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Geo-Information Modeling for Determining the Movement of Human Capital

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ABSTRACT

The paper considers the application of Geographic Information Systems (GIS) to assess the attractiveness of territorial entities of the Russian Federation in terms of the movement of human capital. The relevance of the study is because of the uneven distribution of human capital, the high rate of its migration from underdeveloped regions and municipalities, and the insufficient effectiveness of the policy pursued by regional authorities and local self-government. The purpose of the research is to develop a GIS monitoring of the socio-economic attractiveness of municipalities to determine the movement of human capital. The research methodology is based on the use of complex and statistical analyses, methods of geo-information modeling. The information basis of the study is the data of the regulatory legal framework of reference systems, official statistics of the Republic of Bashkortostan, and investment passports of municipal districts and cities of the region. The authors justify and formulate a list of requirements and limitations for the GIS software and tool complex. Also, the authors identified and disclosed the requirements for GIS information support: reliability, completeness, relevance, consistency, understandability (unambiguity). There have been generated major conditions for the correct operation of the GIS software for monitoring the attractiveness of municipalities, considering the limitations of the current legislation. The research developed and described the functional basis of the GIS, which includes two key components with corresponding structural elements and tools: an organizational block and a modeling and visualization block. The authors proposed a list of key statistical (attribute) and spatial data and the attractiveness coefficient of a municipality as a criterion for assessing the opportunities for the development of human capital in a particular territory. The authors developed the scheme of the algorithm for the functioning of GIS monitoring the attractiveness of municipalities of the Republic of Bashkortostan, as well as they introduced the interface and user tools. The proposed GIS allows users to search for the municipality with the subsequent output of information about it containing the values of demographic, migration, socio-economic and environmental indicators in tabular and graphical forms. The results of the research make it possible to predict the level of attractiveness of municipalities in the short and medium term, depending on the chosen governance strategy and also allow zoning of municipalities by groups. The authors conclude they developed GIS monitoring of socio-economic attractiveness of municipalities to determine the movement of human capital in the Republic of Bashkortostan can serve as the basis for creating a fully functional decision support system at the regional level in all subjects of the Russian Federation.

Keywords: human capital; geo-information system; municipality; socio-economic development; attractiveness; differentiation; zoning; regional policy

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INTRODUCTION

In modern conditions the most important factor in the development of territories is human capital because it is a person, on the one hand, who is a resource and a productive force of economic growth of this territory, and on the other hand, the one who uses and consumes the results created on this very territory. This, in turn, predetermines the goal setting and allocation of economic growth quality criteria, which are based on the fact that the human being is the supreme and ultimate value. However, the population of the Russian Federation (and thus human capital) is extremely unevenly distributed across the country: about 80% of its citizens live in European Russia (which accounts for only 25% of its territory), while only 21% live in Asia (which comprises 75% of its territory). In the northern part of Russia, the proportions are 5% and 74%, respectively. In addition, there are significant differentiations in living standards: the proportion of the population in regions with incomes below the subsistence level ranges from 5.5 to 84.7%; unemployment levels are from 0.9 to 55%; and per capita consumption ranges from 29.4 to 321 thousand roubles.[1]

In underdeveloped regions and municipalities, the reduction in the number of working-age citizens and the decline in their qualification potential leads to the problems of maintaining existing industries let alone developing them. The limited labour market makes it problematic to locate and improve any new industrial technologies, which, in turn, affects the socio-economic development of the territory concerned and its attractiveness and, as a consequence, the outflow of human capital.

From a global cross-country perspective, there is a growing body of evidence that the economy is becoming a powerful driver of socio-spatial trends in population mobility. This is discussed in the works of S.J. South, K. Crowder, E. Chavez [1], M. van Ham, W.A.V. Clark [2], B. Robson, K. Lymperopoulou, A. Rae [3]. In recent decades migration processes directed to the most developed countries or regions of the country (if we are talking about internal migration) have become the cause of one of the main tangles of economic, social, and cultural problems of the global world [4]. Consequently, human capital is redistributed at a particularly high rate in the direction of those territories where the socio-economic level is high enough and is therefore accumulated there.

