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VISUALIZATION OF PUBLIC HEALTH DYNAMICS

ABSTRACT. Public health dynamics is one of the main methodological approaches to study spatiotemporal patterns of the population diseases spreading and to create nosogeographic maps. It is one of validity terms of geographic public health assessment and forecast. Dynamics maps usually show emergence, development, past stages, changes, and movement of analyzed phenomena. Analysis of medical-geographic maps showed that the choice of methods and techniques for elaborating dynamic aspects is limited. The results of comprehensive medical-geographic atlas mapping obtained in the Department of Biogeography and Laboratory of Integrated Mapping (Faculty of Geography, M.V. Lomonosov Moscow State University, Russia) have significantly improved this situation and demonstrated the benefits of cartographic approaches and graphic methods of visualization of public health dynamics. However, these benefits as an integral problem has not been fully realized yet and research in this direction should continue.

KEY WORDS: graphic presentation of dynamics, methods, techniques

CITATION: Tatyana V. Kotova, Svetlana M. Malkhazova, Vladimir S. Tikunov, Temenoujka Bandrova (2017) Visualization of Public health dinamics. Geography, Environment, Sustainability, Vol.10, No 4, p. 27-42
DOI-10.24057/2071-9388-2017-10-4-27-42

INTRODUCTION

The core of medical-geographic research is the study of diseases spatiotemporal patterns, their accurate cartographic presentation (nosogeographic maps), and analysis for development of public health protection measures (Malkhazova 2012). Assessment of morbidity dynamics is one of the important methodological requirements of such cartographic models and one the validity terms of medical-geographic assessment of morbidity and forecast. Maps on dynamics usually show emergence, development, past stages, and spatiotemporal changes of analyzed phenomena (the state borders shown on the years of compiling relevant maps). Their content depends on the purpose and the detail of research, as well as on character (quality) of the original information base – the duration and completeness of the time series, the comparability of the available data, the availability of spatial referencing, etc.

It is clear that dynamics is best visualized primarily through animations and multimedia technology; however, this paper focuses on the potential of non-animated maps. Analysis of published nosogeographic maps compiled as individual products or as part of integrated or sectoral medical-geographic atlases showed that the methods of dynamics presentation are somewhat limited. The methods include mainly graphs and charts that complement the essentially static maps. The purpose of the paper presented herein is to broaden the dynamic aspect of cartographic methods in research and mapping of public health issues. The paper presents the results obtained in the course of compilation of integrated medical-geographic atlases in the Department of Biogeography and Laboratory of Integrated Mapping (Faculty of Geography, Lomonosov Moscow State University).

MATERIALS

The material includes previously published medical-geographic products (Malkhazova et al. 2011), interdisciplinary theoretical works in the field of thematic cartography, and mathematical-cartographic modeling (Tikunov 1997a; Tikunov 1997b; Prokhorov and Tikunov 2001), as well as a number of medical-demographic and medical-geographic maps and atlases developed by the authors and other researchers (Malkhazova 2007a; Malkhazova 2007b; Vatlina 2012; Malkhazova 2012; Malkhazova et al. 2014), created in the Department of Biogeography. Analysis of cartographic publications showed that the sources of background information for the maps on dynamics vary depending on the territorial level (local, regional, national, and global) and include field studies, literature, and statistical data. Statistical sources best meet the requirements for the initial information because they are readily available, comparable, and collected using standardized methods. They also contain reference for administrative units at different spatial levels and cover long periods, thus allowing selecting time-intervals for analysis with consideration of specific natural and socio-economic changes. In some cases, at the global and national level mapping, literature and statistics represent the only acceptable sources of information.

The work on a medical-geographic atlas of Russia "Natural focal diseases" has clearly shown the need to strengthen the dynamic component, to create experimental cartographic models, and to conduct their subsequent analysis and assessment of the cognitive potential and feasibility of the use in medical-geographic studies. The data on public health for the world and the Russian regions are comprehensively provided on the website of the World Data Centre for Geography (icsu-wds.ru).

TYPES OF MAPS ON DYNAMICS

Visualization of medical-geographic data is based on the traditional nosogeographic methods; modern virtual-reality images, cartographic animation images, non-Euclidean matrix images, and multimedia technique have also been incorporated recently (Kapralov et al. 2010). However, analysis of nosogeographic maps created as individual products or as part of integrated or sectoral medical-geographic atlases has shown that the choice of methods of dynamics rendering is very limited. The most widely used methods are graphs and diagrams supplementing statistical, in essence, maps.

A simple, intuitive, and widely used method that does not require detailed explanations is *comparison of multi-temporal maps*. The maps on public health dynamics represent the most vivid example. Thus, maps that show public health of the Russian regions in comparison with other countries for 1990-2013 are the examples of assessment maps of public health dynamics (Tikunov and Chereshnya 2016). Today, health is an indicator of progress and social and economic development. Various methods for measuring public health exist. Public health demonstrates various trends that are described well by an integral index – the Public Health Index (PHI) – which we have proposed and used; this index integrates the objective indicators of public health: infant mortality rate and life expectancy at birth for men and women. We consider these are the most important indicators of public health (Prokhorov and Tikunov 2001), and this notion has been validated by subsequent research. These indicators have several important advantages: the data for almost all countries are available, they do not require expert assessment, and they are reliable. We have calculated PHI for Russia, which allowed us to obtain the national dynamics of public health over a 24 year period Å| from the end of the Soviet regime and the beginning of the transition to a new model of socio-economic development (1992) until the end of 2013. This index clearly illustrates changes in public health. Therefore, for the calculations we used an array of data for 266 countries and regions of Russia, considered as a single 24 year-long data set, 6384 territorial units in total with the abovementioned three parameters. The initial data can be found as file INITDATA on the website of the World Data Centre for Geography (icsu-wds.ru).

