilization level. Since 1986, with the vehicle fleet still growing, emission volume has started to decrease as the result of the introduction of the first exhaust control measures and measurements.

1990-1991 saw insignificant changes in the level of automobilization, but significant changes in the volume of emissions, a growth of 12%, which is, most likely, connected with a new pollution accounting technique. Until 1996 correlation coefficient between the level of automobilization and dynamics of emissions was still statistically significant (0.61), though slightly decreased by a cumulative effect of positive factors. Used cars prevailed in the structure of

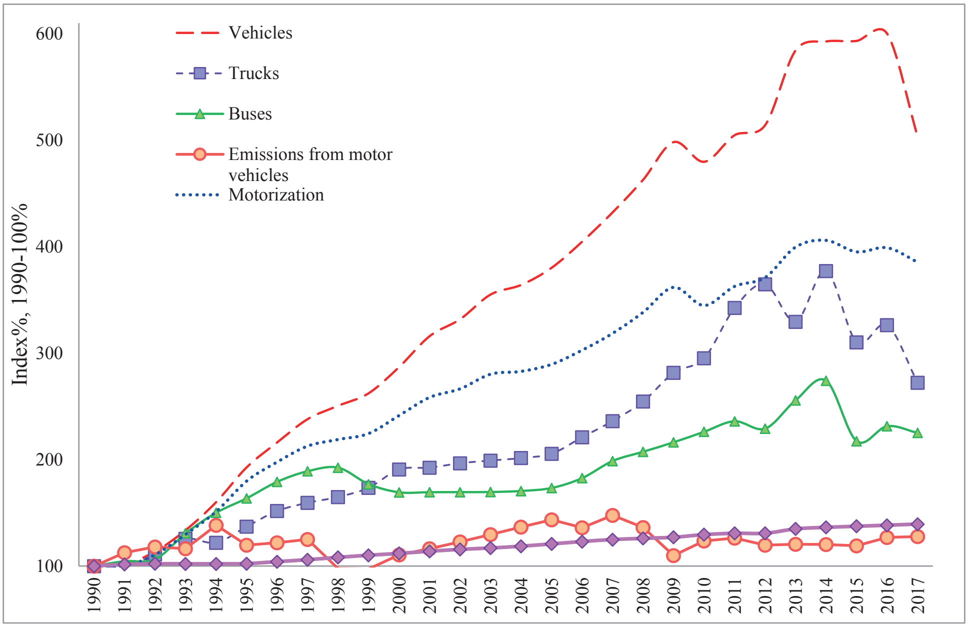

Fig. 2. Changes in the automobilization level in Moscow 1990-2017 (Main indicators, Transport in Russia, Demographic Yearbook)

growth during this period, high growth rates of the Moscow vehicle fleet did not affect the overall trend of its fast aging, and, therefore, the increase in specific emissions. 77% of cars in the structure of vehicle fleet had been used for more than 9 years. Therefore, 34% of the cars checked in 1998 were faulty based on emission indicators (Department of nature management and… 2002). Still in the context of the overall growth in the number of cars with petrol engines by 5%, consumption of gasoline reduced by 15% in 1999 demonstrating a decrease in specific fuel consumption.

Amidst economic growth and booming incomes of the population, the rapid growth of automobilization was in many respects guaranteed at the expense of quality cars. Construction of roads and reconstruction of transport network began (1997-2006), the correlation coefficient between the growing number of cars and atmospheric emission volume, for the first time, became statistically insignificant – 0.42, and at the present stage it is negative. 2009 to 2017 saw gross emission from mobile sources of pollution reduced by nearly 400 thousand tons (from 1342 to 982.4 thousand tons). At the same time the share of emissions from mobile sources also reduced by 2 pp which could be a result of a statistical error since there was no growth of industrial production volume during the specified period.

The most important changes in the structure of influencing factors occurred during the post-industrial period of development of Moscow. While during the Soviet period despite the low level of automobilization and, as a result, low traffic intensity, the correlation coefficient between the growing automobilization and changing atmospheric emission level was 0.65, now the value of the correlation coefficient is decreasing to 0.13. According to FTS, the number of the registered privately owned vehicles per 1000 citizens varies 4 times by the districts of Moscow: 500-900 cars /1000 citizens are registered in the north and northwest of the capital; 380-500 are registered in the central districts, in the south and the southeast. However, interdistrict distinctions based on the total number of the registered cars are much higher, exceeding 25 times. Even given possible divergence between the registered and used cars, such a high level of concentration should be taken into consideration when planning parking spaces, outflows, etc.