Such differentiation, in turn, predetermines the relevance of analysing and assessing the attractiveness of Russia's territorial entities in terms of human capital development in order, on the one hand, to identify "growth points" and identify key factors and conditions that ensure this position and, on the other hand, "risk zones", which will allow to develop measures aimed at minimizing their negative impact on the country's economy. Finding solutions to these problems is impossible without the use of modern information technology.

Geographic information systems (GIS), which combine operations such as recording, storing, and retrieving information from databases with the advantages of full visualization, geographic (spatial) and mathematical analysis, providing a representation of geospatial data on a map,— meet these needs to the greatest extent [5]. These features distinguish Geographic information systems from all other information systems and ensure their unique application for a wide range of tasks, including analysis and modelling of socio-economic processes (spatial develop-

[1] Official website of the Federal State Statistics Service. URL: https://rosstat.gov.ru/ (accessed on: 07.07.2022).

ment of the economy, human capital development, spatial mobility of the population of Russian regions, etc.), allowing for more effective decision-making at different levels of governance and administration.

The market for instrumental Geographic information systems is now well developed. There is a sufficient number of such systems applied to assess the subjects of the Russian Federation with a focus on different aspects. However, it should be noted that for a better understanding of the migration (including intra-regional migration) of human capital [6], it seems appropriate to use municipal entities as a geographical object for linking thematic GIS data.

The present study aims to develop geographic information systems to monitor the socio-economic attractiveness of these territorial units in order to determine the movement of human capital within the subject of the Russian Federation.

RESULTS

In order to build these Geographic information systems, it is necessary to create a software and toolkit including specific software products:

- providing the functionality of map data entry, editing, visualisation, as well as search and retrieval of the map data;
- allowing for the analysis of geospatial materials on the socio-economic development of municipalities in the constituent entities of the Russian Federation with the methods used to solve the problems of the system under development.

In addition to such a complex consisting of integrated software products (including GIS in the narrow sense), the geographic information system for monitoring the socio-economic attractiveness of municipalities should include information support for the system. In particular, two databases should be included: cartographic information and socio-economic indicators related to the subject area [5, p. 62], and spatially referenced for analysis.

In view of the mentioned above, it seems appropriate to identify the factors influencing the movement of human capital in order to form a list of key socio-economic indicators for GIS. It should be said that to date, modern science has not formed a consensus on what to understand by the movement of human capital or the so-called "spatial and social mobility", which, according to N.V. Mkrtchyan, L.B. Karachurin [7], J. Urry [8], N.N. Cattan [9], G. Zimmel [10], are synonymous terms and cover a wide range of relations, processes, and resources.

In the early twentieth century, as scientists began to increase their attention to the impact of urbanisation processes on the social status of people, R. Park and R. McKenzie proposed the theory of human ecology, according to which "the spatial structuring of human movements constitutes an ecological order" [11, 12]. According to this approach human mobility is associated with a change of residence, work, a change in the location of an institution, service, or activity of people.

In turn, W.A.V. Clark, M. van Ham, R. Coulter highlight financial and economic factors as the determinants influencing the spatial and social mobility, suggesting that individuals and families when moving choose areas and regions with better socio-economic conditions for this period of their life [13]. The results of such analysis reflect, as a rule, the desire of people to move to ensure a better quality of life (S.J. South, K. Crowder, E. Chavez [1]) or indicate the desire to leave depressive areas (B. Robson, K. Lymperopoulou, A. Rae [3]).

The Department for Communities and Local Government has attempted to assess

spatial and social mobility and its effects and consequences by calculating multiple deprivation indices, which measure the so-called 'deprivations' in seven different categories, each of which has a different list of socio-economic indicators and a level of significance as a weight [14]:

- Lack of livelihoods and means of sustenance (income deprivation) — 22.5%;
- Lack of access to decent work (employment deprivation) — 22.5%;
- Low level of education and qualifications (deprivation of education, skills and training) — 13.5%;
- Poor health and nutritional status (health deprivation) — 13.5 per cent
- Unsatisfactory environmental conditions — 9.3 per cent
- High crime rates in the area — 9.3%;
- Barriers in obtaining housing and necessary social services — 9.3%.