For the calculation, we used the evaluative algorithm developed earlier (Tikunov 1985; Tikunov 1997a; Tikunov 1997b). It includes normalization of the initial indicators by the formula:

$$\hat{X}_{ij} = \frac{\left| x_{ij} - \overset{0}{x}_j \right|}{\left| \max/\min^{x - \overset{0}{x}_j} \right|}$$

i=1, 2, 3,…, n; j=1, 2, 3,…, m

where $\overset{o}{x}$ is the worst value (for each indicator, in terms of their impact on the health of the population in the countries and regions of Russia [the maximum infant mortality rate, lowest life expectancy]; these values can be found on the website in file X0)$_{max/\overset{o}{min}}x$; are the values most different from the $\overset{o}{x}$ values of parameters; n is the number of territorial units (6384 for the entire period); *m* is the number of indicators used for the calculations.

Ranking is carried out by comparing all territorial units on a conditional basis, characterized by the values of $\overset{o}{x}$. If there are reasonable "weights" for each indicator (for example, 0,5 for life expectancy for men and women and 1 for infant mortality), they also can be included in the formula of normalization, but in our calculations "weights" were the same.

If the normalized values $\hat{x}_{ij}$ are considered as reduced to the comparable form to obtain PHI, they can be simply summed.

$$\hat{S}_i = \sum_{j=1}^{m} \frac{\left| x_{ij} - \overset{0}{x}_j \right|}{\left| \max/\min^{x - \overset{0}{x}_j} \right|}$$

The obtained values $\hat{S}$ characterize the estimated position of the countries and regions of Russia and are presented on the website under the name RAN1MRE as a simplified version of the calculations.

The algorithm can be more strict despite the fact that ranking is carried out by comparing all territorial units on a conditional basis, characterized by the values of $\overset{o}{x}$. However, in this case, it is done using the Euclidean distance as a measure of proximity of all territorial units to the conditional basis (the worst-case values $\overset{o}{x}$ throughout a range of indicators). Then, we processed the array using principal component analysis for the purpose of orthogonalization and a “convolution” system of indicators. The algorithm with various modifications is described in (Tikunov 1997a; Tikunov 1997b). The results of the calculations can be found on the website under the name RAN2MRE and are also presented in Fig. 1 (a and b), Fig. 2, and Fig. 3.

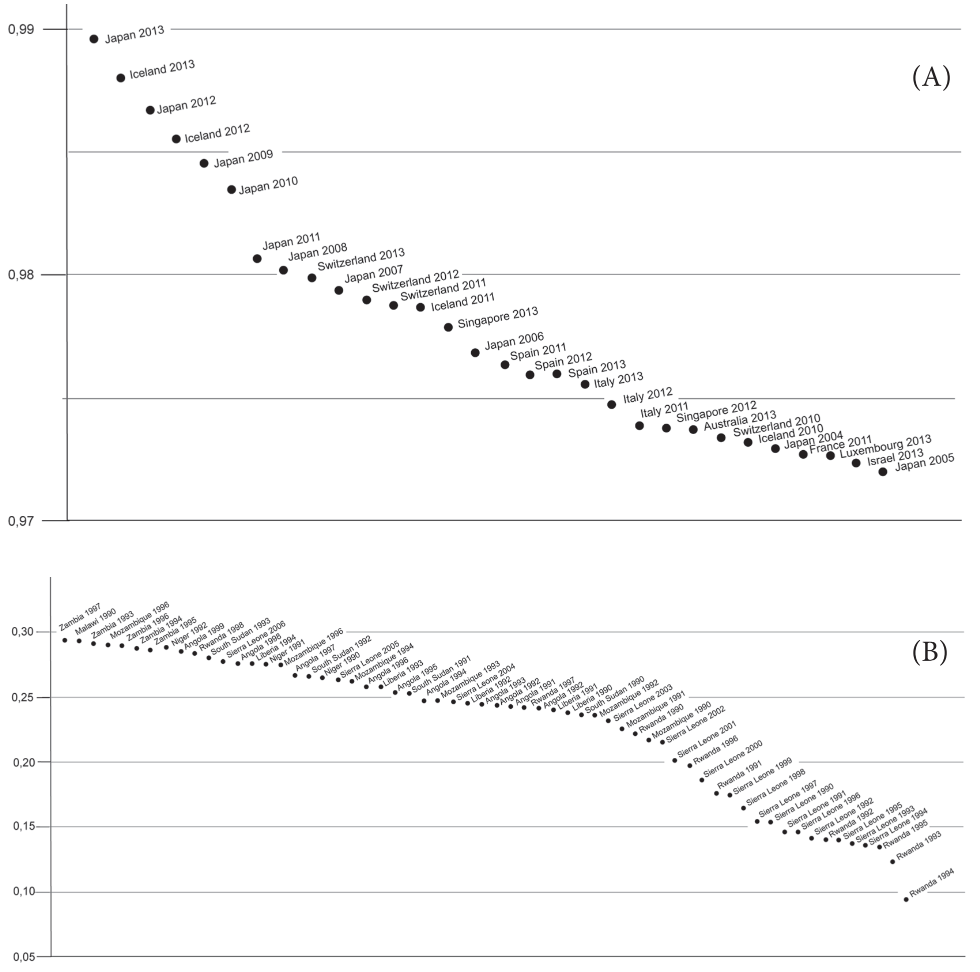

Fig. 1 a,b. Fragments of the calculation results (the upper and lowest parts of the PHI ranked series)

