Approaches to Assessing the Vulnerability of Large City Population to Natural and Man-Made Hazards Using Mobile Operators Data (Case Study of Moscow, Russia)

S. Badina, R. Babkin, and A. Mikhaylov

Abstract The complex nature of threats to large cities residents requires a rethinking of the existing methods for the vulnerability assessment of the population to various kinds of them. Moscow concentrates about 9% of the Russian population, and with the Moscow oblast—about 12%. The high level of spatial concentration of the population and its active dynamics determine the increased level of natural and man-made risk in the city. The purpose of this study is to assess the vulnerability of the Moscow population to natural and man-made hazards, taking into account the actual population size and its movement in the city within different time cycles (daily and weekly-seasonal). Trying to find an appropriate solution, authors used alternative sources of statistical information—mobile operators data. The use of these data made it possible to obtain more detailed information on the state of socio-geographical systems, to overcome barriers associated with the incompleteness and 'static' nature of official statistical information (data provided by Rosstat). Mobile operators data allow obtaining more reliable depictions of the localization of its users at a certain point in time, which made it possible to adjust and clarify the current ideas about the distribution of the population in Moscow. As a result of the study, it was shown that for the center of Moscow and for New Moscow, the population vulnerability level is much higher than reflected in official documents. On the contrary, in the peripheral areas of Old Moscow, the potential risks are reduced because the real population density is significantly lower than it is estimated in the calculations provided by Rosstat.

Keywords Population vulnerability · Natural and man-made risks · Moscow · Urban real-time population density dynamics · Data of mobile operators

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1 Introduction

The increase in the frequency of natural and man-made emergencies, as well as the scale of their consequences (the number of victims, damage, long-term negative effects affecting socio-economic development) require new scientific approaches and methods to assess the risks and vulnerability of citizens. Large cities and urban agglomerations are areas of increased danger due to the high concentration of the population. The use of so-called 'classical' methods of statistical data analysis does not allow obtaining a clear and representative picture of the population spatial distribution across the city's territory during different times of a day; nevertheless, it is critically important for vulnerability assessments and development of security measures corresponding to the real population numbers.

The studies of natural and man-made risks of socio-economic development have become widespread in the last decades due to the high degree of their relevance, and especially because of the increase in the occurrence frequency of natural and man-made hazards on the one hand and the magnitude of human casualties and material damage on the other, which is typical for all countries and regions in the world [28, 49]. According to the modern interdisciplinary approach, the notion of a 'risk' is defined as a probability of damage and its potential scale due to the emergence of a dangerous event. UN-Habitat defines risk as 'the effect of uncertainty on objectives'.[1] The key problem, constituted by the phenomenon of risk, is finding a way to avoid decisive mistakes which can entail this damage [42]. Natural risk studies are carried out at the intersection of physical and socio-economic geography, since risk manifests itself only when there are potential direct and indirect damages to society and the economy. Generally, the majority of modern researches in the field of studying the socio-economic aspects of the natural risk geographies come down to:

- Vulnerability assessments of the population and the local economy to natural hazards, damage level predictions [11, 34, 40, 46];
- Assessments of the natural disasters' impact on the particular territory, its economic structure and growth in general [20, 25, 48];
- Identification of economic mechanisms and assessments the effectiveness of investments in damage reduction from natural hazards and studying insurance as a tool for reduction of negative impacts in various territories [27, 30, 43];
- Analysis of public perceptions of natural disasters and risk reduction in different countries and regions [15, 26, 31];
- Analysis of regional risk management features, aspects of risk reduction in strategic planning [18, 50] and adaptation to risk [17, 38];
- It is also necessary to highlight the researches related to the study of man-made and natural-man-made risks [2, 22].

Some special attention is paid to the analysis and forecasting of natural risk for the world's largest cities and urban agglomerations. Research works on this topic focus

[1] https://unhabitat.org/un-habitat-enterprise-risk-management-implementation-guidelines (accessed 15 July 2021).

on issues of urban growth as a factor of risk increase [21, 24] and vulnerability of urban residents to natural hazards [36, 37, 44]. In the city-level studies, social risks and risks to the population, are more prioritized oftentimes than economic aspects, whereas in research works conducted at state and regional levels the situation is directly opposite.