As a result, all areas are assigned their own scores in each of the listed deprivation categories and then an overall score is calculated, characterising the standard of living in a particular area. In doing so, decile (10% of citizens) groups are highlighted, allowing the most and least deprived areas to be identified separately in England, Wales and Scotland. Accordingly, as populations move from one area to another, deprivation indices are compared to identify key areas of human capital movement.

In the world theory and practice there are other approaches to the measurement of spatial and social mobility, among which the works of the Brazilian researcher L. M. Cavalcante de Melo [15], who singles out socio-professional conditions as a determining factor, and groups of Estonian scientists — K. Mägi, K. Leetmaa, T. Tammaru and M. van Ham [16], who pay special attention to the location of ethno-linguistic groups.

Thus, when building the information base, in particular the list of socio-economic indicators, in the GIS under consideration, it is useful to apply the above mentioned experiences and approaches to the understanding and assessment of spatial and social mobility.

The backbone and foundation of a GIS is the information support, as without proper organization no effective geographic information system can be built. Despite the primary importance of the digital map in any GIS, it should be noted that semantic, attributive data play an important role in the application systems, since prolonged time series of annual statistical indicators are required for a meaningful assessment of dynamic effects. The key requirements for GIS information support, taking into account the foreign experience considered, are:

- credibility;
- completeness;
- relevance;
- coherence;
- comprehensibility (unambiguity).

Credibility can be ensured by choosing an authoritative source of information on the demographic and socio-economic indicators of municipalities. Naturally, official statistics (if available) may be the most appropriate option from this point of view. However, frequently, and especially at the municipal level, the availability of official data is difficult. In this case, the high requirements for reliability (i.e. using only official sources) start to contradict the conditions for completeness of information, which in our case means having publicly available data for all indicators under consideration at each site for the entire given time horizon. Gaps can be filled by using several alternative sources, including public data and statistical information that is not considered to be the official or formal material or information.

At the same time, ensuring the completeness of the data set implies guaranteeing its relevance, which in most cases indicates that it has been available for the most recent time periods in question. Referring to several alternative sources can facilitate the task of supplying the GIS with up-to-date information.

In addition, in the course of the useful lifetime of the GIS, there should be a tool to update the data inputs (including the automated mode) in order to ensure the main purpose of monitoring — that is the ability to make effective operational and strategic management decisions based on it.

But addressing the issue of completeness and relevance of information through several alternative data resources poses some challenges: practice shows that even data provided by one and the same official and formal source can be inconsistent, and problems are ineviTable when multiple sources are used. There are a number of techniques for identifying and automatically correcting such inconsistencies, but their application does not guarantee error-free correction of all the situations or 100% success.

Issues of comprehensibility (unambiguity) of indicators are directly related to the methodology of their collection and calculation in the organisations generating the primary data, as it is not possible to change and improve the quality of these inputs as part of the GIS information management process.

Thus, it is difficult to meet all the requirements for the nature of the information simultaneously and completely (due to the presence of discrepancies). Nevertheless, it is possible to improve the integral value of data quality through the judicious and sensible use of alternative sources of inputs and the use of methods to resolve contradictions between them.

Given the large number of municipalities, as part of the information provision for the GIS, it is advisable to automate not only the processes of creating an array of demographic and socio-economic indicators in terms of municipalities but also the collection, verification and updating of raw data, which requires the development of software modules [17].

Based on the mentioned above, it is possible to formulate the main requirements for a GIS software tool to monitor the attractiveness of municipalities, which should:

- include an information repository (database) containing demographic and socio-economic indicators for municipalities in the region over different time periods;
- have the means for collecting, updating and entering data into the data warehouse, including automated means for dealing with large volumes of information from a predefined set of loosely structured sources, in particular open municipal statistical materials;
- have the capacity to check data correctness and consistency, editing options (including automated conversion) and also generate final refined data sets, with the possibility of versioning and updating them;
- have the tools to link objects from the information repository of demographic and socio-economic indicators with spatial data from the GIS for monitoring the attractiveness of municipalities, including by implementing an automated linking function.