According to our calculations, there are no significant differences between the simplified and complete algorithms, which, among other things, have leveled out in the resulting maps with the step scale. Thus, Table 1 shows fragments of the calculation results (using the simplified algorithm) related to the upper and lowest parts of the PHI ranked series.

The PHI graphs for some countries and groups of Russian regions are presented in Fig. 3. Fig. 4 and Fig. 5 show the maps for selected years.

Fig. 2 shows a graph of PHI for the world, the European Union, and selected countries. As can be seen from the graph, growth of the index is a worldwide trend. The rate of growth is much higher in developing countries. Russia stands out among the general trend. Events of the 1990s have affected the level of public health and sustainable growth was observed only since 2001. Detailed changes in the level of public health of the Russian Federation are shown in Fig. 3.

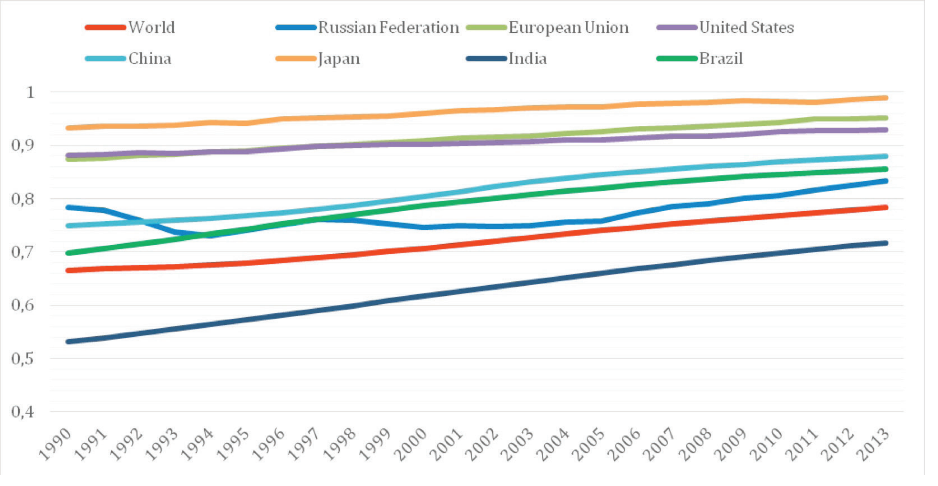

Fig. 2. PHI in selected countries

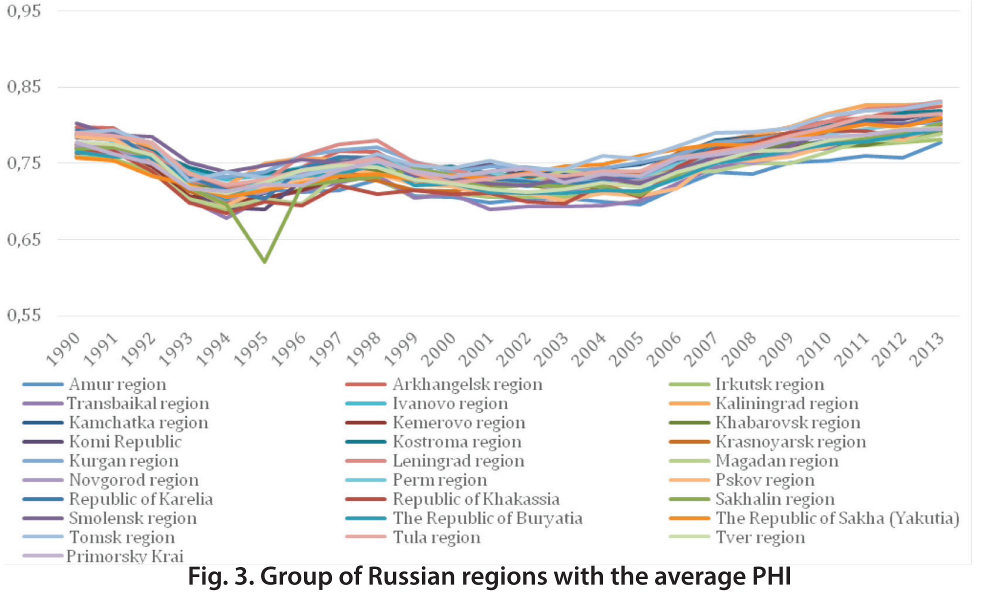

Fig. 3. Group of Russian regions with the average PHI

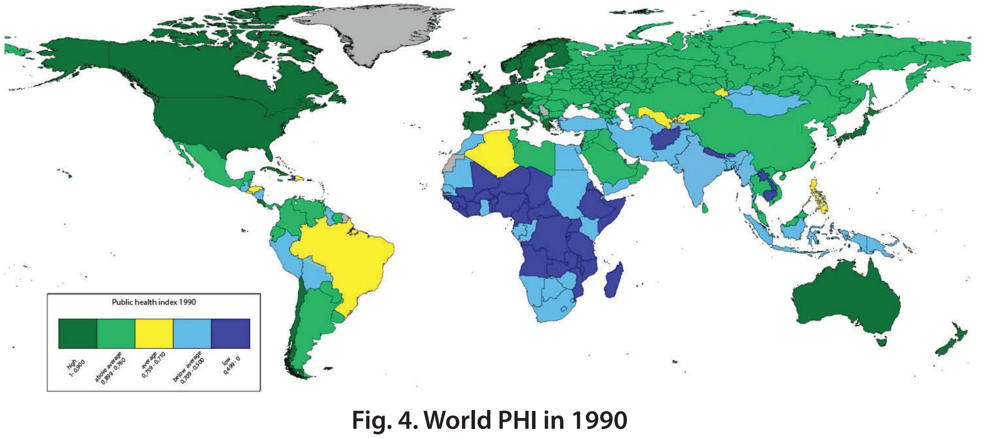

Fig. 4. World PHI in 1990

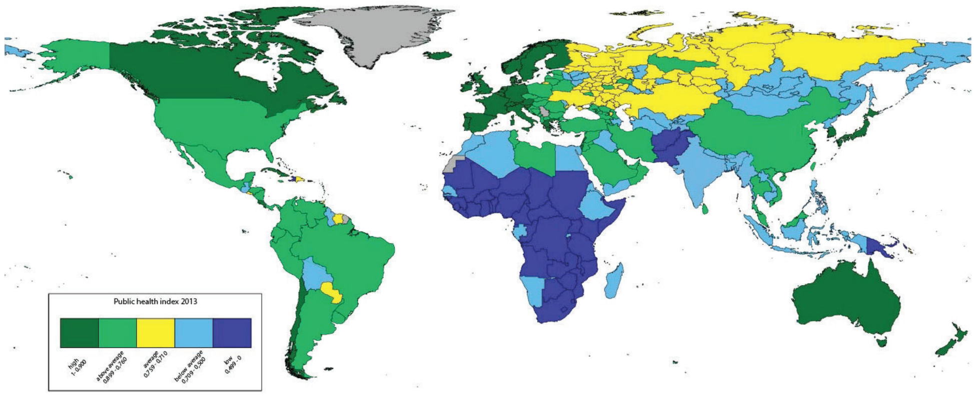

Fig. 5. World PHI in 1990

Fig. 4 and Fig. 5 illustrate spatial changes in PHI. Regions of the world that do not follow the worldwide trend of sustainable growth of public health include the former Soviet republics, and African countries. More detailed analysis of PHI is provided in other work of the authors (Tikunov and Chereshnya 2015; Tikunov and Chereshnya 2016).

Examples of maps that are directly related to morbidity dynamics based on the same method of graphic visualization are maps "Diseases of the nervous system," from "Medical-demographic atlas of the Kaliningrad Region," scales 1: 2 400 000 and 1: 600 000, which reflect the situation for 1990 and 2005, respectively (Malkhazova 2007a). These maps show the number of registered