HEALTH PROMOTION

Russian subject-level index of multidimensional deprivation and its association with all-cause and infant mortality

ANASTASIA ZELENINA
Department of Epidemiology of Chronic Non-Communicable Diseases,
National Medical Research Center for Therapy and Preventive Medicine, Moscow, Russia

Keywords

Deprivation Index • Mortality • Population Census • Russia

Summary

Background. *Social and environmental inequalities in public health are recognized as global problems of our time. From the point of view of the theory of deprivation, social and environmental determinants identified as deprivation indicators, which help to detect health inequality. Indices are one of the most practical and powerful tools for measuring the level of deprivation.*
Objectives. *The aims of our study are (1) to develop a Russian derivation index to measure the levels of deprivation and (2) to analyze its associations with total and infant mortality.*
Material and methods. *Deprivation indicators were obtained from the Federal State Statistics Service of Russia. All mortality data were taken from the official website of the Federal Research Institute for Health Organization and Informatics of Ministry of Health of the Russian Federation from 2009 to 2012. Principal components analysis with varimax rotation was used to (1) select suitable deprivation indicators and (2) create the index. A Spearman's correlation was run to determine the relationship of deprivation with all-cause and infant mortality. Ordinary least squares (OLS) regression was used to assess the relationship between deprivation and infant mortality. Development of the index and statistical analysis were carried out using R and SPSS software.*
Results. *There is not a statistically significant correlation between deprivation and all-cause mortality. OLS regression showed a significant relationship between deprivation and infant mortality (p = 0.02). For every one-unit increase in the index score, infant mortality rate increases by about 20%.*

Background

The World Health Organization (WHO) definition of health are based on the same principles: "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". It follows that for the prosperous existence of a person, the external environment plays an essential role, the factors of which are defined as determinants.
According to WHO, "the social and environmental determinants of health are the full set of social and physical conditions in which people live and work, including socioeconomic, demographic, environmental and cultural factors, along with the health system" [1]. It is difficult to single out and classify all the determinants. Social determinants conditionally include the socio-economic status (SES), race and ethnicity, cultural and linguistic characteristics, housing conditions and social support. SES is reflected by education, income level, employment status and professional affiliation. Separately, it is necessary to highlight environmental determinants, which include noise levels, access to green spaces, air pollution, drinking-water quality and sanitation, weather extremes and flooding.
According to WHO, social and environmental inequalities in public health are recognized as global problems. Environmental risk factors account for 23% of all deaths in the world and 20% of the total burden of disease, measured in disability adjusted life years (DALYs). For example, risk factors such as outdoor and indoor air pollution are responsible for 25 and 26% of the total burden of stroke, respectively, and 24 and 18% of the total burden of cardiovascular diseases, the leading causes of global death. Overall, environmental risk factors account for 42% of the total burden of stroke and 35% of the total burden of coronary heart disease [2]. Cancer is the cause of about 30% of all premature deaths from noncommunicable diseases among adults aged 30-69 [3]. About 19% (12-29%) of all cancers were estimated to be attributable to the environment [4].
From the point of view of the deprivation theory, we can identify social and environmental determinants as deprivation indicators, which help to detect health inequality. The theory was developed in the second half of the XX century by the English sociologist Peter Townsend [5]. Townsend defined deprivation as "the lack of resources to sustain the diet, lifestyle, activities and amenities that an individual or group are accustomed to or that are widely encouraged or approved in the society to which they belong". Currently, the deprivation theory is a theoretical basis for assessing the impact of differences in living conditions on individual and public health.
One of the most practical and powerful tools for measuring deprivation both at the individual and

population levels are deprivation indices [6, 7]. The main advantage of using the index instead of separate indicators is the assessment of problems and mechanisms of health inequality in more depth, which would provide an opportunity to draw competent conclusions to develop and target strategies for improving public health in the future.

If we look at the problem of health inequality in Russia, in fact this phenomenon is associated with the transformation of social attitudes that Russian society underwent in the early 90s of the last century due to a change in the political paradigm in the country. In the Soviet period, there were approximately equal living and work conditions as well as access to health care therefore the obvious socio-economic inequality of society was not observed. With the country's transition to a market economy, the commercialization of all spheres of society's life began to be actively pursued, resulting in a significant gaps and inequities in the quality of life of the various population groups "stratification of society". In conditions of socio-economic stratification of society, differences began to appear in the distribution of fertility, morbidity, all-cases and infant mortality across the regions [8, 9].

