Investigation of spatial density of public and business objects in the largest city with help of geoinformation technologies

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Abstract. The article reveals the study of spatial distribution of the density of public and business objects with the use of geoinformation technologies. The source of the data was data from the open geoinformation project OpenStreetMap. Earlier, we showed that for the radial component of the density of public and business facilities. This paper is a continuation of the previous one. The angular distribution of density of public and business objects is studied by example of the largest city - Ekaterinburg. Spatial density has "tails" that characterize the predominant directions of the city development. At the same time, the average spatial configuration for the average density distribution shows the radial-ring structure for urban planning. The obtained results are interpreted within the framework of the "frame-fabric".

1. Introduction

The Soviet urban planning school confined a functional approach to the management of area development, when each area had its own function: housing, industrial, recreational, etc. The core efforts in this approach seek to create the best planning structure through the optimal mutual placement of zones with a certain functional purpose. A prominent Soviet urban planner, A. E. Gutnov was the first who realized the shortcomings of this approach. The principle he expressed in the book “The Evolution of Urban Development” was the need to shift from the functional purpose of land to the description in terms of its use intensity. Thus, the term “urban planning system” was introduced that shifted “the center of gravity from urban research to the study of internal intrinsic interrelations of the facility and to the identification of the most common properties of its structural and functional organization (SFO)” [1].

The mathematical formula describing cities in terms of their land use intensity is as follows: “revealing the dependencies between the basic properties of urban area F, D, T, where F is the type of functional use, D is the intensity of use, T is the location (positional properties)” (ibid., p.119). In other words, we are talking about the establishment of dependencies like

$$f = f\left(F, D, T\right) \quad (1)$$

In the foreign tradition, a similar approach originates in the work of the English economist and the statistician Colin Clark [2], who studied the curves of population densities for 36 cities from Los

Angeles to Budapest in the range from 1801 to 1950. Because of the research, Clark obtained an exponential model of population density decrease depending on the distance from the city center

$$D = a \cdot exp\left(-b \cdot r\right) \tag{2}$$

where D is population density, r is distance from the city center, a is density in the central districts of the city, b is empirical coefficient.

In the previous work, we investigate the law of diminishing the density of public-business objects, depending on the distance to the city center. This work supplements the previous one – A.N.Gushchin, S.I. Sanok & Y.S. Tatrnikova [3], and is devoted to the study of the angular distribution of the spatial density of public-business objects. In combination with previous radial distributions, this is equivalent to studying the morphological structure of a city in polar coordinates. Such a method should be useful for studying the structure of a compact city.

2. Method and Materials

The key research methods, as it is indicated in the title, are geoformation technologies. In the research, the authors make use of the freely distributed QGIS (Quantum geographic information system) [4]. QGIS is a full-featured geographic information system closely integrated with online geo data.

2.1. Data Source

As a data source, authors make use of the OpenStreetMap project [5]. Project OpenStreetMaps ("open street map") is a non-commercial web-mapping project for creating a detailed free geographic map of the world. Community of participants – Internet users are maintaining the set of maps. The project data is distributed under the terms of the Open Database License [6]. The quality of the OpenStreetMap project data was investigated by Mordechai Haklay [7]. His findings showed that the information was accurate enough. A later investigation of the data accuracy was carried out by Barron et al. [8] confirmed conclusion of Mordechai Haklay. The examples of geo data using for the Russian regions can be found in the paper Yu Kruglov, V. Stetsurina and E.S. Snezhkina [9] and I. Chadin [10]. Thus, we can name the geo data from OpenStreetMap as completely reliable.