cases per 1000 adults using the cartogram method (based on the administrative territorial units). Map-users arrive at conclusions through visual comparison of the maps. This method is disease-specific and utilizes integrated indices (for individual groups of pathology classes) for different dates. Temporal reference represents an important descriptive indicator linking thematic attributes with a certain temporal span.

Superposition of multi-temporal images, similarly to the previous method, is a quite simple and clear method; however, it requires a greater effort in the selection of graphic techniques used to achieve clarity. It is especially widely used in cases where it is necessary to trace infectious diseases that, as a rule, actively emerge and spread. Fig. 6 reflects dynamics of expansion of nosologic area of West Nile fever in the territory of the Russian Federation over 15 years, a dangerous disease, previously not relevant to this area.

The dynamics of the Crimean hemorrhagic fever and plague are shown in a similar way in "Environmental atlas of the Rostov Region" (Zakrutkin and Rishkov 2000). Maps "Crimean hemorrhagic fever" and "Plague" reflect morbidity of these diseases in 1912-1938, 1963-1971, and 2000.

Fig. 7 shows maps related to the health care on the territory of Bulgaria. The first map depicts the spatial dynamics of the number of hospital beds per 1,000 people. The choropleth maps method enables the user to get an idea of the phenomena distributed on a regional territories. In addition, a chart showing the average number of beds and patients in one hospital for 3 selected years 1998, 2000 and 2003 is also provided. The impression is given of the time dynamics of the depicted phenomenon. The second map of analogous representation methods shows spatial and temporal dynamics of the phenomenon depicted: the number of patients per doctor by choropleth map and the number of patients per doctor, nurse and dentist for the three comparative years.