The aim of our study is to develop a Russian derivation index (RDI), taking into account the peculiarities of the geographical, industrial, ecological, and socio-economic characteristics of the regions, for the analysis and quantitative assessment of the problem of social and environmental inequality in health. An analysis of its associations with total and infant mortality was carried out to evaluate predictive validity of the index [10].

Materials and methods

Data sources

Data were obtained from official statistical publications of the Federal State Statistics Service of Russia (Rosstat) and the All-Russian Census of Population for 2010. The census took place from October 14th to 25th and covered the 83 federal subjects. The federal subject is the first-order administrative level divisions in Russia. The 83 federal subjects comprise various different types of unit; these are viewed as administratively equal, though some enjoy significantly more autonomy than others: specifically there are 46 oblast', 21 republics, 9 kray,4 autonomous okrug, 2 cities of federal significance and 1 autonomous oblast'. The study of the deprivation of areas was carried out at a level of subjects of federation due to the possibility of obtaining the most complete information about the socio-economic situation and the state of the environment. All data are available on the official website of Rosstat (https://rosstat.gov.ru/).

Selection of variables

The selection of indicators was carried out in two stages. At the first stage, a total 58 indicators were selected (the full list of indicators can be obtained from the corresponding authors upon request) in accordance with the theory of deprivation and taking into account the socio-economic and environmental characteristics of the country, as well as the previous experience of constructing similar indices in other countries.

At the second stage, principal components analysis (PCA) was used to (1) select suitable deprivation indicators and (2) create the index.

Statistical analysis

PCA is subject to the same restrictions as regression, so the distributions of each variable were checked for normality [11, 12]. To evaluate normality of variables we used SPSS-generated histograms and normal Q-Q plots. If data were nonnormal, natural and 10 log transformations were applied to increase normality [13].

To eliminate the indicators the following criteria are used (1) the indicators have no significant loadings, (2) even with a significant loading, the indicators 'communality is less than 0.50, (3) the indicators have a cross-loading (more than one significant loading) [14]. A component loading of 0.40 and over is significant [15].

The factorability of the indicators was examined using Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) test. Bartlett's test of sphericity evaluates the studied data for the possibility of their compression with a significant result: the null hypothesis assumes that the variables are orthogonal, not correlated. P-value less than the significance level suggests that PCA can be performed. KMO test measures sampling adequacy for the complete model. KMO values less than 0.60 indicate the sampling is not adequate [16].

The steps taken were:

1. selection of the set of variables to be used;
2. calculation of the correlation matrix for all variables involved in the analysis;
3. extraction of factors by the method of principal components;
4. selection of a suitable number of factors using a scree test and the Kaiser rule – components with an eigenvalue greater than one;
5. varimax rotation of components to create a simplified structure.

A Spearman's rank-order correlation was run to determine the relationship between deprivation and all-cause mortality. All-cases mortality were age-standardized by the direct method. For standardization, used the standardized European population (1976).

In addition, Spearman's correlation and ordinary least squares (OLS) regression were used to assess the relationship between deprivation and infant mortality. The dependent variable is infant mortality rate and the independent variable is the index scores. Infant mortality rate is log-transformed. All mortality data were taken from the official website of Federal Research Institute for Health Organization and Informatics of Ministry of Health of the Russian Federation (CNIIOIZ) from 2009 to 2012 (https://mednet.ru/).

To carry out PCA, the SPSS Statistics Base 22.0 (IBM Corporation New Orchard Road Armonk, NY 10504) statistical software package was used. Spearman's rank correlation and OLS regression were run using the cor. test and lm functions in R. The significance level was set at 0.05.