Methods for natural risk assessment have not been unified yet. They depend on specific research tasks, the place-specific features of the study area and the set of particular threats taken into account. This study proposes an approach to vulnerability assessment for the population of a large city, based on determining the most probable number of people at a certain time interval in a certain place on a relatively large scale (0.25 sq. km cells). The data of mobile operators is used as the main source of information, making it possible to trace the population movement and obtain the spatial distribution of the population in the city which corresponds to the reality better than in case of use of the 'classic' data sources. Over the past 5–10 years, significant numbers of scientific papers using data of mobile operators have been written about pulsation processes in the settlement system of the Moscow metropolitan area [16, 32, 33, 41]. It is also important to note that the similar data sources were used in studies of structural and functional shifts in settlement system due to the influence of various infrastructural projects [33].

The data of mobile operators has been used in the analysis of settlement systems since the mid-2000s. By now, considerable research experience has been accumulated in such countries as the USA, France, Great Britain, Belgium, Estonia and many others [1, 19, 23]. There are some attempts being made in order to integrate the data of mobile operators into official statistics. A study commissioned by Eurostat was carried out in 2012, aiming to assess the possibility of using mobile data to obtain a variety of statistical information [4]. Comparison of mobile operators' data with census statistics and population register showed their high correlation, while it was noted that mobile data is much more relevant in the analysis of dynamic socio-economic processes. While speaking about the largest international projects using this kind of data in studying the consequences of natural disasters and emergencies, it is necessary to outline the analysis of the earthquake consequences in the Republic of Haiti in 2011, as well as the paper of an international team of scientists dedicated the spread of malaria in Kenya [14, 47]. It should be noted that nowadays the studies carried out using the data of mobile operators are pioneering for Russia, and yet are at the early stages of inclusion into the contemporary Russian scholar discourse.

2 Methods and Data

The methodological approach adopted in this study is based on the 'risk' concept, which is a likelihood function of an emergency and the magnitude of the potential consequences for the population, urban economy and infrastructure (material damage and the number of people affected). In other words, it is a combination of danger and vulnerability. Therefore, to a decisive extent, the Moscow metropolitan area[2] is characterized by an increased risk level, due to the extremely high density and concentration of the population in Russian context. The majority of risk assessment models are based on the calculation of population numbers in the zone, potentially affected by the threat (the higher the concentration of the population—the higher the risks). The population number is a key parameter, in addition to which such variables as the age and sex population structure, the proportion of people under or over working age, the share of citizens with special needs in population, can also be used. The population size of a particular area is a key characteristic of social vulnerability to natural and man-made emergencies used by the Ministry of Emergency Situations of Russia accordingly to normative assessments of the needs for basic necessities in case of emergencies, as well as in calculations of financial and material resources reserved in case of a potential hazard. Therefore, it is important to understand the dynamics of actual spatial population distribution across the city of Moscow, and not to rely on 'static' official statistical information.

The official statistics on the spatial distribution of the population in Moscow are very approximate nowadays. Moreover, within the framework of the daily, weekly and seasonal mobility cycles, the indicator of the present population number undergoes significant transformations, which are practically not taken into account by official statistics. The development of transport infrastructure, a significant expansion of the daily commuting zone in the Moscow metropolitan area, the changes of the phenomena of extended cycles of labor commuting—semi-migrants and seasonal migrants significantly complicate the dynamics of the population mobility within the existing urban and suburban spatial structure. Accordingly, in the area of a probable natural or man-made emergency, at a certain point of time there may be a significantly larger number of people than it is usually expected, which can significantly complicate rescue measurements, cause a shortage of material resources and forces, and increase the risks of deaths or sufferings for a large number of people. So far studying the settlement system and the features of its spatio-temporal functioning becomes especially vital.