Of course, such work for all the municipalities of the Russian Federation requires certain costs and expenses. In this regard, in the framework of this study the development of GIS monitoring of socio-economic attractiveness of municipalities is carried out on the example of the Republic of Bashkortostan, but the highlighted requirements,

features and approaches are applicable to other subjects of the Russian Federation and their municipalities and can be transposed to the territory of the entire country.

A separate problem in the creation of GIS, which is particularly relevant in the current climate of sanctions, is the obligation for the federal executive authorities and state extra-budgetary funds to use only domestic software products for their tasks and solution seeking. This is regulated by Order No. 486 "On Approval of the Classifier of Programs for Electronic Computing Machines and Databases".[2] However, no suiTable Russian developments are currently available, so it seems reasonable to use "open source" software, as this does not contradict legal requirements.

"In this regard, the following software products were chosen to develop a geo-information system for monitoring the attractiveness of municipalities in the Republic of Bashkortostan:

- QGIS — to prepare cartographic material and create a geodatabase;
- XAMPP — to publish services with spatial data;
- PostgreSQL — DBMS for creating a database;
- JavaScript — to program the user interface;
- PHP — to work with the database, display data on a web page;
- HTML — for the layout of a web page;
- CSS — for the design of the user interface;
- Notepad++ — as a web application development environment" [17].

In accordance with the features and requirements highlighted above, the GIS structure should include two key blocks: organisational, modelling and visualisation.

In doing so, the first actually provides the functional backbone of the entire GIS and includes four interrelated elements integrated into a single system:

- sources of information;
- spatial scales;
- functionality module;
- modelling and visualization module.

In turn, the modelling and visualization block defines the system's capabilities within mapping, zoning, editing, searching, and forecasting.

Let us take a closer look at how the structural elements of the proposed GIS function.

The first component of the organizational block — "Information Sources" — is based on statistical data on the socio-economic development of municipalities of the Republic of Bashkortostan. To form the information base, data from the territorial body of the Federal State Statistics Service and investment passports of municipalities and cities of the region were used.

The indicators that characterize the attractiveness of a given territory and have a significant impact on the movement of human capital (taking into account the reviewed foreign experience in assessing spatial and social mobility and the specifics of municipal statistics) were chosen as the following:

1. Population, people.
2. Total fertility rate, ppm (per thousand).[3]
3. Total mortality rate, ppm.
4. Number of departures, persons.
5. Average monthly nominal accrued wages, thousand rubles.
6. Number of pollutants emitted into the atmosphere from stationary sources, thousand tonnes.

[2] Ministry of Digital Development, Communications and Mass Media of the Russian Federation. 22.09.2020. Order No. 486 "On Approval of the Classifier of Programs for Electronic Computing Machines and Databases". URL: https://digital.gov.ru/uploaded/files/prikaz-486-gv.pdf (accessed on: 07.11.2022).

[3] The fertility rate — is the ratio of the number of births (live) in a calendar year with respect to the average annual population. Calculated in ppm, i.e. per 1,000 population.

Table

Feature layer sets

Name of the spatial feature layer set	Description of the spatial feature layer set	Spatial feature layers	Geometry type
Districts	Map of administrative areas	Administrative division	The polygon
Base-map	Base-map OpenStreetMap	Administrative division	The polygon

Source: compiled by authors.

7. Value of own-produced goods shipped, works and services performed by own forces (excluding small businesses), mln rub.

8. Volume of investment in fixed capital, mln rub.

The above-mentioned indicators should be collected over a period of at least 5 years. It should also be noted that in addition to the initial absolute values, there is also a calculation per 1,000 population, as well as rationing of these values, which subsequently allows the resulting base to be used for correct analysis.

The main role of the second component of the organizational block — "Spatial Scale" — is primarily the visualization of the collected statistical base of the municipalities of the region and implies the use of cartographic data. "The general geographical layers in scale, with the projection coordinate system EPSG:4326-WGS 84-Geographic, describing the territory of the republic and including the layers of municipalities, and cities" are used as the basic ones (see *Table*) [18].

The QuantumGIS desktop Geographic Information System (QGIS) is the basis for combining statistical (attributive) and spatial data for each municipality. Its application in the study allows to integrate the cartographic basis for each of the selected areas and to link to it the information describing the socio-economic development in different time intervals.