Changes in the structure of the vehicle fleet have a complex and divergent nature. Along with the growing automobilization, Moscow witnesses an intensive implementation of higher ecological classes (EC) of the engine (approximately 2-3% per year) and a declining share of trucks (approximately twofold reduction in 1991-2006) that promote improvement of ecological parameters of vehicles. It is also connected with stricter requirements to environmental standards of fuel and cars. Changes in the structure of vehicle fleet also led to better quality of fuel promoted by the growth in environmentally oriented demand. At the same time, the formation of vertically integrated companies capable of supplying high-quality fuel to the market provided for investments in oil processing aimed at the production of gasoline of better quality. Standards below Euro-4 (with running exhaust emission, g/car*km, twice less than for Euro-3 and three times less than for Euro-2) were banned in 2013, standards below Euro-5 have been banned since January, 2016. Transition from motor fuels class 3 to class 4 caused reduction of emissions of sulphur dioxide by 79%, benz(a)pyrene by 22.7%, solid substances by 13.5%, nitrogen oxides and carbon oxide each by 4%. By 2014, up to 50% of motor fuels in Moscow corresponded to class 5. According to expert estimates based on the data on age structure of vehicle fleet by the beginning of 2014, passenger cars of ecological classes higher than 4 accounted for 50%, trucks – 30%, buses – 16% (Department of nature management and… 2017).

But at the same time fuel consumption is not decreasing quickly enough as the changes occurring in the structure of vehicle fleet of Moscow are very specific. The fleet has more cars with increased fuel consumption as compared to average Russian values (according to tax administration). The share of cars with the engine of 150-250 hp is 3 times higher than on average in the country and their growth values are maximum (47% of growth in 2011-2017 and even in recent years in the context of a 12% reduction of the fleet, the number of cars with an engine of 200-250 hp has grown by 12%) (fig. 3).

Thus, divergent trends have become the most important feature of formation of air pollution level in Moscow in recent years: automobilization is growing but pollution is reducing thanks to better quality of vehicle fleet and fuel. Periodic adjustments of emission accounting technique make it impossible to reveal more pronounced trends, but relative changes of these indicators allow to reveal specifics of the recent years.

However, once the planned level of motor fuel quality is reached, there will be almost no reserves to further decrease the emissions. *Improvement of gasoline quality and changes in the structure of vehicle fleet have reduced gross and specific (running exhaust emission has decreased by 4 times) emission from vehicles.* As a result, since 2007 the intensive growth of vehicle fleet in Moscow has not been followed by growing volumes of

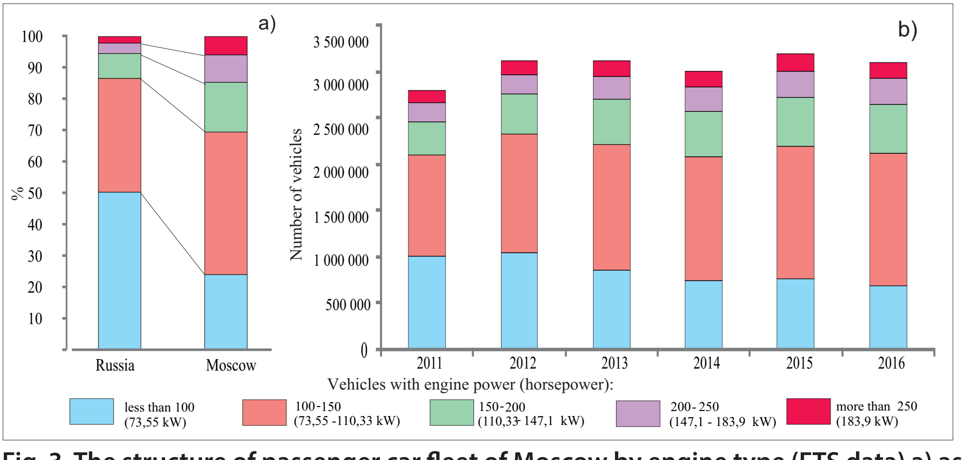

Fig. 3. The structure of passenger car fleet of Moscow by engine type (FTS data) a) as compared to Russia b) Dynamics in 2011-2016

pollutants. At the same time, there was no significant decrease in the load on linear infrastructure, so it is impossible to reveal a significant improvement in ecological situation for a number of districts.

Density of the street road network (SRN) is the most important factor of changes in ecological situation. Impact of SRN density is one of the most contradictory factors: on the one hand, construction of roads creates new areas of emission, on the other hand, motor emission volume decreases if there are no traffic jams which increase running exhaust emission by 30%, therefore, the development of road network reduces motor emission volume (Bityukova, Kasimov, Vlasov 2011).