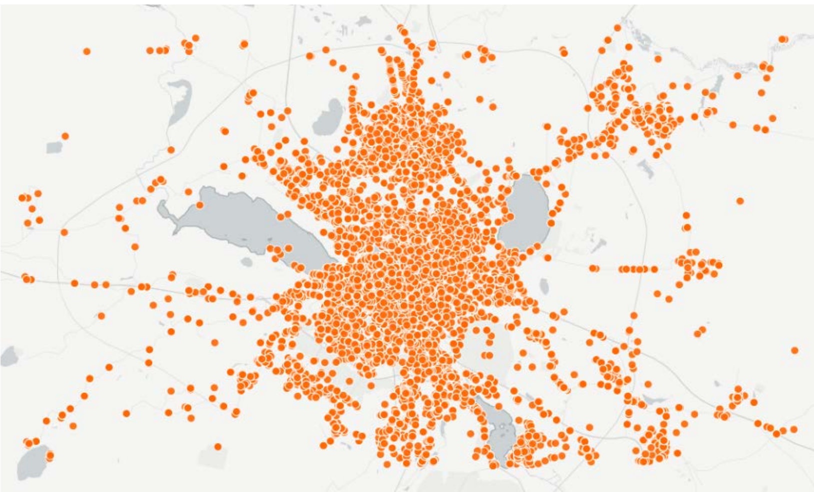

Figure 1. Spatial distribution of public and business objects in Ekaterinburg. Source: authors.

The resulting activity map is demonstrating in Figure 1. The classification of objects is make used of according to official document [11,12].

2.2. Angular Distribution

Figure 2 illustrate the scheme for calculating the angles for each object. The formula for calculating the angle between the fixed axis "north-south" with the origin in the common system of coordinates of the centers of circles, and the direction given by the sector drawn from the origin to the point where the next object is located is shown below.

$$\varphi_i = \pi/2 - arctg\left(\left(y_i - y_0\right) / \left(x_i - x_0\right)\right) \quad (3)$$

here (xi, yi) are the coordinates of the i-th object falling into the ring. (x0, y0) are the coordinates of the center common to all circles.

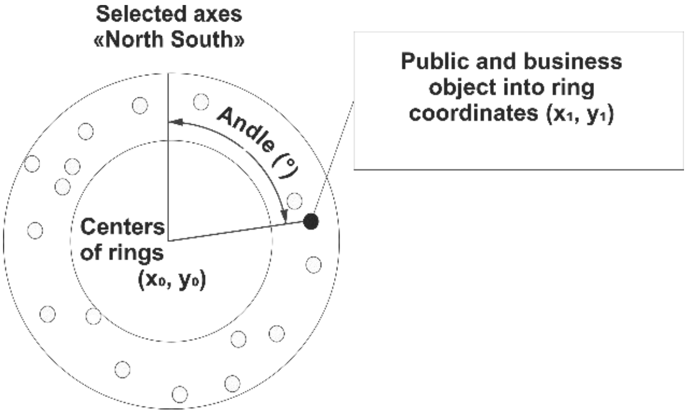

Figure 2. The scheme for calculating the angles for each social and business object. Source: authors.

Further, a histogram was constructed from the obtained angles with an interval of 20°. Such histograms are constructed for each of each of the fifteen rings. An example of a histogram of the angular distribution for the first spatial ring is demonstrate in Figure 3.

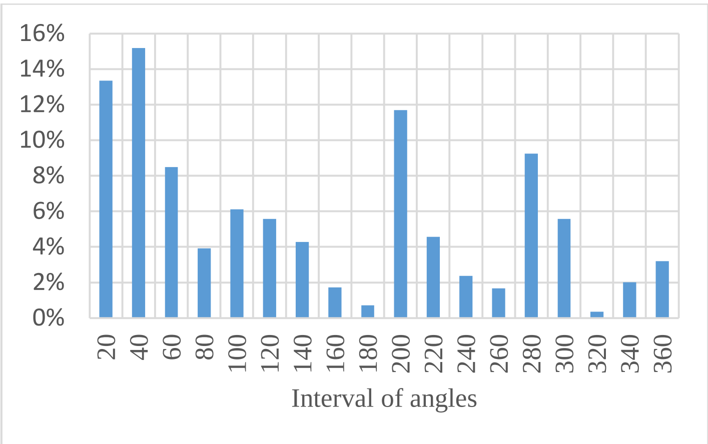

Figure 3. Histogram of the angular distribution of objects for the first ring. Source: authors.

3. Results and discussion

The general morphological characteristics of the spatial distribution shown in Figure 1: the nearest neighbors index is 0.34. The index of nearest neighbors - a characteristic adopted in geostatistics - represents the average number of nearest neighbors for each object [13]. The calculated value indicates a strongly clustered character of the spatial distribution, i.e. indicates that the spatial distribution of objects is not homogeneous, and objects tend to cluster - clustering.