Results

Development of the deprivation index

The final index includes 17 deprivation indicators (Tab. I). KMO coefficient = 0.79, Bartlett's test of sphericity was significant ($\chi2$ (136) = 1557.56 $p < 0.001$). Only the first three components displayed eigenvalues greater than 1, and the results of scree test suggested that only the first three components were meaningful. Therefore, only the first three components were retained for rotation. Combined, components 1, 2 and 3 accounted for 73.5% of the total variance. Deprivation indicators and factor loadings are presented in Table II. In interpreting the rotated factor pattern, an indicator was said to load on a given component if the factor loading was 0.40 or greater for that component, and was less than 0.40 for the other. Using these criteria, five indicators were found to load on the first component, which was subsequently labelled the social deprivation component. The first component explains 24.8% of the total variance and includes the following indicators: living in crowded households, children under age 5 years old, children +3, unemployment rate, and phone. Five indicators were found to load on the second component, which was subsequently labelled the economic deprivation component. The second component explains 24.6% of the total variance and includes indicators: stove heating, no hot water supply, no sewerage system, not central sewerage system, low income. Seven indicators were found to load on the third component, which was subsequently labelled the environmental deprivation component. The third component explains 24% of the total variance and includes indicators: dead forest, fire forest incidence, environmental crime, transport-related emissions, and emissions from stationary sources: NO_2, SO_2, CO. A variable with a positive loading indicates a negative association to the component.

Finally, all components are aggregated into the deprivation index according to the following equation:

$$RDI = w_1 \text{ (factor 1 score)} + w_2 \text{ (factor 2 score)} + w_3 \text{ (factor 3 score)}$$

Tab. I. Definitions of deprivation indicators.

Domain	Variable	Description	Data source
Family structure / Demographics	Children +3	Percentage of families with 3 and more children (ages 0-18)	Census 2010
	Children under 5 years old	Children ages 0-4 as a percentage of total population	Census 2010
Housing	Stove heating	Percentage of households with stove heating	Census 2010
	No hot water supply	Percentage of households without heat water supply	Census 2010
	No central sewerage system	Percentage of households with toilets emptying into a cesspit	Census 2010
	No sewerage system	Percentage of households without sewage system	Census 2010
	Overcrowded	Percentage of households (individual (single-family) houses, individual and communal apartments) with > 5 persons	Census 2010
Communication	Phone	Percentage of households with telephone	Census 2010
Income and Wealth	Low income	Percentage of people below a low income threshold in the total population	Regions of Russia. Social and Economic Indicators – 2011
	Unemployment rate	Population 15 or older unemployed	Labour and Employment in Russia – 2011
Air quality	NO_2	Nitrogen dioxide (thousand tons) from stationary sources	Environment Protection in Russia – 2012
	SO_2	Sulphur dioxide (thousand tons) from stationary sources	Environment Protection in Russia – 2012
	CO	Carbon monoxide (thousand tons) from stationary sources	Environment Protection in Russia – 2012
	Transport-related emissions	Air emissions from vehicle (thousand tons)	Environment Protection in Russia – 2012
Natural disaster	Fire forest incidence	The number of fire forest incidence (unit)	Environment Protection in Russia – 2012
Green space	Area of dead forest	The area of dead forest (hectares)	Environment Protection in Russia – 2012
Crimes	Environmental crimes	The number of recorded environmental crimes	Environment Protection in Russia – 2012

Tab. II. Component loadings and communalities based on a principal components analysis with varimax rotation for 17 variables.

Variables	Component			Communality
	Social deprivation	Economic deprivation	Environmental deprivation	
Children +3*	**0.910**	0.176	-0.261	0.928
Children under 5 years old*	**0.821**	0.344	-0.053	0.796
Unemployment rate**	**0.698**	0.243	-0.272	0.620
Phone*	**-0.826**	-0.186	0.198	0.756
Overcrowded	**0.888**	0.007	-0.347	0.908
Stove heating	0.295	**0.798**	0.097	0.732
No hot water supply	0.299	**0.906**	-0.006	0.910
No sewerage system	0.237	**0.926**	0.008	0.913
No central sewerage system	0.387	**0.836**	-0.117	0.862
Low income	-0.165	**0.665**	-0.217	0.517
Area of dead forest*	-0.299	0.328	**0.556**	0.506
Fire forest incidence*	-0.263	0.294	**0.699**	0.644
Emissions from stationary sources:				
NO_2*	-0.221	-0.299	**0.863**	0.883
SO_2*	-0.121	-0.099	**0.774**	0.624
CO*	-0.073	-0.180	**0.843**	0.749
Transport-related emissions*	-0.107	-0.343	**0.629**	0.524
Environmental crimes*	-0.334	0.218	**0.686**	0.629

Extraction method: Principal component analysis; Rotation method: Varimax with Kaiser normalization. Loadings larger than .40 are in bold.
* Natural log transformation: new variable = ln (1+old variable). ** Log 10 transformation: new variable = log10 (old variable).