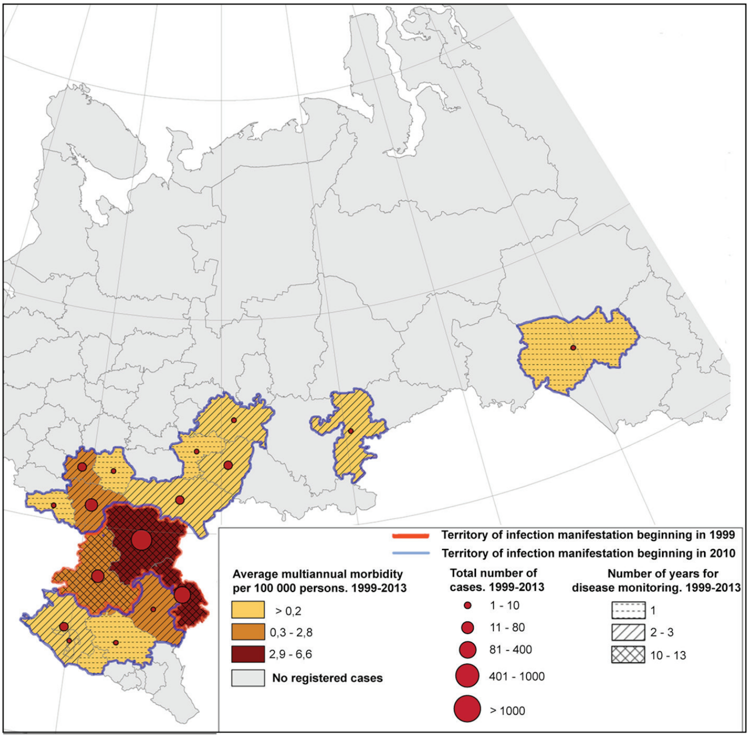

Fig. 6. Map "Morbidity by West Nile fever." 1999-2013. Scale 1: 25 000 000

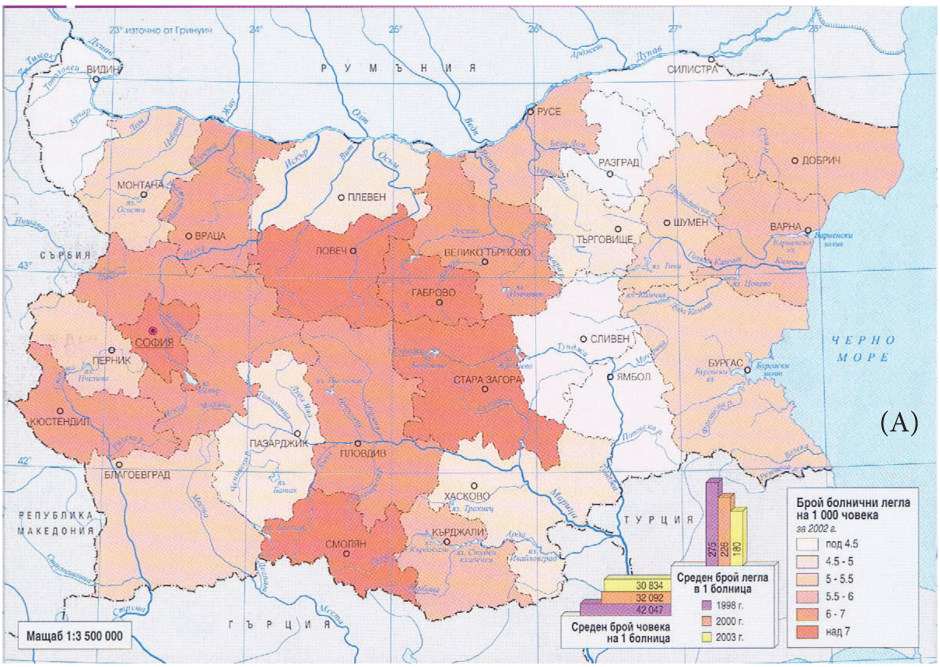

Fig. 7. Maps healthcare: a — hospital beds; b — doctors. Scale 1: 3 500 000 (Bandrova 2008)