Temporal differences of population numbers Moscow reach 40% during a year. The most dramatic ones can be observed between a winter weekday and a summer weekend night. The first one is the time of maximal concentration of people in Moscow, especially in its most attractive districts with a variety of jobs, situation of educational, shopping and entertainment functions. For example, the population of the capital on a weekday winter day reaches 13.3 million people. In the summer the population inside the city limits is about 7 million people. The intraday population density varies for 10–15% (Fig. 1). A more detailed analysis of population pulsations with high spatial and temporal detailing requires the use of fundamentally new types of analysis. For example, the methods of neural networks have been already included in practice of some European countries [29].

[2] The metropolitan area of Moscow consists of the Moscow City and the Moscow Oblast (administratively, they are two separate regions of the Russian Federation).

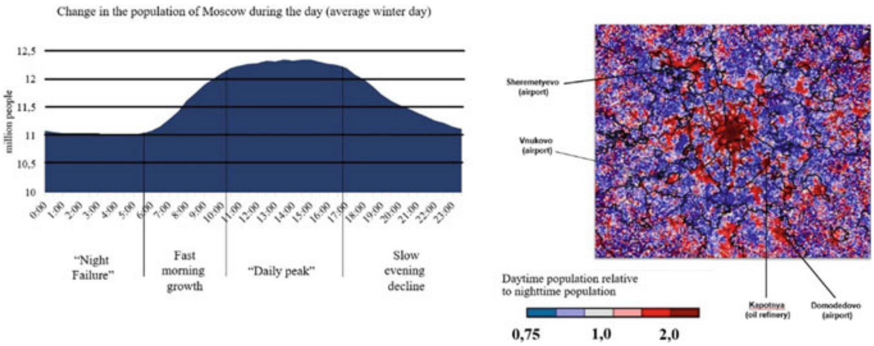

Fig. 1 Intraday changes in the population of Moscow (*Source* compiled by the authors based on data from mobile operators)

The key vulnerability parameter in the study is the density of the present population. In author's previous papers [6–12], the rationality of use of the density characteristics with the vulnerability parameters was substantiated and the relationship between them was empirically confirmed. According to the probability multiplication theorem, the higher the concentration of population and economic activity is in the area, the higher amount of damage in case of natural and (or) man-made hazards there can be. This pattern is especially clear for hazards that have an 'areal' impact and affect large territories.

The assessment of the vulnerability of Moscow residents was made taking into account the real number and movement of the population in different time periods. In addition to official statistical sources, mobile operators' data is also involved, characterizing the localization of users at a certain time moment, which can clarify the currently existing 'portrait' of spatial distribution of the population across Moscow, as well as provide better understanding for the nature of peak concentrations in the key elements of urban infrastructure and the likely risks of 'shock' population fluctuations due to potential emergencies.

Since June 1, 2021, the national standard "Safety in emergencies. Planning of measures for evacuation and dispersal of the population in case of a threat and occurrence of emergency situations"[3] has come in operation in Russia. According to this standard, the regions of Russia must develop scenarios for evacuation and spatial dispersal of the population in case of emergency. Planning evacuation scenarios is extremely important for Moscow, as it helps to avoid overloading of the transportation system (for example, serious traffic jam have practically paralyzed the city after the terrorist attacks in the Moscow Metro in 2010) and life support systems of the city. McKinsey named the transportation system of Moscow as one of the most efficient in the world: Moscow achieved 5th place in the ranking of urban mobility out of

[3] https://docs.cntd.ru/document/566430562 (accessed 15 July 2021).

24 considered global cities.[4] However, despite the fact that since the beginning of the 2010s the urban road network is continuously modernized, the traffic congestion level remains high. This fact can play a negative role in case of massive spontaneous evacuation of urban residents.

The study is based on the anonymized data of mobile operators, depicting localization of users for 2019, provided by the Moscow Department of Information Technologies. The data of mobile operators represent information on the location of network users during the day (with a time fraction of 30 min, and spatial—0.25 sq. km cells). Location determination is conducted by measurement of the distance of the person's distance from three nearest cellular stations by the signal strength of his cell phone. At the same time, the system registers only those subscribers who make calls, accumulating information about their movements during the day (measurements are carried out each 30 min). Further, calls are depersonalized and the sample is cleared of signals from modems, tablets, as well as phones used for data transmission via the Internet, and data of the subscribers who use two or more SIM cards. In total, over 36 million measurements were analyzed in more than 7 thousand time slices. The use of data from cellular operators involves the analysis of changes in the real population in Moscow that characterizes the daily and seasonal fluctuations due to the influence of commuting patterns in domains of housing, labor and leisure.