The third component of the organizational block — "Functional Capacity Module" — in addition to presenting statistical data in terms of municipalities of the Republic of Bashkortostan allows assessing their socio-economic attractiveness in terms of human capital development by calculating the municipality's attractiveness ratio for the working-age population [18].

By component analysis of the above-mentioned socio-economic indicators, the results of which are presented in more detail in the studies [19–21], an appropriate attractiveness coefficient is determined for each municipality of the Republic of Bashkortostan.

To visualize the results on a map and to classify municipalities, the GIS functionality module classifies them into groups according to their attractiveness using one of the most common methods of grouping and classifying objects according to a set of indicators — hierarchical cluster analysis based on the Ward's universal method.

In this way, territories are grouped according to their belonging to a certain cluster, which makes it possible to determine the level of their socio-economic attractiveness in the context of human capital movements.

The fourth component of the GIS organisational block — "Modelling and Visualisation" — enables scenario-

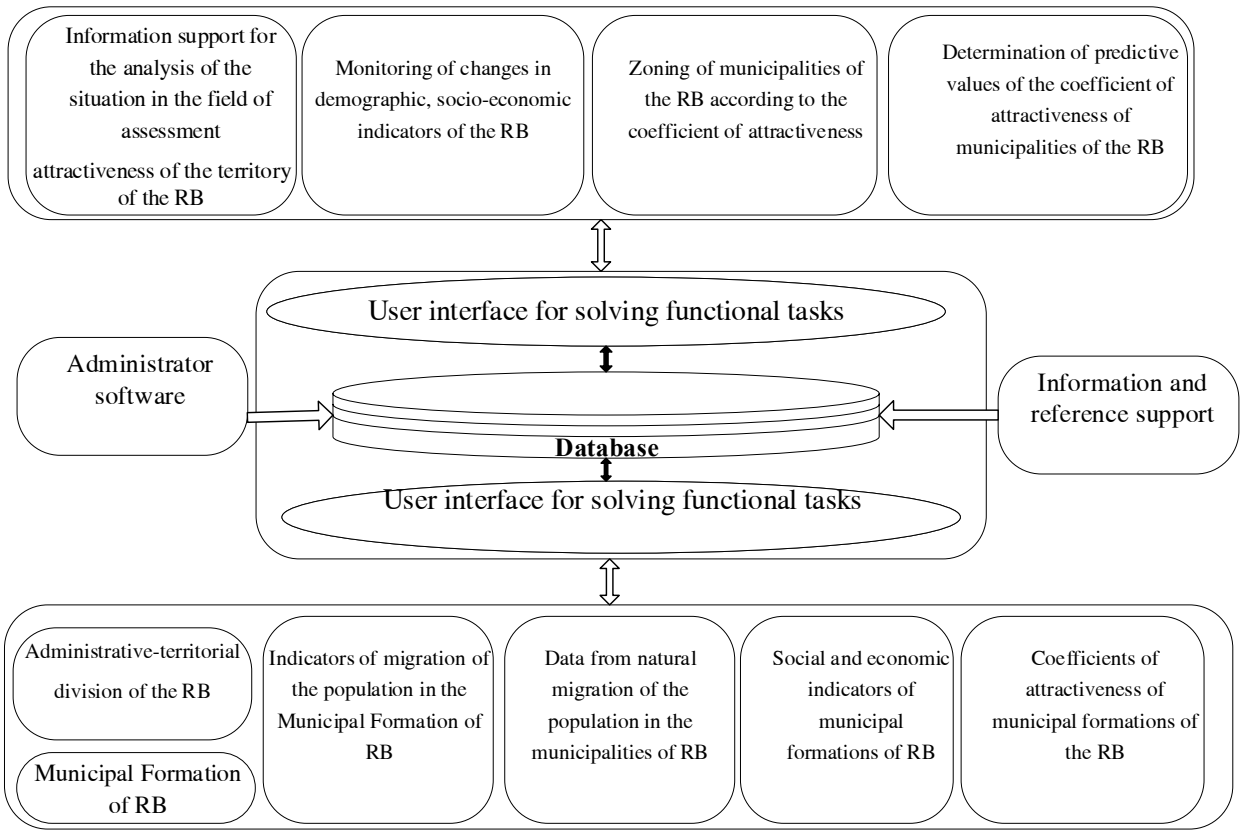


Fig. 1. **Logical structure of GIS for monitoring the socio-economic attractiveness of the municipalities of the Republic of Bashkortostan**

Source: compiled by the authors.

based forecasting of the level of socio-economic attractiveness of municipalities by calculating coefficients and visualising them on a map, forming an information and analytical basis for strategic management decisions.