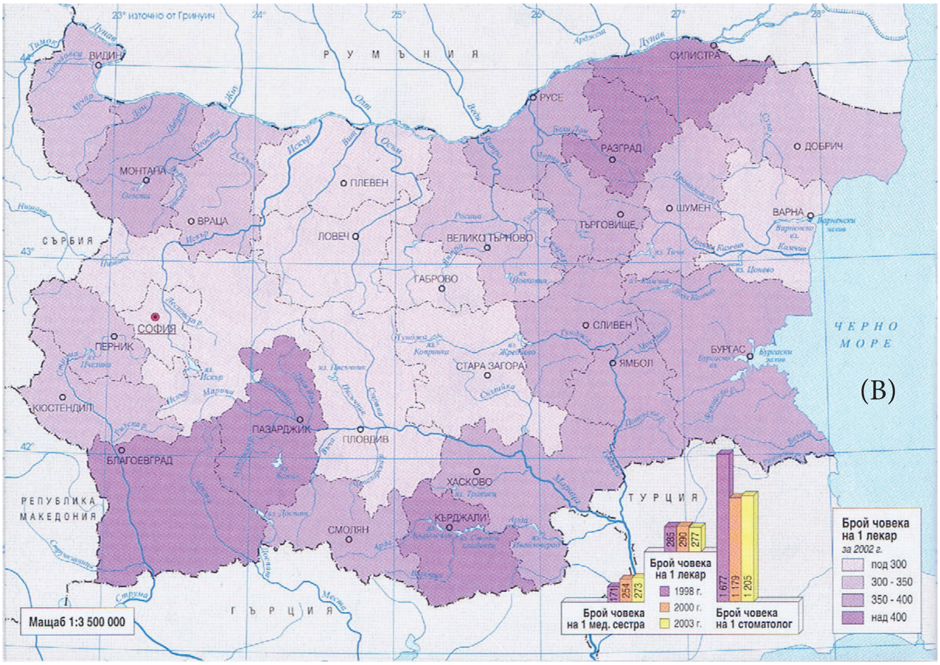

Fig. 7. Maps healthcare: a — hospital beds; b — doctors. Scale 1: 3 500 000 (Bandrova 2008)

Both cases show the possibilities of 2D maps to represent spatial and temporal dynamics of the phenomena.

Integration of indicators and characteristics is a quite simple, but a very informative method, which gives a comprehensive temporal description of nosogeographic territorial units.

Map "Nosologic profiles,"
scale: 1:20 000 000, was prepared for a medical-geographic atlas of Russia "Natural focal diseases" (Kotova et al. 2012). The overall picture of the natural focal diseases registered on the territory of the subjects of the Russian Federation over 11 years (Fig. 8) is represented by a matrix: the records contain information on the cases of natural focal diseases and the fields show the years when the cases were registered (1996–2006). Though the map does not contain quantitative data, it is still very informative. It reflects the annual change of the spectrum of natural focal diseases observed in the territory of the subjects of the Russian Federation and is very meaningful for analysis of the distribution of different groups and classes of diseases by various years and at the level of the subjects of the Russian Federation and for the country as a whole.

Combination of various indicators on a single map can be quite productive, which renders the manifestation of the multidimensional nature of phenomena dynamics. For example, map "Tuberculosis morbidity and mortality of the population" in "Medical-environmental atlas of the Moscow Region," (Semenov 2004) shows cases per 100 000 persons, which is another presentation of one more aspect of characteristics of dynamics.

Numerous parameters of dynamics statistical analysis, rather adequately described in the literature (Tikunov 1997a; Tikunov 1997b; Chistobaev and Semenova 2013), can be used for morbidity mapping. Traditional medical-geographic mapping uses the most important parameters that reflect patterns of various levels and relationships with other factors.

Fig. 8. Fragments of map "Nosologic profiles" and legend. Scale 1: 20 000 000

Typically, the visualization of the results of data dynamics statistical analysis is performed using statistical rendering methods, i.e., cartograms and cartodiagrams. Fig. 9 presents a map of variation in the number of cases relative to the multiannual average value. Linear diagrams for the subjects of the Russian Federation reflect positive and negative deviation about the multiannual average.

One of the objectives of such statistical research is to identify the main trends, which is important for compilation of forecast maps. The identified trends may be supplemented by either quantitative indicators or by only a verbal description. Maps "Trends in general morbidity of the population in 1997-2011," "Trends of adult morbidity in 1997-2010," and "Forecast of the general morbidity of the population," with characteristics of the average rate of increase (decrease) of the number of cases in % by cities and districts, in "Medical-demographic atlas of the Republic of Dagestan" (2013) represent examples of the first type. Examples of the second type include the maps in "Medical-demographic atlas of the Smolensk Region." Maps "Dynamics of adult morbidity" show two trends – decline and growth of morbidity in 1999 – 2007 by districts.

Maps on *morbidity dynamics typology* were developed with the help of mathematical-cartographic modeling techniques (Tikunov 1997a; Tikunov 1997b). The main criterion for the typology model is the uniformity of territorial units, broken into groups (taxa) derived from a set of initial features-indicators that characterize the disease for the selected time period. This method assumes normalization, linearization, and orthogonalization of time series and their subsequent classification. Since the average multiannual relative morbidity incidences for each territorial unit differ, their time series are normalized for comparison of the levels of morbidity variability. In this case, specific values of the time series for each subject of the Russian Federation were divided by their arithmetic mean values calculated with these series.

The legends were based on the arithmetic mean values of the relative morbidity for each year calculated within each taxon and shown as charts. Such charts of average morbidity level out individual fluctuations in the dynamic series and characterize patterns of morbidity variability for the entire monotypic groups of the subjects of the Russian Federation. The advantage of these maps is the ability to explore the patterns of variation of incidence by grouping the territorial units (the subjects of the Russian Federation) in the taxa with similar rhythms of morbidity fluctuations. This typology reveals territorial patterns of dynamics and explores not the individual series but their groups that are less subjected to random fluctuations. Based on the analysis of relative morbidity for 1997-2010, typological classification of disease dynamics and identification of the key spatial and temporal patterns in the distribution of this parameter for diseases relevant to the territory of the Russian Federation (tick-borne encephalitis, tick-borne borreliosis, hemorrhagic fever with renal syndrome, diphyllobothriases, opisthorchiasis) was conducted.