Where w_k - weight which is calculated by dividing the percent of variance accounted for by k_{th} - principal component by the cumulative percentage of variance accounted for by all preceding principal components whose eigenvalues are 1 or greater; factor *j* score - regression factor score that is the actual value for each region on the underlying components in a particular row of data.

RDI scores were calculated for the 83 federal subjects. Moreover, the scores were divided into four quantiles (1Q, 0% -25%; 2Q, 25% -50%; 3Q, 50% -75%; 4Q, 75% -100%), where the first quantile (1Q) is the least deprived area and the fourth quantile (4Q) is the most deprived area (Tab. III). The distribution of RDI scores is shown in Figure 1.

Validation of the deprivation index

There was a positive correlation between deprivation and infant mortality, which was statistically significant ($r_s = 0.31$, $p = 0.003$). Regression model confirmed a significant relationship between deprivation and infant mortality ($p = 0.02$). For every one-unit increase in the value of the index, infant mortality rate increases by about 20%. The R^2 value was 0.108 thus 11% of the variation in infant mortality can be explained by the model containing only deprivation.

There is not a statistically significant correlation between deprivation and the age-standardized mortality rates (both sex, females and males) (Tab. IV).

Discussion

When selecting indicators for the index, economic, environmental and social issues were taken into account. The index includes socio-economic and environmental indicators due to the fact that a complex two-stage method base on conceptual (theory about deprivation) and empirical (previous experience with indicators, used PCA) approaches was used.

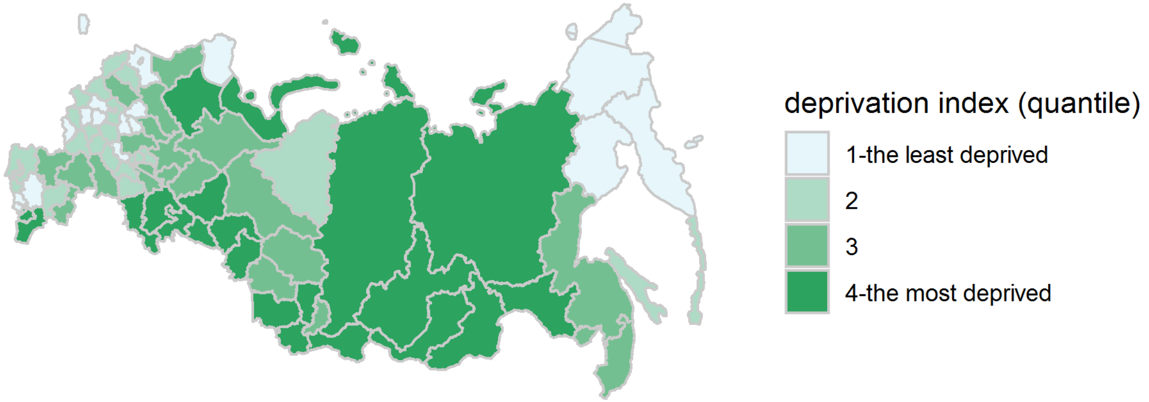
Russia is the largest country in the world, covering over 17,125,191 square kilometres. The largest federal subject of Russia is the Republic of Sakha (Yakutia),

Tab. III. Mean index score by quantile.

Quantile	Number of federal subjects	Mean	SD	95% CI
1 – the least deprived	20	-0.687	0.268	(-0.813, -0.562) (-0.262, -0.176) (0.042, 0.170) (0.616, 0.921)
2	21	-0.219	0.094	
3	21	0.106	0.140	
4 – the most deprived	21	0.768	0.335	

SD: standard deviation; CI, confidence interval.

Fig. 1. Region-level deprivation across Russia.



Tab. IV. Spearman's rank correlation between deprivation and the age-standardized mortality rate.

Variable	r_s	P - value
Total population	0.15	0.164
Females	0.21	0.051
Males	0.08	0.462

with a total area of 3,083,523 km^2 and a population of 958,528 people; the smallest federal subject is St. Petersburg with an area of 1,403 km^2 and a population of 4,879,566 people. Our study showed that generally the most deprived regions are industrial with poor ecological conditions [17] such as Chelyabinsk, Kurgan, Sverdlovsk, Tyumen, Omsk Oblasts, and Sakha and located in Ural and the Western Siberia. Less deprived regions such as Voronezh, Ivanovo, Yaroslavl, Moscow Oblasts, and Moscow located in European part of Russia. Our study, unlike other similar ones [18, 19], was carried out at large area level because of the full dataset of the census and other indicators is publicly available only at a level of subjects of federation (the largest territorial-administrative unit of the country).