The homogeneity of the distribution of public and business objects is also checked by the characteristics of the angular distribution of public and business objects. It can be expected that for cities with a compact structure the angular distribution will be isotropic (homogeneous). The characteristics of the histogram in Figure 3 cause us to doubt the hypothesis of homogeneity. To check the homogeneity of the distribution, a well-known statistical criterion was used [14].

$$X = S_n / X_{cp} \tag{4}$$

where χ is the coefficient of variation, Sn is the standard deviation for a sample of n points, and Xcp is the mean. The value of the criterion χ <33% indicates that the sample is homogeneous, i.e. that the differences in the values of the data are due to random causes. In our case, the value of the criterion χ> 33%, which allows us to reject the hypothesis of homogeneity.

Analysis of the data on the angular distribution within other spatial rings makes it possible to determine the preferential directions of urban development. For this purpose, two values were calculated: the average number of public-business objects within a spatial ring with the number N, and the number of objects lying in the sector 100-120 degrees (sector "south-east") – Figure 4.

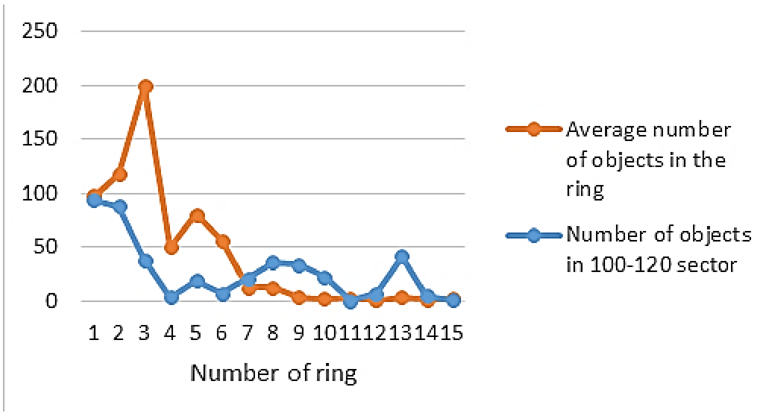

Figure 4. The number of public-business objects inside on average and within the selected direction "south-east". Source: authors.

The difference between the two types of behavior of the curves is clearly visible in Figure 4, namely, the rate of decrease in the number of objects in the southwest beam is significantly smaller than the average rate of decrease in the number of objects. The authors believe that this behavior is related to the availability of high-quality transport highways and the construction of large public and business facilities: an exhibition site for exhibitions "Innoprom", located near the route to the airport "Koltsovo", which led to a further increase in the number of public and business facilities. From the theoretical point of view, Figure 4 is an excellent illustration to the "framework and fabric" model. The long "tail" of the sample along the ray "south-east" is a forming frame. According to AE Gutnov, the frame is formed, in particular, at the expense of large public and business objects: "in one case, the high intensity of development may be due to a combination of concentration of business facilities with related services, in another - a powerful cultural and recreational center, in the third - trade and service center of a housing estate, etc. " [1]. That confirms the point of view of the authors. The second feature of the graphs in Figure 4 is the sharp peak of the number of objects in the region of the third spatial ring. This effect is largely due to the effects of calculation. If you recalculate data not by the absolute number of objects, but by their spatial density (the number of objects per square kilometer), then the effect is not observed.

At first glance, it seems that experienced professionals will come to the same conclusions just by looking at the spatial density in figure 1 or even the urban layout. It is possible that an experienced specialist will determine the direction of "North-West" as a likely direction of development. It is possible that an experienced specialist will be able to determine not only the direction of "South-East", considered above as a likely direction of development, but also the direction of "North-West" and possibly other areas. However, the advantage of quantitative calculation is that an objective view of the processes is achieved and these conclusions become obvious not only to an experienced specialist, but also to a beginner.