Intensive reconstruction of city transportation routes is a distinctive feature of the past decade significantly improving ecological situation in a number of districts. The reconstruction of MKAD has decreased emission volume by 76.6 thousand tons/year, an equivalent of decrease in specific fuel consumption for each car by 0.4 l / 100 km, i.e. a transition to a different class of cars. The most large-scale recent endeavour in the development of the transport system of Moscow is the construction of the Third Ring Road (TRR). TRR has decreased the polluting emissions by 14.5% by 2000 and changed the territorial structure. The new ring road has temporarily lessened the load on transportation routes of the city centre, reducing the surface area of areas with the maximum emission by 1% and with high emission by 18%.

However, decrease in traffic intensity and traffic jams in the centre, and a subsequent reduction in emission volumes owing to the construction of TRR was only a temporary phenomenon, since due to the further growth of vehicle fleet in the city TRR was no longer able to cope with this task. TRR has hardly changed the length of transport network of the city (only a 1% increase), so there was no reduction in the specific density of cars per 1 km of the road network. Moreover, the new transportation route to a certain extent became an incentive for a more intensive use of vehicles by residents of the capital which in its turn led to further increase in negative impact of cars on the environment of the city.

Modern transport construction does nothing but preserves the above-mentioned radial and ring structure. Experts back in the 1970s understood the inadequacy of this scheme suggesting construction of a "chordate triangle" (powerful high-speed chordate highways on the peripheries of the city creating a "vacuum effect" for the city centre) envisaged by the Master plan of Moscow 1972 (Yakshin 1975). But, at the same time, there is an increase in SRN density in the districts with a slightly lower density as compared to the average level for the city. Planning and development of roads in problem zones of the centre, in the southwest of the middle belt (between Garden Ring Road and Third Ring Road), as well as and in northern districts adjacent to MKAD helped to reduce emissions in those areas. Thus, a greater uniformity of SRN across the city has also become a factor of decreasing emission volumes and ensuring a more uniform distribution across the city (fig. 4, c, d).

New transport construction in the context of the current planning structure and capacity of roads additionally increases load on MKAD and main radial highways. The Soviet town-planning norms were based on 60 cars per 1000 citizens, therefore, areas of mass construction of the 1960-80s are not designed to meet high western standards of automobilization.

In 2011-2017 in Moscow, in the borders of 2012, there were over 16 million sq.m[1] of housing put into operation, they were commissioned primarily in the districts with a relatively low density of population; also buildings which promote the uniformity of vehicles impact. But localization of large residential complexes stimulates the use of radial highways which, according to our calculations, are also characterized by a quite uniform distribution of density of emissions from mobile sources (figure 4). Average density of emissions on the TRR –

[1] Data by individual houses were provided by Popov A.A., the Head of CIAN Analytical Centre

MKAD interval has increased for the majority of motorways as compared to the Garden Ring – TRR interval. The only exceptions are Shchelkovskoye Highway, Leninsky Avenue and Marshal Zhukov Avenue where emission density decreases from the centre to periphery. This can be attributed to a considerable width of the route in the central part of the city as well as to specific features of traffic light regulation resulting in traffic jams while, as we approach MKAD, the problem is levelled.

Population density of cities reflects the type of prevailing housing stock and impacts the forms of city transport organization. In cities with high population density trends, local authorities are choosing intermodal transport systems with the emphasis on public transport (Rodrigue 2017). Development of public transport in Moscow, due to a number of measures of economic and prohibitive nature, allowed to considerably lessen the load on the centre in recent years. As a result, the volume of emissions from vehicles has decreased by 10-20% in the central districts and in the districts where new lines of underground transport were constructed (MCC, new lines of the subway) (fig. 5, a, b).

Town-planning strategies of the Government of Moscow. Unfortunately, amidst intensive automobilization, Moscow did not use an important advantage, i.e. the experience of western cities which had undergone this stage thirty years earlier, first of all, in terms of the arrangement of parking spaces across the city. As a result, the width of even large highways is contracted by one third, and even twice in the centre, creating additional traffic jams and additional emissions. As it was mentioned above, TRR did not have any environmental effect. Experts are not too optimistic regarding the fourth ring either.