2.1 A Brief Overview of Natural and Man-Made Hazards: Case of Moscow

Areas of maximum risk are determined by the ratio of the vulnerability parameters for the existing population and the maximum danger parameters. The area of Moscow is characterized by an increased likelihood of a wide range of emergencies, both natural and man-made. Additionally, there are higher risks of terrorist attacks. The statistical base for the study included the open sources data, regulatory documents, state reports "On the state of protection of the population and territories of the Russian Federation from natural and man-made emergencies" for 1999–2020 [for example, 36], the General plan of Moscow city. The key natural hazards on the city territory include dangerous hydrometeorological phenomena [3], hazardous engineering and geological processes and phenomena (including flooding) [39], smoke pollution of vast areas of the city due to massive forest and peat fires in the surrounding Moscow Region etc.

There are some key man-made hazards which should be especially highlighted among the others in the context of Moscow. They include man-made fires, accidents at electric power facilities, accidents at railway and road transport with the release of hazardous substances and the emergence of vast areas of fire, collapse of structural

[4] https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/Elements%20of%20success%20Urban%20transportation%20systems%20of%2024%20global%20cities/Urban-transportation-systems_e-versions.ashx (accessed 15 July 2021).

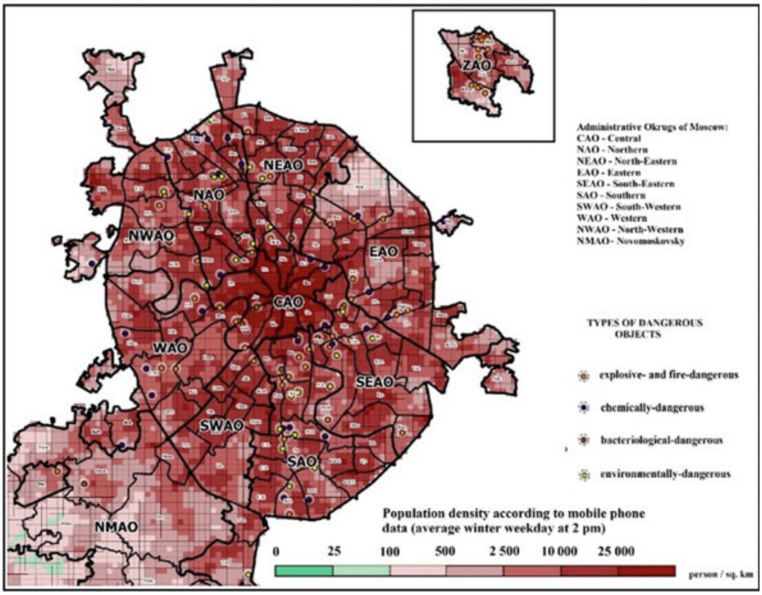

Fig. 2 Localization of hazardous industrial facilities in Moscow (*Source* compiled by the authors based on data of mobile operators)

elements of buildings and structures of transport communications, etc.), the emergence of floods due to the potential destruction of water-limiting devices on Moskva river and adjacent water reservoirs. Particular attention should be paid to the dangers associated with potentially hazardous industrial facilities (explosive, chemical, radiation and fire hazardous),[5] institutions working with pathogens of high pathogenicity. There are 117 potentially hazardous facilities on the territory of the city, including 17 radiation hazardous, 40 chemically hazardous, 6 biologically (epidemiologically) hazardous, 54 explosive and fire hazardous (see Fig. 2).[6]

Chemically hazardous facilities in Moscow (the likelihood of accidental emissions of chlorine, ammonia, acids) are primarily represented by food industry enterprises that use ammonia as a refrigerant and waterworks that use chlorine for water disinfection. Even though Mosvodokanal (Moscow Water Supplement Company) has now almost completely switched from the use of liquid chlorine to sodium hypochlorite, some enterprises still have supplies of chlorine in case of potential emergencies. The situation is similar with the use of ammonia. The transition to freon use is gradually being carried out—however, freon refrigeration equipment requires 2.5 times more

[5] Hazardous production facilities in accordance with the Russian Federal Law of 21.07.1997 N 116-FZ (as amended on 08.12.2020) "On industrial safety of hazardous production facilities".