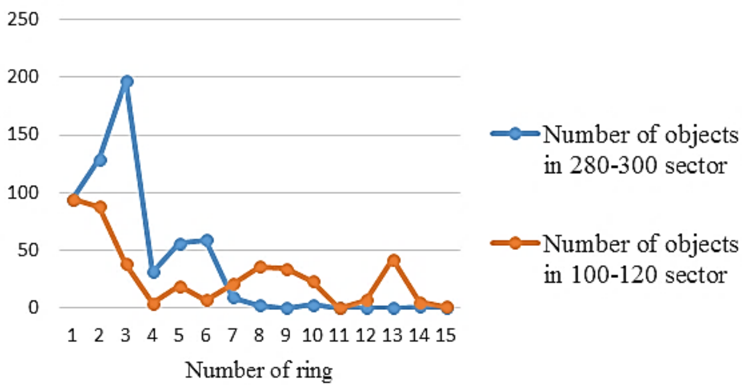

Figure 5. Comparison of the number of objects in the directions "south-east" and "north-west". Source: authors.

Comparison of the number of objects in the directions "north-west" and "south-east", shown in Figure 4, shows that in the direction "north-west" there is no such extended "tail" of public-business objects as in the direction "south-east". This means that the direction "south-east" is today the most likely direction of urban development. The figure shows a sharp increase in the number of public and business facilities in the area of the third spatial ring. A similar picture is observed in Figure 4. Given the local nature of the observed maxima - they are all limited to a certain sector; we can conclude that there is a change in the model of urban growth. If earlier the city developed as a city with a compact radial layout, now it can begin to develop on a multi-core Harrison-Ulman model [15]. Visually, this development will be expressed in the appearance of compact areas of high-rise buildings, saturated with public and business facilities. The city administration at public hearings more than once claimed that the city will no longer grow in breadth, but will develop due to high-rise buildings. This confirms the above assumptions.

To obtain a composite characteristic of the angular distribution of objects, the authors used the following method. For each angular sector, the total number of objects located within each spatial ring was calculated. In the resulting vibrational series, the median was calculated. Then its position was determined graphically and the resulting values were connected together, forming a polygon. The results are demonstrate in Figure 6. Figure demonstrate the central core of the city. It represents a geometric figure without noticeable asymmetry. At the same time, it can be said that a planning axis is being formed in the direction "northwest" - "south-east". The data in Figure 6 agrees with the data obtained earlier.

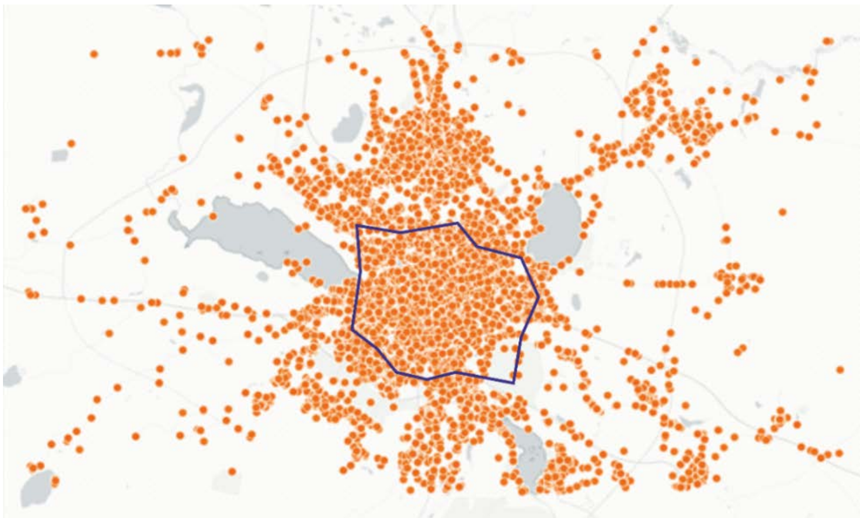

Figure 6. Composite characteristic of the angular distribution. Source: authors.

4. Conclusion

In general, the analysis done in the work is consistent with the idea of the spatial structure of the city, which is described in the master plan as a "compactly dispersed, radial planar structure" [16]. At the same time, analysis using geoformation technologies and methods of exact sciences makes it possible to more accurately reveal the characteristics of the spatial development of the city the direction of the primary development, the type of urban development. The practical benefit of such an investigation is the general methodological significance of the methods proposed as a universal means of studying the most common territorial-spatial aspects of urban morphology.

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