Changes in territorial proportions of emission from vehicles are almost more important for Moscow than the scale of vehicles impact itself. 2017, as compared to 2007, saw more uniformity in vehicles emissions density. The first and main difference is that for the first time in the Post-Soviet period areas with a density of emission more than 5 thousand tons/sq.km disappeared completely. Those areas used to be typical of almost the whole territory of the centre within the Garden Ring, and a considerable part within the Third Ring Road, along the

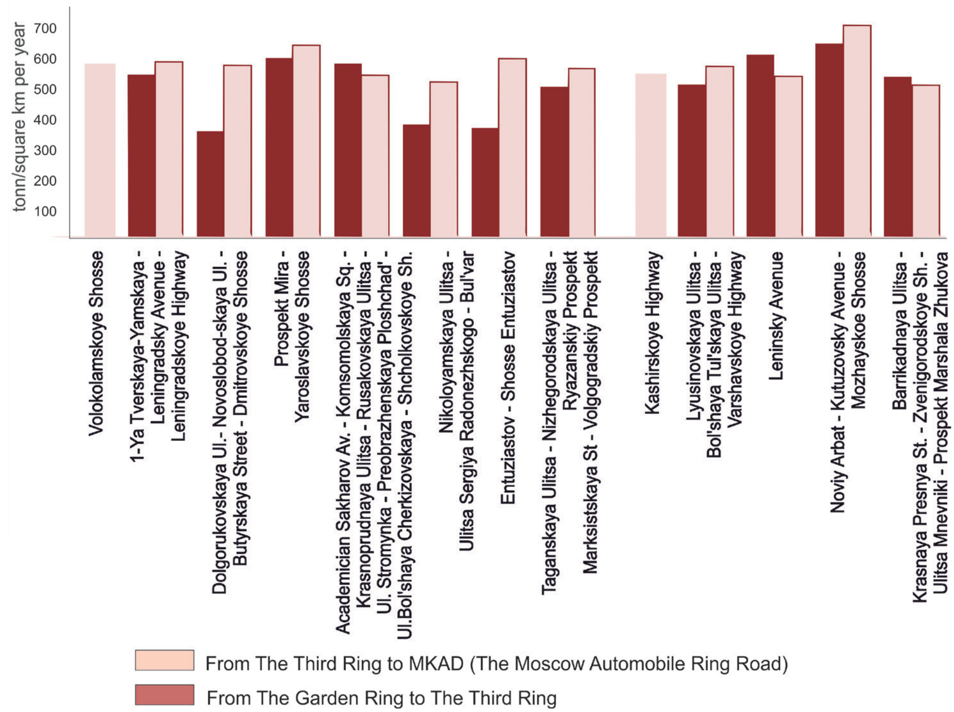

Fig. 4. Motor emission density by radial motorways tons/ sq.km per year.

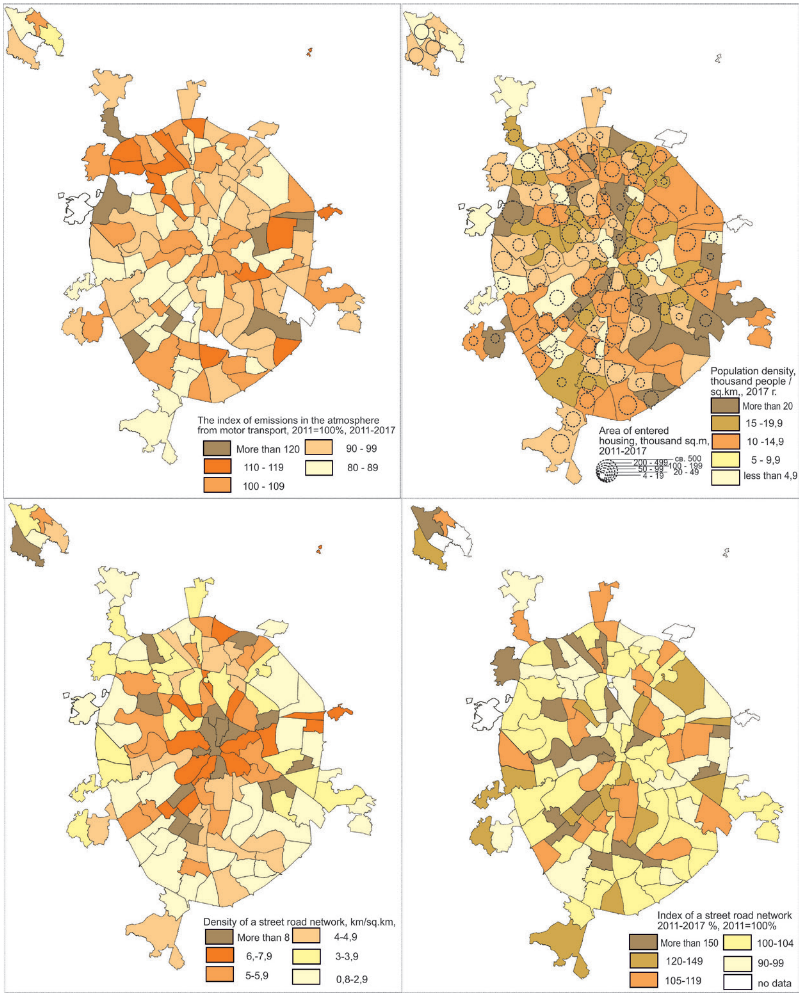

Fig. 5. Spatial differentiation of main factors and motor emission dynamics in 2011-2017