[6] According to the resolution of the Government of Moscow of September 23, 2011 N 443-PP on the approval of the state program of the city of Moscow "Safe City" (as amended by resolutions of the Government of Moscow 2012–2019).

electricity, which is a significant barrier, and freon also cannot be considered absolutely safe. The group of chemically hazardous facilities also includes enterprises of the key and most dynamically developing sub-sectors of the Moscow chemical industry—pharmaceuticals, perfumery and cosmetics, and their production cycles include a wide range of potentially hazardous chemicals.

The radiation situation in Moscow is stable, but there is a likelihood of accidents at research reactors and equipment pieces using radioactive substances, which can cause the formation of zones of radiation contamination [45]. Additional factors of vulnerability increase can also be attributed to the reduction of sanitary protection zones around potentially hazardous facilities due to the lack of land resources (especially because of their partial residential development, stimulated with high housing demand levels). Thus, the established sanitary protection zones are actually smaller than the calculated ones in terms of area and do not fully or partially cover the impact areas around many of potentially hazardous objects (according to the analysis of data from the Integrated Automated Information System for ensuring urban planning activities in the city of Moscow). An important factor in vulnerability increase is the physical aging of fixed assets in industry and the life support sector, a decrease in working discipline control and a growth of the number of deviations from the established technological regimes, the emergence of a large numbers of small enterprises lacking the necessary technological supervision, partially insufficient equipment of industrial enterprises and facilities with modern protection systems. So far, according to the General Plan of Moscow, about 1.8 thousand hectares of residential areas with a total number of residents accounting for 93.2 thousand people are located within the sanitary protection zones. Therefore, significant financial resources which are aimed for prevention of natural and man-made emergencies in Moscow can reduce potential risk levels considerably, but not to zero.

As shown in the charts (see Figs. 3 and 4), the greatest threat to the population in Moscow consists of man-made hazards, and, in contrast to natural hazards, their sources are more clearly localized in the city space.

556 emergencies have occurred in Moscow during the period from 1999 to 2020, with only 6 of them natural, 11 biological-social. About 900 people died, and about 4000 suffered because of these emergencies. A significant part of man-made threats

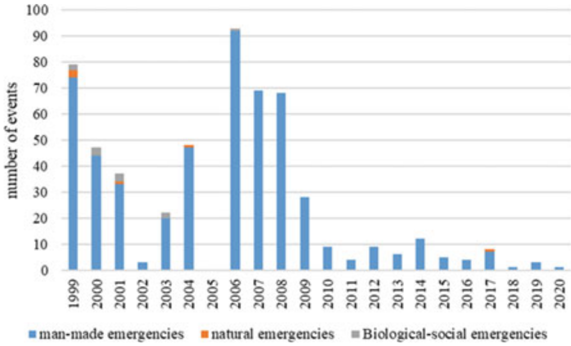

Fig. 3 The number of emergencies in Moscow, 1999–2020 (*Source* compiled by the authors based on the data of state reports "On the state of protection of the population and territories of the Russian Federation from natural and man-made emergencies" for 1999–2020)