The logical structure of the GIS under consideration, demonstrating the principles of this system, the composition and types of the implemented information processes, their division into GIS elements based on functional content, as well as the order and rules of their interaction in processing and exchange of information are shown in *Fig.1*.

In order for the user to understand the capabilities of the proposed GIS, a schematic diagram of its functioning has been developed (*Fig. 2*).

The modelling and visualisation block is directly linked to the GIS interface for monitoring the socio-economic attractiveness of municipalities and is a map of the municipalities of the Republic of Bashkortostan with layers and a toolbar, the functionality of which corresponds to the relevant tasks.

The following GIS tools are available for the users to work with spatial data:

- connecting and disconnecting layers;
- viewing explanatory pamphlets of the map;
- navigating on the map; zooming in/out;
- viewing information about the objects displayed on the map;
- searching for municipalities by name;
- editing;

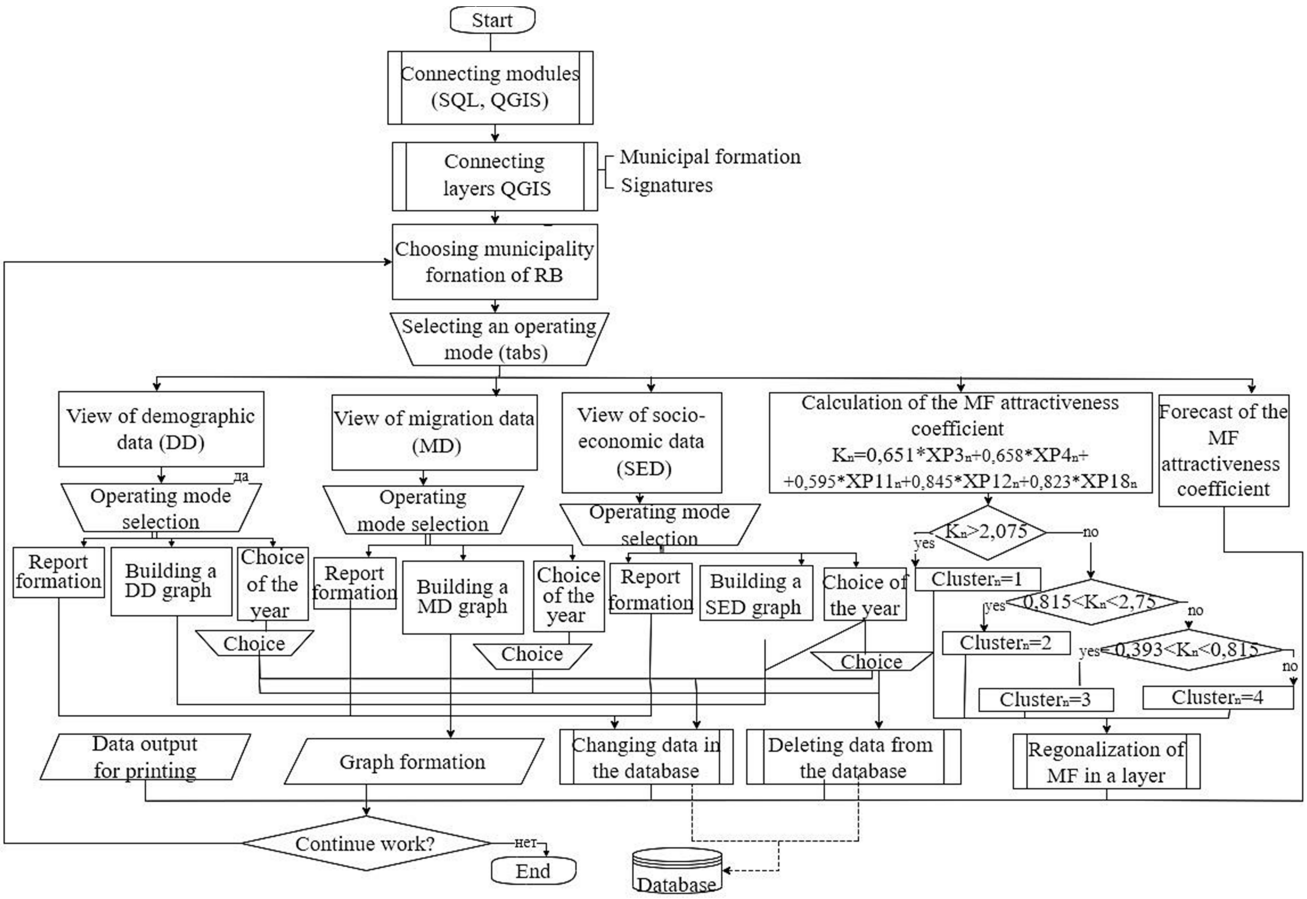


Fig. 2. **Scheme of the GIS functioning algorithm for monitoring the attractiveness of municipalities of the Republic of Bashkortostan**