majority of the largest radial highways and MKAD, in the northeastern part of MKAD and along a part of Yaroslavskoye Highway. It happened despite the increase in traffic intensity and as a result of the effect of positive factors in the city: improvement of fuel quality and reduction of its specific consumption, improvement of car quality and reduction of the share of trucks causing decrease in specific atmospheric emissions. A part was also played by measures for the improvement of the road surface and the nature of traffic, over the five years (2011-2017) it saw transport construction and road reconstruction projects implemented, and vehicle fleet growing rates slowed down. The number of areas with a density of 3-5 thousand tons/sq.km declined though they have already remained stable for a period of time. Most of these areas are still in the center. The share of areas with the lowest level of emission (up to 100 and 100-500 tons/sq.km), that used to be stable since the early 2000s, almost doubled as compared to 2007-2014. Motor emission density values were subject to averaging, i.e. anthropogenic impact on the territory becomes more uniform. This could have been viewed as a positive trend, but the reduction of "peaks" primarily around joining of radial highways with the Garden Ring was compensated by the growth of pollution in peripheral districts of the city that becomes especially evident in the absence of any significant differences between administrative districts of the city (Table 1).

Table 1. Distribution of areas by groups based on polluting emissions density, the share of the surface area of areas in the total area of Moscow

Density of emissions, (tons / square km)	The share of the surface area of areas in the total area, %													
						Administrative districts								
	1992	2002	2007	2014	2017	Central	North	Northeast	East	Southeast	South	Southwest	West	Northwest
<100	3	2	12	14	23	19	21	24	22	23	20	21	20	21
100-500	16	23	23	22	49	55	57	58	56	57	57	58	55	57
500-1000	18	25	32	34	14	13	14	12	14	12	14	15	16	15
1000-3000	37	43	28	25	8	6	6	5	6	5	6	5	7	5
3000-5000	22	5	5	4	6	9	2	1	2	2	3	2	2	2
>5000	4	3	1	0,5	0	0	0	0	0	0	0	0	0	0

Assessment of vehicles emissions in the South-East Administrative District.

Very interesting example of changing density emission because of roads networks modernization is on the Southeast part of Moscow. As the projects of road network reconstruction are being implemented in the South-East Administrative District (SEAD) there are positive shifts in the intensity and speed of traffic that, according to the Government of Moscow, is supposed to reduce the number of areas with maximum pollution. State of the Environment Report prepared by analytical services of the mayor's office confirms that the maximum concentration of complaints of the population about the condition of atmospheric air is in the South-East Administrative District. At the same time the number of the functioning enterprises in the territory of the district is reducing, and emission from stationary sources is declining. The presence of specific enterprises in the district, such as oil refinery, affects perception of the ecological situation as well. In terms of perception of the acoustic situation, vehicles accounts for more than a third of noise-related complaints.

Volgogradsky and Ryazansky Avenues and Lyusinovskaya Street are the main highways in the district which connect suburban districts with the central part of Moscow and are almost the sole communication route between TRR and MKAD in the South-East Administrative District.

A large infrastructure project was completed in the South-Eastern Administrative District in 2016, i.e. the reconstruction of Volgogradsky Avenue which included construction of the tunnel on Lyublinskaya Street aimed at lessening the load on this traffic intersection. Ostapovsky Drive was expanded to four lanes, a flyover at the crossing with Volzhsky Boulevard was constructed, several above-ground and underground crosswalks were put into operation.

Main works on the reconstruction of Ryazansky Avenue were completed in 2015, but the U-turn near Nizhegorodskaya Street MCC station has been built quite recently. The carriageway has been expanded, cycle infrastructure has been partially created, public transport lanes have been dedicated. The main traffic problems in the district are now related to active construction of Nekrasovskaya line and Big ring metro line.

Nevertheless, it is estimated that transport infrastructure capacity of the South-East Administrative District at rush hours is insufficient resulting in frequent traffic jams and increasing environmental stress in the area (figure 7).