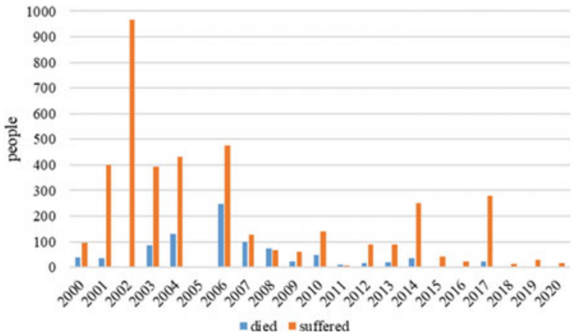

Fig. 4 The number of victims (dead and suffered) in emergencies in Moscow, 1999–2020 (*Source* compiled by the authors based on the data of state reports “On the state of protection of the population and territories of the Russian Federation from natural and man-made emergencies” for 1999–2020)

is associated with fires, collapses of buildings and structures, as well as accidents at transport facilities. The decrease in the emergency numbers in the last decade is associated with an improvement in the organization of the work of the Ministry of Emergency Situations of Russia [13], an increase in protective and preventive measures funding (the city of Moscow accounted for a third part of financial resources reserved for the emergency elimination, and 16% of all other material resources among the regions of Russia in 2020) including measurements dedicated to prevention of terrorist attacks. Terrorist attacks constituted a dramatic share in the structure of emergency situations in Moscow until 2010 and, despite the increased security levels, the likelihood of their occurrence still remains at a high level.

2.2 *Limitations of Official Statistics*

The Moscow metropolitan area is a complex dynamic system characterized by continuous population movement and shows specific daily, weekly and seasonal patterns. The complexity of the research object (settlement system) and the subject (population vulnerability to natural and man-made hazards) require new research approaches based on data with higher spatial and temporal detailization. For a long time, the most accurate source of Russian demographic statistics was the Rosstat (Russian Federal Statistics Service) data, including current registration and census population datasets).

Two main distorting factors need to be highlighted in the case of Moscow: the imperfect technology of census organization and the high dynamism of the population inside the urban agglomeration. Earlier studies have often highlighted the imperfection of census technology. As a result, the discrepancy between the official statistics and the real situation has been articulated [5]. One of the clearest examples of this discrepancy shows the systematic inconsistencies between the data of the population censuses and the current population registration: according to the population censuses of 2002 and 2010, there were significantly more residents in Moscow than it was estimated during the census dates [35].

As a result, census data overestimate the size of the largest urban centers such as Moscow, while current census data, on the contrary, underestimate it. At the same time, the scale of the existing distortions was not clear for a long time and was the subject of numerous speculations. It was often mentioned in the media sources that much more people live in Moscow and its satellite towns than is stated by official statistics. However, no representative data source was provided to test this hypothesis, although within the framework of various design works there were attempts to calculate the real numbers of Moscow population using so-called 'indirect indicators' of metro traffic, waste volumes, housing construction or food consumption, which provided only approximate results.

Moreover, there is practically no commuting data available in Russian statistics. This fact interferes any research on the mobility dynamics. At the same time, every day Moscow receives hundreds of thousands of commuters, which radically change the density of population distribution across its territory. The high population mobility levels are associated with weekday-weekend and winter-summer cycles, which also creates a specific imprint on the density indicators data.

As a result, it is impossible to present a reliable picture of population spatial distribution using methods of analysis based on official statistics. Nevertheless, these data depicting the differentiation of urban space according to the vulnerability degree is vital for correct operation of the Ministry of Emergency Situations and related organizations in terms of the rational distribution of forces and resources throughout the city. This situation would be considerably improved by application of dynamic data methods and technologies. Moreover, it is necessary the development of long-term plans for the urban spatial development of Moscow aiming to reduce potential vulnerability by a more even distribution of housing construction and creation of working places. The goal of Sendai Framework for Disaster Risk Reduction 2015–2030[7] is to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster". In our opinion, in addition to these key measures, special emphasis should be placed on measures for territorial planning.

3 Results and Discussion

The majority of the population distribution assessments across the Moscow are static and do not reflect the real dynamics of the city's population observed in the framework of labor, educational, consumer, cultural, leisure and recreational mobility. The data of mobile operators shows that density as a characteristic of the potential vulnerability of urban areas for a weekday winter day (the time period when the maximal share

[7] https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf (accessed 15 July 2021).

of people is situated at their working places) undergoes significant transformations in comparison with a weekday winter night, when most of the city's residents are staying at home.