Source: compiled by the authors.

- histogram construction;
- zoning the territory of the Republic of Bashkortostan.

A distinctive feature of the developed GIS is the ability to view comprehensive background information on a particular municipality, systematised according to the above-mentioned socio-economic indicators to assess the factors affecting the development of human capital in it — to do this, click on the layer of interest and it will display the relevant information pop-up window containing the field name and its values (*Fig. 3*).

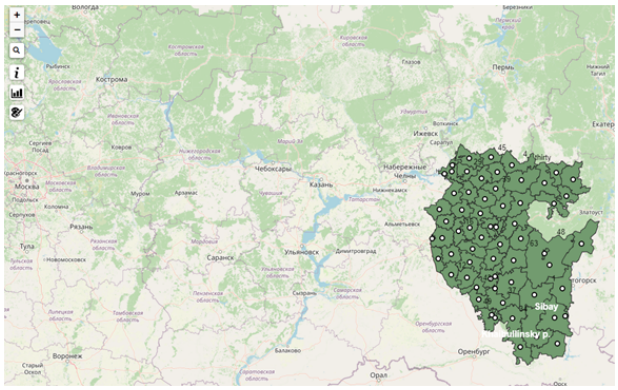
It also contains an example of a histogram showing the population of Bakalinsky district of the Republic.

The GIS provides such a possibility as the construction of graphs for the values of socio-economic indicators of municipalities for a selected period of time in order to visualize the flows of redistribution of human capital.

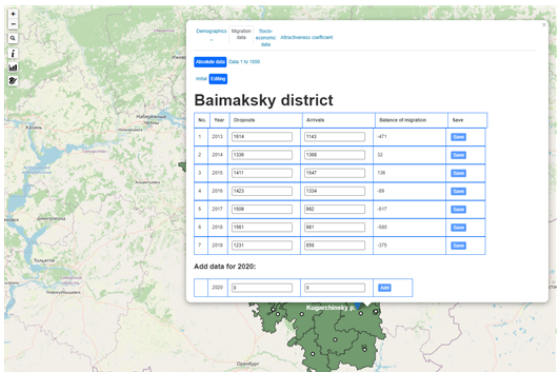
The system also includes the tools to adjust statistical data to socio-economic indicators, which is particularly relevant in terms of repeated clarification of economic and demographic data at the end of the reporting period.