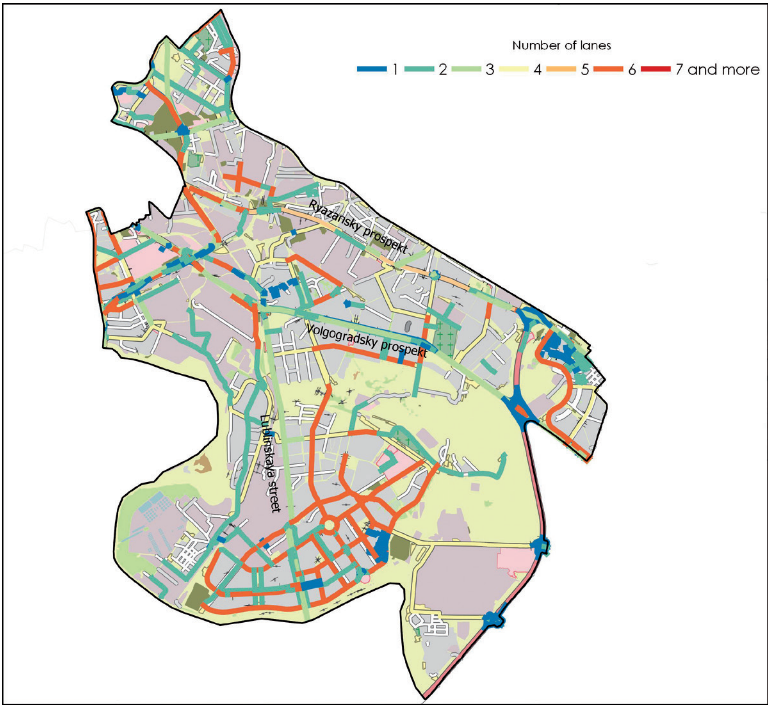

Fig. 6. Maximum road capacity in the South-East Administrative District (without Nekrasovka)

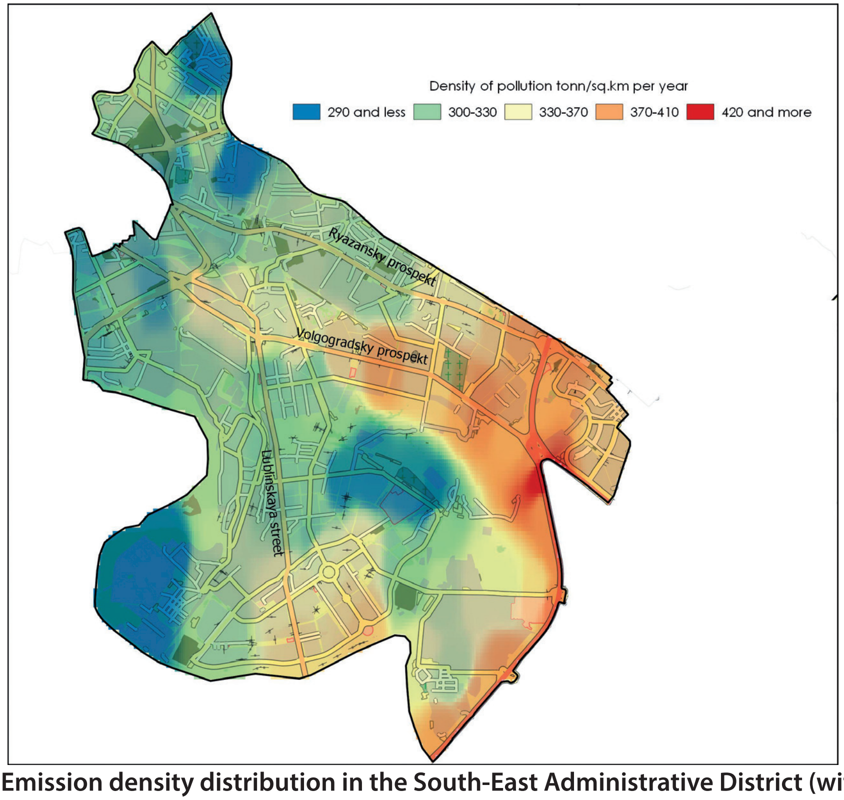

Fig. 7. Emission density distribution in the South-East Administrative District (without Nekrasovka)

Outgoing highways of the district and the territories adjacent to MKAD are subject to the main average daily load. Despite the presence of natural emission reduction from MKAD to TRR, emission volumes do not differ significantly. Expansion of highways closer to the central part of Moscow up to TRR increases the average speed of traffic and decreases the duration of jams. Nevertheless, transformations of transport infrastructure in the district have not resolved the problem of road capacity in the South-East Administrative District. Ryazansky and Volgogradsky Avenues are still among the most loaded highways of the city at rush hours and the road from MKAD to TRR in the district can take up to 43-50 minutes.