A map on morbidity dynamics for tick-borne encephalitis serves as an example of the final result (Fig. 10). It includes five taxa that can be broken conditionally (based on the calculated index and the semantic analysis of the results) into three types and five subtypes, respectively. The first type includes two taxa (I and II) with a clear decrease in the incidence over the observed period; the second type (IV taxon) exhibits a general downward trend but with significant variations in morbidity; and the third type (III and V taxa) approaches the form of a plateau with very small differences from year to year. Each subtype is characterized by specific morbidity dynamics and they are arranged by the degree of growth of this parameter. The charts serve as the legend of this map.

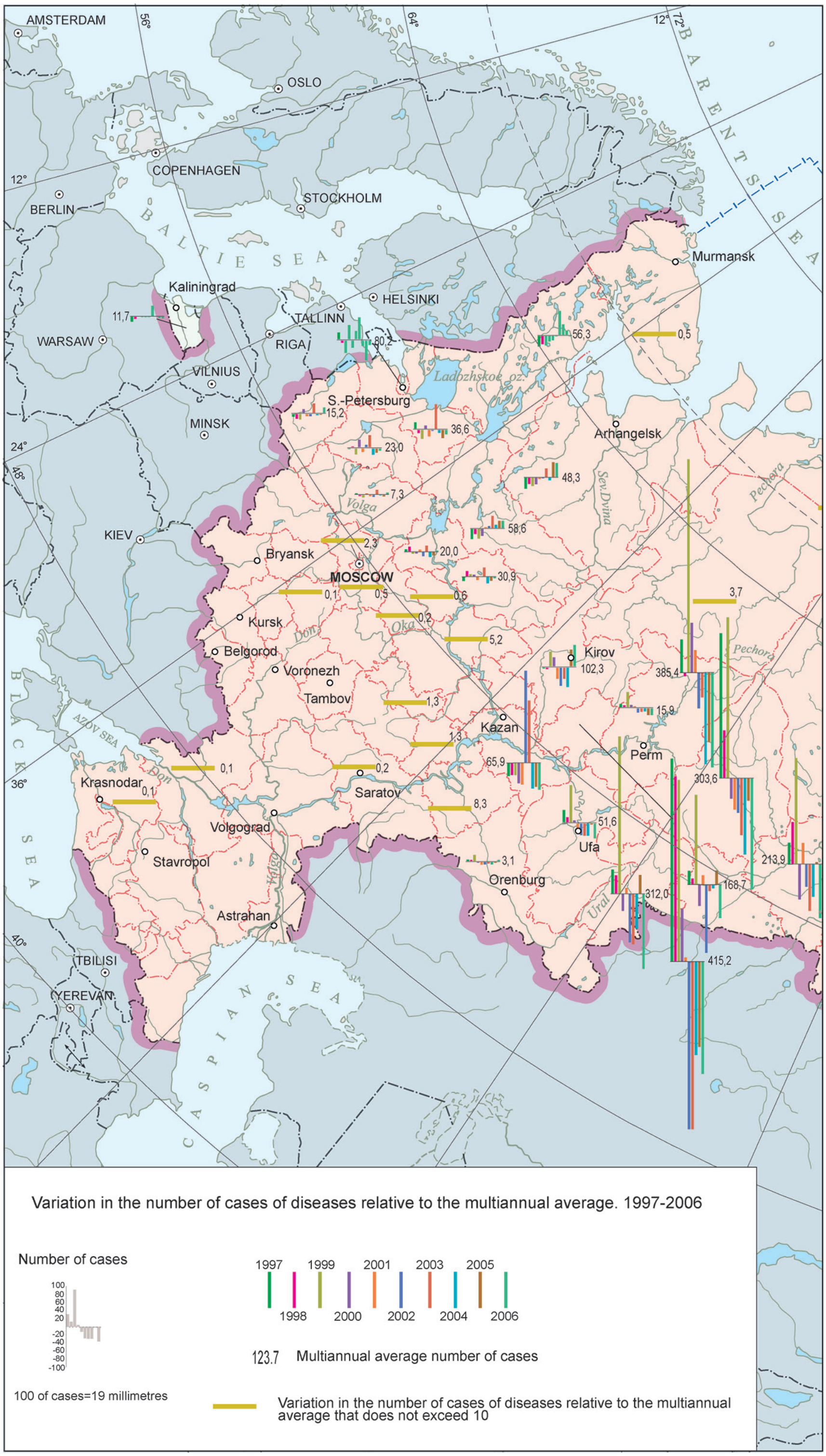

Fig. 9.Fragment of map “General morbidity of population dynamics.” 1997-2006. Scale 1: 20 000 000

Fig. 10. Map "Typology of morbidity from tick-borne encephalitis. 1997-2010". Scale 1: 30 000 000

As follows from the analysis of the map, the first type of morbidity dynamics is characteristic of six subjects of the Russian Federation. The Republic of Bashkortostan, the Khanty-Mansi Autonomous Area — Yugra, the Omsk and Chita Regions, and the Khabarovsk Territory belong to the second type. Dynamics of the third and fifth types is typical of the northern regions of Russia and the central and southern regions of the European part of Russia.

Ring maps are based on diagrams that reflect the distribution of morbidity by years. They are particularly well-suited for the visualization of the relationships between spatial data and their chronology (change in time) (Huang et al. 2008). The types of sources can vary relative, absolute, or estimated morbidity parameters. Initially implemented in the GIS environment, this simple and innovative method may well be used in traditional mapping.