The spatial structure of Moscow is transformed the same way within the framework of weekly-seasonal cycles. On weekends approximately 0.7–1.0 million inhabitants leave the city limits. The tendency reaches its peak during the summer periods, when the city loses up about a third part of its population (3.0–3.5 million people).

At the municipal level the magnitude and direction of inconsistencies vary widely. Depending on these characteristics, it is possible to distinguish areas in which population density is overestimated or underestimated in comparison with the official statistics (see Fig. 5).

Let us consider two of the most indicative time sections characterizing the population distribution at night and daytime hours for the winter season, when the majority of residents prefer to stay in the city.

Generally, three groups of municipalities with particular specifics of density characteristics can be distinguished in the city: 1. Highly attractive areas of the Center

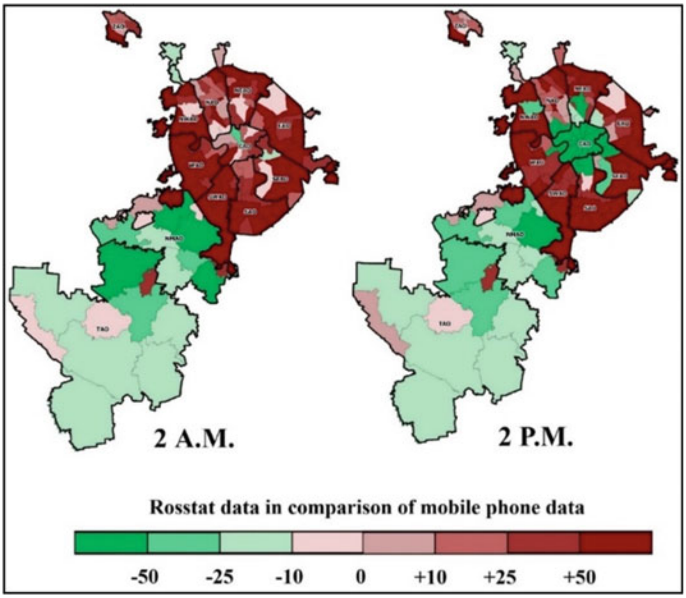

Fig. 5 Comparison of population density calculations according to data from mobile operators and Rosstat (for beginning of 2020) (*Source* compiled by the authors based on data of mobile operators)

of Moscow; 2. Peripheral areas of Old Moscow (so-called 'sleeping areas'[8]); 3. Territories of 'New Moscow'.[9]

There is a relatively high concurrence between the night population density values and the official data in the city center. However, in the daytime the population density in municipalities of Arbat, Tverskoy, Meshchansky and others usually increases by 3–4 times.

On the contrary, there is an overcounting of the number of residents living here by the official statistics in the "sleeping areas" of the city. The official statistics, in comparison with the mobile operators' data, averagely overestimates the population of the residential areas of Moscow by 10%. A significant part of the population living in these municipalities commutes to work in the city center, so far there is a significant excess of the night population over the daytime on weekdays. There are four municipalities with significant levels of underestimation of the inhabitants by Rosstat: Metrogorodok, Nekrasovka, Molzhaninovsky and Kurkino. All of them are characterized by a relatively low absolute population size, which leads to a so-called 'low-base' effect caused by active housing construction.

For the rest of Moscow municipalities, the distortion levels are constituted by the influence of several factors. Firstly, some of Moscow residents registered in their dachas and second suburban[10] houses (more than half a million owners of SIM cards registered in Moscow stay out of the city limits on a weeknight). Secondly, the situation is caused by shortcomings of the population censuses, which serve as reference points for the subsequent current registration. Finally, significant underestimations of the population density by official data are observed in New Moscow (in which the general distortion sometimes reaches 2.5 times), as well as in areas similar to it in terms of the urban spatial structure (for example, in the aforementioned districts of new development: Nekrasovka, Kurkino and Molzhaninovsky).