CONCLUSIONS

The analysis of all the above-mentioned factors allows to reveal a number of trends in the dynamics of vehicles atmospheric emissions density over the past 7 years:

– the overall level of density of harmful substances emitted into the atmosphere of the city is decreasing in the entire territory of Moscow. Since the early 2000s the density of polluting emissions remained invariable for 40% of the territory, within 1000-3000 tons/ sq.km per year, but over the past 7 years, large-scale road construction, development of public transport, improvement of the structure of vehicle fleet led to the situation when density of emissions does not exceed 500 tons/ sq.km per year for 70% of the territory of the city;

– currently, almost all areas with increased density of the pollutants emitted into the atmosphere are located only within the exposure limits of vehiclesation highways;

– the amplitude of fluctuations of atmospheric emission density has also decreased (by 1.5 times) suggesting the levelling of differences in pollution of the environment of the city. In general, a "blurring" of pollutants from vehicles across the territory of Moscow is observed for the reviewed period of 2011-2017. The previous periods witnessed a very high concentration of pollutants within the Garden Ring, while 2017 witnessed both the overall decrease in concentration of pollutants and a redistribution of harmful substances from vehicles between the territory of the Garden Ring and TRR. Thus, for the past 7 years a more uniform environmental pollution of the city is observed. On the one hand, anthropogenic impact is objectively moving from industrial and commercial areas to residential areas, with their hospitals, child care facilities, etc. Therefore, the number of people seriously affected by vehicle increases with a growing share of the most vulnerable demographic groups of population (children, the elderly, the sick and so forth).

On the other hand, this blurring of pollution areas reduces the sharpness of its perception, causes additional tolerance, unwillingness (and inability) to influence the authorities. The impact of environmental factor on the price of residential real estate which is quite low for a city with a high level of education can serve an example. According to realtors and buyer polls, there are more than fifteen factors influencing the price of residential real estate in the cities: quality of the object (house type, material of walls, condition of the apartment), size of housing and its location (proximity to the center, transport accessibility (first of all, subway)), prestige of the district, ecological situation, etc. (Bityukova et al. 2016).

Dynamics of air emission from vehicles is the result of both transformational and inherited factors. Impact level factors include the inherited quality of domestic cars. However, the majority of inherited development aspects boil down to motor emission distribution across the territory: the terrain, planning structure, bridges, road width, topology of the road network, low connectivity of the network, increased role of transit functions, etc.

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REFERENCES

Azarov V.K., Kutenev V.F., Stepanov V.V. (2012). On the emission of particulate matter by vehicles, Ecology, №6 (77) pp. 55-58 (in Russian with English summary)

Basic Indicators of Environmental Protection--2017 (online) Federal State Statistics Service, http://www.gks.ru/bgd/regl/b_oxr17/Main.htm. [Accessed 02.12.2018]

Bityukova V., Sokolova E. (2008). On the brink of collapse Moscow's tangled traffic// Osteuropa: Zeitschrift fuer Gegenwartsfragen des Ostens. v. 58. № 4–5. P. 351-358+493

Bityukova V., Savoskul M., Kirillov P., Koldobskaya N. (2016). Transformation of environmental problems in Moscow: sociological dimension // GEOGRAPHY, ENVIRONMENT, SUSTAINABILITY, № 4, pp. 74-87

Bityukova V.R. (2019). Socio-environmental problems of the development of Russian cities. Moscow: Editorial URSS. (in Russian with English summary)

Bityukova V.R., Kasimov N.S., Vlasov D.S. (2011). Ecological Portraits of Russian Cities. Ecology and Industry of Russia, № 4, pp. 6-18 (in Russian with English summary)

Bityukova V.R., Mahrova A.G., and Sokolova E.P. (2006). Ecological situation as a factor in the differentiation of housing prices in Moscow, Moscow University Bulletin. Series 5. Geography.; 6, pp. 31-41. (in Russian with English summary)

Blinkin M., Koncheva E. (eds.), (2016), Transport systems of Russian cities: Ongoing transformation. Transformation research, economics and policy series. – Springer

Database of municipal indicators 2006-2018 (online) Federal State Statistics Service. http://www.gks.ru/free_doc/new_site/bd_munst/munst.htm [Accessed 02.12.2019]

Database on the forms of statistical tax reporting 2006-2018 (Report on the tax base and the structure of excise tax accruals on cars and motorcycles) (online) Federal tax service of Russia https://www.nalog.ru/rn38/related_activities/statistics_and_analytics/forms/#t00 [Accessed 02.03.2019]