In our study, there is no the relationship between deprivation and overall mortality, unlike other similar studies that used indices to measure deprivation. Choi et al. [20] estimated an association between the most deprived population and all-cause mortality. The study found that all-cause mortality increased by 23% (RR: 1.23, 95% CI 1.16 to 1.30) in the most deprived population compared to the least deprived one. Deprivation was determined using the index that consists of no house ownership, no passenger car, poor house environment, single household, low level of education, male unemployment, divorced or separated, elderly people, female-headed variables. McCartney et al. [21] estimated the association between all-cause mortality and deprivation between four time periods (1981-1983, 1990-1993, 2000-2002, 2010-2012). Deprivation was determined using the Carstairs index, which consists of four indicators: male unemployment, overcrowding, low social class, and lack of car ownership. The study found that the mortality ratios among the population of England, Wales and Scotland aged 35-79 years were higher in more deprived areas without significant gender differences. Kraftman et al. [22] assessed the dependence of the all-cause mortality on deprivation in 2003 and 2017. In 2003, the mortality from all causes among adult increased by 1.4 times in the more deprived area, and in 2017 the mortality increased by 1.6 times. Simultaneously, all-cause mortality among women living in the most deprived areas was 1.3 times higher in 2003 and increased 1.5 times by 2017. To determine deprivation level, the Index of Multiple Deprivation 2015 (IMD) was used, including domains related to income, employment, education, crime, environmental and housing conditions as well as living environment. Pearce et al. [23] created an environmental deprivation index consisting of the following indicators: air pollution, average UV radiation, green space, average annual ambient temperature, and established a positive association of all-cause mortality (Incidence Rate Ratio (IRR) = 1.14) with the most deprived area.

In our study along with other similar studies, deprivation is significant associated with infant mortality. However, unlike our study, they generally used indices that formed only from socio-economic indicators. Yun et al. [24] developed a deprivation index that includes the following indicators: unemployment rate, low social class, lack of car ownership, overcrowded housing, married status, family structure, and low education level. Furthermore, they established that the risk of infant mortality increased by 26% (Hazard Ratio (HR):1.261, 95% CI 1.199 to 1.326) among the most deprived population compared to the least deprived one. Padilla et al. [25] also analyzed the association between infant mortality and deprivation between two time periods (2002-2005 and 2006-2009). The study showed that infant mortality was higher in more deprived census tracts than in less deprived ones. The deprivation index included five domains: family structure, immigration status and mobility, occupation and income, education and housing conditions. Guildea et al. [26] established that risk of infant death increased by 53% (RR: 1.53, 95% CI 1.35 to 1.74) in the most deprived areas compared to the least deprived ones. To measure deprivation level, they used Townsend index that included unemployment rate, car ownership, owner occupation, and overcrowding variables.

Similarly, socioeconomic inequality in health outcomes have been observed around the world. Pathirana et al. [27] conducted a systematic review and found that low level of education was associated with a 64% increased odds of multimorbidity (summary Odd Ratio (OR): 1.64, 95% CI 1.41 to 1.91). Another systematic review [28] investigated the relationship between stroke survival and socio-economic inequality in China. It was found that both low level of education (a pooled Relative Risk (RR): 3.07, 95% CI 1.27 to 7.45) and low per capita income (the pooled RR: 1.58, 95% CI 1.50 to 1.65), as well as rural status (the pooling RR: 1.47, 95% CI 1.37 to 1.58) increase the risk of death from stroke. Kim et al. [29] reviewed studies which analyzing the relationship between income and obesity. The result of the meta-analysis demonstrated that lower income is associated with obesity (OR: 1.27, 95% CI 1.10 to 1.47; RR: 1.52, 95% CI 1.08 to 2.13).

Cohort studies conducted in Asia and Australasia [30] showed that low level of education increased the risk of mortality from all causes by 56% (HR: 1.56, 95% CI 1.38 to 1.76) in Asia and by 14% in Australasia (HR 1.14, 95% CI 1.05 to 1.23). Furthermore, low level of education increased the risk of mortality from cardiovascular diseases by 78% (HR: 1.78, 95% CI 1.42 to 2.23) in Asia and by 20% (HR: 1.20, 95% CI 1.04 to 1.38) in Australasia as well as increased the risk of mortality from cancer by 39 % (HR: 1.39, 95% CI 1.15 to 1.69) in Asia.