Therefore, we would like to stress the need to adjust some of the population estimation methods of the Russian Ministry of Emergency Situations basing of the results obtained. For example, according to the methodological recommendations of the Ministry of Emergency Situations, the regional forecasts for potential emergencies are made using the population size (each forecast is based on the size of the population and the affected population), and the need for priority supplement reserves for population are calculated. There are strict standards for providing the population with everything necessary in such cases (organization of the protection from damaging effects of a man-made accident, provision of personal protective equipment, basic supplements, standards of medical support, medicines, etc.). All these reserves are created according to the requirements of each territory. However, the calculations

[8] The 'Sleeping areas' are the zones of standardized residential buildings, which were formed mainly in the peripheral territories of the city during the 1960-1980s.

[9] 'New Moscow' is a peripheral part of the city to the southwest from the center, administratively included in the city limits in 2010. 'Old Moscow' is an unofficial name of the other parts of the city, mostly situated inside the Moscow Circle Highway (MKAD).

[10] The following tendency is often observed in Moscow metropolitan area: residents buy cheaper (including the cost of utilities) housing in the Moscow Oblast and provide their apartments in the city for rent to tenants.

take into account not the actual but the statistically registered population. Authors recommend to adjust it according to the actual population distribution, using the maximum possible population size in each area as a benchmark for calculations of reserves.

4 Conclusions

The complexity of the Moscow spatio-temporal structure and its interactions with other regions and countries predetermines constant changes in one of the most important socio-economic indicators—population density. The level of population vulnerability also changes: in a certain location, the number of potential victims dead and suffered in an emergency during one time period may be several times less than in another.

The discrepancies in the distribution density of city residents revealed in this paper make it possible to distinguish three groups of Moscow municipalities with different variations in the distortions between the official Rosstat data and the data of mobile operators. The first group—highly attractive areas of the urban center, they are characterized by a significant discrepancy with the official statistics of the daytime population. During the daytime, about 2 million residents of other parts of the urban agglomeration come to work there, which greatly increases the population density and leads to increased risks in case of a potential emergency. The second group is the peripheral areas of the city, for which the data of mobile operators show smaller numbers of night and day population than the current accounting data provides. Finally, the third group—areas of new development, especially areas of New Moscow. There is a twofold underestimation of the population by official statistics due to active housing construction. Contradicting to the cases of the first group, the night and day populations in these municipalities are comparable with each other.

According to calculations based on data of mobile operators, there are 850 thousand residents of Moscow in the immediate vicinity of potentially dangerous objects (within a radius of 1000 m) during the cold season of the year (in the summer months there are less numbers of them—600–650 thousand people). During the daytime, this number increases by one and a half times to 1.3 million people (in the summer it reaches to about 1.0 million people). Thus, about 9–12% of the city's population is regularly situated in a high-risk zone in the case of a man-made emergency. The residents of the Southern, South-Eastern and Northern Administrative Districts of the capital are in the greatest danger. There are a significant number of hazardous objects of all considered groups (explosive and fire hazardous; chemically hazardous; enterprises working with causative agents of dangerous diseases; environmentally hazardous) on their territory. This situation leads to the need of development of comprehensive specific measures to prevent potential risks. The least dangerous facilities are located in the South-West Administrative District, as well as in New Moscow. The rest of the districts are characterized by an average number of such enterprises.

In further research works related to this field, the indicated discrepancies can be used both in order to improve the methodology for vulnerability analysis of the population to potential emergencies, and in order to optimize the spatial structure of the Moscow Region in terms of risk level reduction, as well as in order to improve the quality of risk management (organization of preventive measures, measures for elimination of negative effects, etc.). The goal of Sendai Framework for Disaster Risk Reduction 2015–2030[11] is to "prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster". In our opinion, in addition to these key measures, special emphasis should be placed on measures for territorial planning. A reliable picture of the population distribution throughout the city in different time periods makes it possible to form a list of necessary measures aiming to prevent excessive concentrations of people in particular areas. Authors also see the practical possibility to adjust some methods of the Ministry of Emergency Situations basing on results obtained—recalculation of reserves needed in case of emergencies, assessment of the capacity of infrastructure facilities for population protection etc.

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