Demographic Yearbook. 2000-2018. (online) Federal State Statistics Service, http://www.gks.ru/free_doc/new_site/business/trans-sv/t3-4.xls [Accessed 02.03.2019]

Department of Natural Resources and Environmental Protection of Moscow (2002, 2018) Report on the state of the environment in the city of Moscow in 2002-2018. https://www.mos.ru/eco/documents/doklady/ [Accessed 02.03.2019]

Department of nature management and environmental protection of the city of Moscow State of the Environment Report in Moscow in 2017 (2018) (online) https://www.mos.ru/eco/documents/doklady/view/217165220/ [Accessed 11.07.2018]. (in Russian with English summary)

Department of nature management and environmental protection of the city of Moscow State of the Environment Report in Moscow in 2002 (2003) (online) https://www.mos.ru/eco/documents/doklady/view/217165220/ [Accessed 11.07.2018]. (in Russian with English summary)

Environmental protection in Russia —2016, 2017, 2018 (online) Federal State Statistics Service. http://www.gks.ru/bgd/regl/b16_54/Main.htm. [Accessed 02.12.2018]

GOST 56162-2014, 2014, (Emissions of pollutants into the atmosphere. Method of calculating emissions from motor vehicles when conducting summary calculations for urban settlements). Moscow: «Standartinform» (in Russian)

Hovavko I.Yu. (2012). Internalization of external effects of vehicles (on the example of Moscow) Moscow University Bulletin. Series 6. Economy. № 1, pp. 74-84 (in Russian with English summary)

Isalou A.A., Litman T., Shahmoradi B. (2014). Testing the housing and transportation affordability index in a developing world context: a sustainability comparison of central and suburban districts in qom, Iran TRANSPORT POLICY, Elsevier Science Publishing Company, Inc. pp. 33-39

Kichendzhi V., Khatoyama K. (2010). Moscow: transport problems of the metropolis. Moscow: Nauka (in Russian with English summary)

Kosheleva N.E., Dorokhova M.F., Kuzminskaya N.Y., Ryzhov A.V. and Kasimov N.S. (2018) Impact of motor vehicles on the ecological state of soils in the western district of Moscow. Moscow University Bulletin. Series 5. Geography. №2, pp. 16-27. (in Russian with English summary)

Litman T. (2002). Transportation Cost Analysis: Techniques, Estimates and Implications (online) Victoria Transport Policy Institute Website. June. URL: http:// www.vtpi.org/tca/tca00.pdf/ [Accessed 11.12.2018]

Parsaev E.V., Malyugin P.N. Teterina I.A. (2018). Metodology for the calculation of emissions for non-stationary transport flow, The Russian Automobile and Highway Industry Journal, vol. 15, № 5. , pp. 686-697.

Popov A A. (2007). Territorial differentiation of the quality of the urban environment in Moscow, Moscow University Bulletin. Series 5. Geography.; 4 pp. 29—36. (in Russian with English summary)

Regions of Russia. Annual Update (The number of owners of cars in the regions of the Russian Federation per 1000 people) 2000-2018. (online) Federal State Statistics Service, http://www.gks.ru/free_doc/new_site/business/trans-sv/t3-4.xls [Accessed 02.12.2018]

Revich B.A. (2018), Fine suspended particles in atmospheric air and their impact on the health of residents of megalopolises // PEMME, vol. XXIX, № 3, pp. 53-78 (in Russian with English summary)

Revich B.A., Kuznetsova O.V. (Ed.), (2018), Man in a megacity: the experience of interdisciplinary research. Moscow: LENAND. - 640 p. (in Russian with English summary)

Rodrigue J.-P. (2017) The Geography of Transport Systems. New York: Routledge.

The concept of assessing the level of development of urban agglomerations (2016) (online) The Institute for Urban Economics Foundation http://www.urbaneconomics.ru/sites/default/files/koncepciya_ocenki_urovnya_razvitiya_gorodskih_aglomeraciy_13.01.17.pdf [Accessed 02.03.2019]

Transport of Russia (2015) (online) Federal State Statistics Service, http://www.gks.ru/free_doc/new_site/business/trans-sv/t3-4.xls [Accessed 02.03.2019]

Vuchik V.R. (2011). Transportation in cities suitable for life. Moscow: Territoriya budushchego (in Russian with English summary)

Yakshin A.M. (1975) Prospects for the development of a network of urban highways. Moscow: Strojizdat (in Russian)

Yakushev, AB, Kurolap, SA, Karpovich, MA, (2013), Environmental Impact Assessment of Automobile Transport on the Air Basin of the Cities of the Central Black Soil Region - Voronezh: "Scientific Book"(in Russian with English summary)

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