Only few studies have analyzed the relationship between deprivation and infant mortality using indices formed from environmental indicators. For instance, Genowska et al. [31] created index, which consists of total particle pollution, sulfur dioxide, nitrogen oxides, industrial waste, and untreated industrial waste water variables and found that an increase in index of 1 SD was related to an increase in the expected infant mortality rate of 16 (95 % CI 2 to 30) per 100,000 live births.

Strengths and limitations

Strengths of the study is firstly using deprivation indicators from open access datasets that makes the data aggregation transparent. Moreover, it allows researchers to trace the entire process of transform primary indicators and to restore the original data. Secondly, the index includes both socio-economic and environmental characteristics that allow analyzing the multifaceted nature of factors influence on health. Furthermore, our methodology of development of the index allows including many more different variables (not only socio-economic ones as in many indices) and avoiding overloading indicator systems. Limitations to the study should be noted. Our study did not take into account possible confounders that could affect the results [32]. For instance, when studying the relationship of deprivation with overall mortality, there are not individual – level information on age, behavioral risk factors (alcohol, smoking use, physical activity), and when studying the relationship with infant mortality, there are not information on infant sex and gestational age as well as maternal age, behavioral characteristics and morbidity. Nakaya et al. [33] applied two regression models to estimate the relationship all-cause mortality with deprivation. First model adjusted by age, sex, and public health centre district and showed that the most deprived neighborhoods have 1.144 times higher (95% CI 0.987 to 1.326) HR for all-cause mortality compared with the least deprived ones. Second model adjusted by age, sex, public health centre district, histories of diabetes and hypertension, and body mass index and demonstrated that the most deprived neighborhoods have about 1.160 (95% CI 1.001 to 1.344) times higher HR for all-cause mortality compared with the least deprived ones. Calling et al. [34] analyzed the relationship between deprivation and mortality of the preterm infant. The index included low education, low income, unemployment rate, and social benefits. Two logistic models were used: (1) adjusted for maternal age and (2) adjusted for infant sex, gestational age, small for gestational age, maternal age and maternal marital status. First model showed that OR for mortality in preterm infants born in the most deprived neighborhoods was 1.33 (95% CI 1.12 to 1.58) times higher compared to preterm infants born in the least deprived ones. Second model showed that there is not statistically significant result when comparing the most deprived areas with the least deprived ones (OR: 0.99, 95% CI 0.82 to 1.20).

Conclusion

The study assessed the relationship the level of deprivation with all-cause and infant mortality and showed that there is a statistically significant relationship between deprivation and infant mortality, whereas there is not a link with all-cases mortality.

RDI require further study. We will continue to analyze the relationship of deprivation with health behaviors and outcomes. Evidence will be obtained from the Epidemiology of Cardiovascular Risk Factors and Diseases in Regions of the Russian Federation study (ESSE-RF) [35]. ESSE-RF is a large cross-sectional multicenter population-based study conducted in 2012-2014, covering 13 federal subjects of Russia, differing in climatic, geographic, economic, and demographic characteristics. Data were obtained from questionnaires administered face-to-face, by a brief physical examination, and fasting venous blood samples. Dataset of ESSE-RF study will be used to increase opportunities for high-quality research and analysis of the impact of deprivation on health in Russia, taking into account possible confounders. Also, in the future, it seems necessary to create an index using the methodology from this study to measure the level of deprivation at a small area level.

Overall, we sought to create an easy-to-calculate and interpret index, which implies its use both in the practical activities of public health specialists and policymakers. As far as we are aware, this is the first deprivation index characterizes the level of physical environmental and socio-economic deprivation of Russian regions. Moreover, it makes it possible to carry out comparative regional assessments of inequality in relation to population health. The research findings demonstrate the need for further study of the impact of deprivation on health both at the population and individual level in order to a more in-depth study of the mechanisms of the development of the social gradient of health.

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Conflict of interest statement

The authors declare no conflict of interest.

Authors' contributions

All authors discussed the results and contributed to the final manuscript.

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Correspondence: Anastasia Zelenina, Department of Epidemiology of Chronic Non-Communicable Diseases, National Medical Research Center for Therapy and Preventive Medicine, 10, Petroverigskiy per., Moscow 101990, Russia. E-mail: nasty-zelenin@yandex.ru

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