The mapping population density in a sparsely populated region: a case study the Irkutsk Region

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Abstract. Adequate assessment of population density is becoming an increasingly pressing issue on both state and regional levels. It is due to the heterogeneity of population distribution patterns. We have developed the principles and methods of mapping the population density in a sparsely populated area on the example of the Irkutsk Region. Most of the region is rather characterized by the linear and local settlements with an extremely sparse network of permanent settlements except for the south of the Trans-Siberian Railway than the total areal population settlements. Applying a spot mapping method to define the borders of a populated territory, we use a buffer area radius of 3 km. Settlement lines formed by the single or double settlement chains located along the communication lines are adjacent to the areal populated territory. We have constructed the quantiareal map of the entire population density (rural-urban population areas), which adequately reflects the peculiarities of the population distribution. The map allows visualizing the quantitative differentiation of the populated territories based on the population density and separating them from the unpopulated areas. The map of population distribution areas can serve as the basis for mapping demographic, ethnographic, ecological, and socioeconomic characteristics of a population.

1. Introduction
The principles of mapping the population density of a region that is not evenly populated have their peculiarities. In terms of methodology, the greatest challenge is constructing the maps of population density that are designed to identify local specificities of population distribution. We have developed the methods and principles for mapping sparsely populated areas using the case of the Irkutsk Region.

The total area of the Irkutsk Region equals 774,846 km². On January 1, 2018, the total population was 2,404,195 people. Average population density is 3.10 people per km². For comparison, the average population density in the Russian Federation is 8.56 people per km².

The Irkutsk Region is a thinly populated region with a sparse network of settlements. Sparsely populated areas generally include the territories with the average population density of 1-10 people per km²; the territories with sparse settlement networks include the areas with 1 or 10 settlements per 1000 km². The peculiarities of the region due to unfavorable climatic conditions and insufficient economic development. Thus, within the Irkutsk Region, the territories that are the most favorable in terms of their natural and economic conditions are the most densely populated and better developed.

Among the available types of population density map, such as cartograms, isolines, maps of potential population distribution areas, and quantiareals, the latter is the only type suitable for sparsely populated and underpopulated regions. In a cartogram, population density is shown in the grid cells of a predefined territorial division, mostly, administrative. Thus, a cartogram has a distorted image of the...
population distribution due to the absence of the connection between territorial division and the distribution of the population density. Isolinear maps reflect population density without any sharp transitions; they are very smooth and generalized. Maps of potential population distribution areas reflect the level of population proximity (or remoteness) within a certain territory. The weak point of such maps is a high level of geographical formalities and conventionality. Quantiareal maps (from Latin "quantitas" meaning "quantity"), on the contrary, have none of such flaws. In these maps, dasiareas (from Greek "dasi" meaning "thick") act as quantiareas (quantitative areas). Certainly, the spot method also has some flaws. Its weakest point is determining the delineation radius.

Comparing the maps of the European part of the USSR, V.P. Semenov-Tyan-Shansky drew the borderline at a distance of a verst (translator’s note: a Russian unit of distance equal to 1.067 kilometers (0.6629 mile)) from the farthest group settlement, relying on the fact that pasture areas usually stretched to that distance, and that it contained some buildings and village fences, and, thus, supposing that a populated area was likely to expand to that borderline. V.P. Korovitsyn believed the same radius length to be the most appropriate when he was constructing the population density map of the Kalinin Region [1].

However, this radius length is only relevant for the well-developed western regions of Russia, but it does not apply to the Irkutsk Region. Determination of the population density should consider the size of the territory covered by the economic activity of the population. Therefore, the delineation radius should be big enough for the settlement spots to accommodate all (or almost all) of the economic units. The delineation radius of three kilometers was chosen for the Atlas of the Irkutsk Region since it is “the average distance the separates the fields from the populated areas located near the railroad lines in the most densely populated area of the Irkutsk Region” [2, p. 5].

2. Models and methods

Knowing the location and population of all permanent settlements in the form of a database is prerequisite for mapping the population density of the Irkutsk Region. To construct a population density map of the region, we have developed a relational database of the populated areas of the Irkutsk Region within its factual border (areal layer) relevant to 1 January 2018. The established database contains administrative, geographic and demographic information about all the populated areas located within the borders of the Irkutsk Region. The set of named columns comprises 28 attributes:

1 – the unique identification number of a populated area consisting of four consequent two-digit numbers describing respectively: the code of a constituent territory of the Russian Federation (38 for the Irkutsk Region), code of a municipal unit of a higher level (urban districts and municipal areas), code of a municipal unit of a lower level, and code of a populated area.

2-7 – name of a populated area; municipal unit of a lower level; type of a populated area (c – city, uts – urban-type settlement, c-p – checkpoint, v – village, ss – small settlement, rs – rural settlement, vs – village settlement, rs – village settlement located at the railroad station, lp – land property, kh – khutor (translator’s note: type of rural locality)); municipal unit of a higher level (urban district or municipal area); administrative status of a populated area (rc – regional center, udc – urban district center, mac – municipal area center, csmall – center of a municipal area of a lower level); type of settlement (1 – urban, 2 - rural).

8 – the rank of a populated area, depending on its population on 01/01/2018.

9-19 – the number of residents of the populated areas in different periods of time between 1973 and 2017.

20-21 – codes of a populated area according to the all-Russian classification of the objects of administrative and territorial division and all-Russian classification of the territories of municipal units.

22-23 – code of a local tax office and postal code.