One of the key functions of the Geographic information system for monitoring the socio-economic attractiveness of municipalities in the Republic of Bashkortostan within the block of modeling and visualization is the zoning

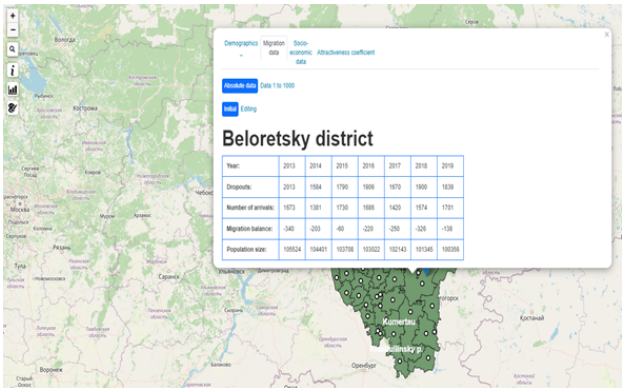
General view of GIS monitoring of municipalities of the Republic of Bashkortostan



Window with attribute information about demographic indicators



Window for editing socio-economic indicators



Distribution of the Republic Bashkortostan municipalities by attractiveness coefficient

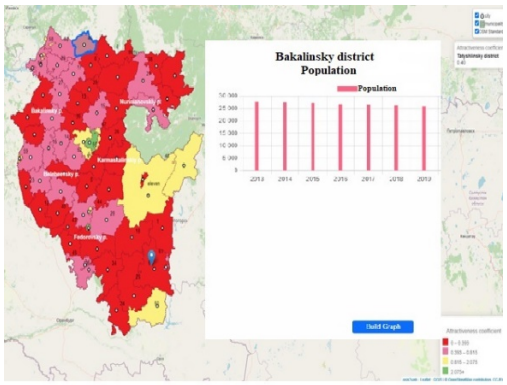


Fig. 3. **Output of GIS data for monitoring the socio-economic attractiveness of municipalities of the Republic of Bashkortostan**

Source: compiled by the authors.

of territories according to the value of their attractiveness coefficient. The resulting map (see *Fig.* 3) allows us to do this. On the other hand, such clustering makes it possible to determine the range of relevant tasks related to the improvement of housing conditions, increase in labour activity and socio-economic development of both individual municipalities and the region as a whole. Consequently, the results of the zoning of municipalities in accordance with the attractiveness factor can become the basis for forecasting the movement of human capital and improve the efficiency of managerial decision-making in the formation of migration policy in the subject of the Russian Federation.

CONCLUSIONS

As a result of this research, the need for geo-information systems to assess the movement of human capital has been substantiated, resulting in the development and testing of a geo-information system for monitoring the socio-economic attractiveness of municipalities.

For this Geographic information system, the key requirements and main limitations of the information and software tools were formulated, taking into account the existing regulations. In the process of creation, its functional framework and corresponding tools have been described in detail and an interface has been proposed.

As a result of testing this Geographic information system on the example of municipalities of the Republic of Bashkortostan it was possible to form a comprehensive statistical database on all municipalities with the possibility of editing and visualizing information in tabular and graphical forms, as well as zoning the region by attractiveness factor and the distribution of the municipalities into groups depending on their belonging to a particular cluster, which predetermines the opportunities for "gravity" and human capital development.

The developed Geographic information system for monitoring the socio-economic attractiveness of the municipalities (created on the basis of agent-based modelling) can become the basis for a fully functional decision-making support system at the regional level with the ability to visualize the results of modelling, develop and evaluate alternative options of management decisions on human capital development. It should be noted that this kind of toolkit is a promising direction of digitalization at the global level and is in demand to solve the problems of tactical and strategic management at the level of Russian regions. The introduction of such info-communication technologies can become the basis for a manifold increase of the operability and efficiency of the governmental authorities' activities in the sphere of human capital development.

In particular, such a Geographic information system can be integrated as a separate functional module into the existing complex of information systems of the Management Centre of the Republic of Bashkortostan, whose activities are aimed at developing and monitoring the implementation of a wide range of tasks in the socio-economic development of the region.

Thus we can conclude that the developed geoinformation system for monitoring the socio-economic attractiveness of municipalities to determine the movement of human capital is suiTable for use in all regions of the Russian Federation, providing a wide range of opportunities to assess the performance of regional and municipal authorities, and forms the basis for the creation and implementation of a fully functional decision support system, which corresponds and is in line with global and nationwide trends in digitalization and management optimization.

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Fattakhov R.V. — development the paper's concept, formulation of the research hypothesis, participation in preparing experiments, exegesis of the results.
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