Fig. 11 shows a map on morbidity trend over a 17-year period. In this map, the expanded graphic representation of the time-span allows one to treat time as the "notion parameter" and not just as an attribute parameter as in the first case. The use of this model is much more beneficial at the regional level with a relatively small number of administrative units. Visual and informative aspects of the model are achieved by the rational arrangement of the diagrams that may be tied to the territorial units with the help of references.

The spatial distribution of morbidity may be shown with the help of "gravitational" and diffusive models and the Monte-Carlo method (Tikunov 1997b). In this case, modeling of disease spatial distribution is conducted for each year separately and the results are combined in animations that allow one to visualize the process in time. To date, a large number of cartographic visualization methods have been developed; among them we should note several applicable to research on morbidity dynamics, namely, animated two-dimensional maps on dynamics, animated two-dimensional maps on change, classical two-dimensional maps that use animation effect, animated linear, areal, and volume anamorphoses, animated dynamic three-dimensional presentation, and animation in virtual reality (Kapralov et al. 2010; Gusein-Zade and Tikunov 2015).

CONCLUSION

Research and mapping of dynamics of medical-geographic phenomena is an urgent practical task. Analysis of medical-geographic maps has identified limitations of the methods and techniques used for visualization of dynamic aspects. We have

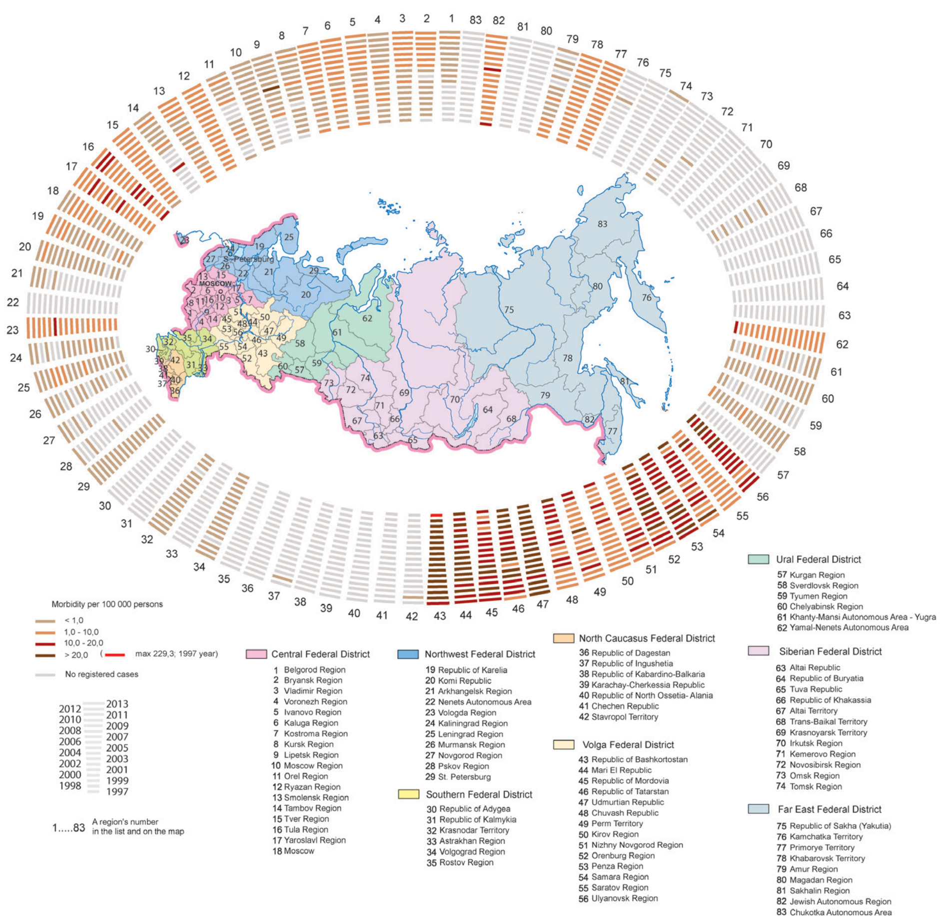

Fig. 11. Map "Morbidity from hemorrhagic fever with renal syndrome." Scale 1: 60 000 000

summarized the methods and techniques of mapping dynamic processes using public health and morbidity as examples. We also introduced other methods based on the results of preparation of integrated medical-geographic atlases. We have demonstrated the potential of cartographic presentation of spatiotemporal patterns of morbidity distribution and graphic techniques of their visualization.

Various parameters of morbidity have been used in map compilation: absolute, relative, estimated, statistical, etc. Their selection and use in thematic layers (analytic, integrated, and synthetic maps), combination, the use of either qualitative or both qualitative and quantitative parameters, and development of graphic methods of presentation on maps are determined by the goals and objectives of medical-geographic mapping, availability of informational base, mapping concepts, etc. The potential of morbidity dynamics mapping as an integral problem has not been fully realized and research in this direction should continue.

ACKNOWLEDGEMENTS

Part of this research (methodology and mathematical modeling) was funded under a grant of the Russian Science Foundation (project № 18-17-00074); part of this research was funded under the Russian Fund of Basic Research grant №16-05 00827.

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Received on October 24th, 2017 Accepted on November 22nd, 2017

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