24-27 – latitude and longitude of a populated area in degrees, minutes, seconds, and decimal degrees in WGS 84 geodetic system.
There is also an issue of mapping the population leading a nomadic and seminomadic lifestyle in large territories. The necessity of developing a specific approach to mapping the population density in the areas of reindeer pastures has been highlighted for a long time. However, according to the Federal Law № 399-FL (12/06/2011) on "Amendments to the act of the Russian Federation of the freedom of movement and choice of place of stay and residence within the borders of the Russian Federation", the Russian Federation citizen, who belongs to the indigenous minorities, leading a nomadic or seminomadic lifestyle and having no permanent residence, can be registered in one of the settlements (chosen by the citizen) located in the municipal area, within the borders of which the nomadic routes of this citizen pass, at the address of the local administration of the indicated settlement, taking into account the list of residence places and traditional economic activity of the indigenous minorities of the Russian Federation approved by the Government of the Russian Federation. Therefore, this category of the population is registered at the address of one of the settlements.

Most of the population density maps reflect only the density of rural population, whereas a different criterium, i.e. the number of citizens, is used for the urban population. Practically, it is not a map of the density of the entire population but of the rural population and the number of people who lives in urban settlements. However, these are exactly the names of these maps.

All this leads to the following contradiction: the location of two parts of one object of the population on the map is represented by two different criteria that are not compatible with each other. V.S. Preobrazhensky and M.I. Pomus first showed this commonly accepted method of identifying rural and urban population. The review of the Atlas of the Irkutsk Region indicates that it is possible to identify the phenomena of different kinds (in the current case, the location of population) using different methods, but they must be organically compatible with each other; however, in this case, rural and urban population is described through different methods that are not interrelated [4, p. 146]. The map of rural population density and the number of people living in urban areas is not valid not only in terms of logic but also a practical perspective, as it excludes the possibility of comparing the distribution of rural and urban population, i.e. the degree of population density. This map does not fulfill its main task: providing a clear image of the distribution of the entire population’s density, which is a serious methodological flaw [5, p. 124].

3. Results and discussion
To identify the borders of a populated area with a value of 3 km we considered several reasons. Firstly, it corresponds to the map’s scale and a certain qualitative developmental threshold of the area. Secondly, it will allow us to preserve the continuity, consistency and comparability with the already existing maps in the Atlas of the Irkutsk Region (1962) and the Population Map of the South of Eastern Siberia (1979) [6, 7].

Thus, the entire populated area consists of the settlements that are connected by common economic and territorial features. The solid lines of settlements, which consist of the single or double chains of the populated areas located along the ground lines of communication (land routes and waterways) and serve as the hubs of economic activity, are adjacent to this populated territory.

The settlement center is formed by one or several closely spaced populated areas, which are located at a distance of less than 8-12 km from the nearest populated area of an areal or linear populated territory. Settlement centers are displayed in dash lines in the areas of communications.

The settlement areas were later specified through nighttime remote sensing using DMSP OLS (Operational Linescan System of Defense Meteorological Satellite Program) of NASA [8]. The remote sensing data allows identifying spatial social and economic phenomena. After processing the images, we can construct maps that reflect permanent light radiation in populated and usable territories [9].

The main idea to combine the dasymetric method and that of “night lights” lies in the fact that “night lights” specifies the borders of a locality within the density area. Thus, we obtain more accurate data on population range in a given territory.
As a result, we have identified the light areas of the localities of 1000 residents (remote sensing features). We then calculated the number of residents within the areal borders and determined the population density.

Quantiareal population density maps have another flaw. As a rule, the density of the urban population in such maps is not at the forefront, whereas it is vitally important for the reflection of the significance of towns and cities.

Based on the above, we decided to use one common sign to identify the density of population and the number of urban residents in the population density map. The size and the shape reflect the number of urban residents, and the internal color — the density interval. All towns have the highest density indicators; as a result, urban density is visible in the common background (figure 1).

Figure 1. Population density map of the Irkutsk Region (fragment).
Eight intervals express the differentiation of the population density. Moreover, we have also identified unpopulated areas, which are over 90% of the Irkutsk Region and only become equal to the populated territories in the south of the region. The orange quantiarea, occupying a significant part of the south of the Irkutsk Region along the Trans-Siberian Railway, reflects the most widespread density of the population. This population density interval (1-5 people per km²) is typical of the settlement areas located in extra-urban territories. The quatiareas formed by the towns and cities have a population density that exceeds 100 people per km². The regional center – Irkutsk and the nearby towns of Angarsk and Shelekhov have the highest population density, exceeding 600 people per km².

The rapid development of GIS technologies allows us not only to simplify the dasymetric map constructed by the methods of V.P. Semenov-Tyan-Shansky but also perfect it, preserving the ideology of the method itself or particularly the methodology [10].

4. Conclusion
We have used the combinations of the following old and new methods:

- the dasymetric method of V.P. Semenov-Tyan-Shansky, in which the population density is determined through settlement areas.
- nighttime remote sensing, which was used to specify the settlement areas through the light areas of the localities;
- a relational database of the populated areas of the Irkutsk Region, which was used to obtain up-to-date information about the localities (number of residents, administrative status of a locality, type of municipal area, etc.).

We have constructed the quantiareal map of the total population density (urban and rural population areas), which more precisely reflects the peculiarities of the population distribution, avoiding the imbalance towards urban or rural population.

The map allows visualizing the quantitative differentiation of the populated territories based on the population density, separating them from the unpopulated areas and avoiding the flaws of the cartogram, which provides only the average indicators of the administrative entities.

The further use of population distribution maps is to become the foundation for mapping the demographic, ethnographic, ecological, and socioeconomic features of a population.

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