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Original paper

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A REGISTER-BASED APPROACH FOR INTELLECTUAL POTENTIAL ANALYSIS OF THE SCIENTIFIC INSTITUTION

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Abstract. An assessment of the intellectual potential of scientific personnel on the platform of electronic demography was carried out. The current situation in the field of forming population registers, conducting demographic studies, as well as a number of works related to the use of new sources of information and big data have been studied. Analyzed studies cover the assessment of human resources, the intellectual potential of the country and issues of scientific migration. To determine the factors influencing the intellectual potential of countries, an analysis of trends in demography and economic activity of the population, the level of education, the system of training and its financing was made. In order to monitor and predict scientific activity in accordance with the existing potential, to conduct analytical and statistical analysis, a Unified Electronic Information System on Scientific Personnel has been created. The article analyzes the intellectual potential of scientific personnel based on registry data on scientific personnel, which are clustered using the *k*-means method, which is a machine learning algorithm. Based on the results obtained, data on age groups, academic degrees, universities and the number of scientific publications were studied. Subsequent studies will take into account the issues of scientific productivity and scientific migration, which are of great importance in terms of assessing the country's intellectual potential.

Keywords: e-demography, population register, public register, intellectual potential, scientific personnel, clustering.

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РЕЕСТРОВЫЙ ПОДХОД ДЛЯ АНАЛИЗА ИНТЕЛЛЕКТУАЛЬНОГО ПОТЕНЦИАЛА НАУЧНОГО УЧРЕЖДЕНИЯ

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Аннотация. Выполнена оценка интеллектуального потенциала научных кадров на платформе электронной демографии. Изучена современная ситуация в сфере формирования регистров населения, проведения демографических исследований, а также ряда работ, связанных с использованием новых источников информации и больших данных. Проанализированы исследования, охватывающие оценку человеческих ресурсов, интеллектуального потенциала страны, вопросы научной миграции. Для определения факторов, влияющих на интеллектуальный потенциал стран, выполнен анализ тенденции демографии и экономической активности населения, уровня образования, системы подготовки кадров и ее финансирования. В целях мониторинга и прогнозирования научной деятельности в соответствии с имеющимся потенциалом, проведения аналитического и статистического анализа создана Единая электронная информационная система о научных кадрах. В статье проведен анализ интеллектуального потенциала научных кадров на основе

данных реестра о научных кадрах, которые кластеризованы с использованием метода k -средних, представляющего собой алгоритм машинного обучения. На основании полученных результатов исследованы данные по возрастным группам, ученым степеням, вузам и количеству научных публикаций. В последующих исследованиях будут учтены вопросы научной продуктивности и научной миграции, имеющие большое значение с точки зрения оценки интеллектуального потенциала страны.

Ключевые слова: электронная демография, регистр населения, государственный реестр, интеллектуальный потенциал, научные кадры, кластеризация.

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Introduction

Development of modern society in knowledge economy stage determines its direct dependence on the effective use of intellectual potential, which is one of the most important factors of the country's innovative development [1]. It is clear that it is difficult to estimate and evaluate the impact of human intelligence on the development of the economy. From this standpoint, it is very important to analyse the level of the intellectual potential of the region and to study the potential of scientific personnel and conduct demographic studies to determine the directions of development. Currently, the analysis of intellectual potential and the study of its impact on the socio-economic development of countries is one of the most topical issues. Formation of intellectual potential is considered today as a factor affecting competitiveness at different economic levels [2].

Digitization, e-infrastructures and the development of e-government warrant the creation of a single public register [3–6]. Essentially, the population register is not considered the first register created for collecting information about the population in the country [7]. Government or local agencies, as well as other legal entities, collect personal data of existing or potential users of public services, thus creating institutional registers. Government agencies authorized to issue identity documents also collect information about individuals. Likewise, one or more institutions (for example, hospitals, municipalities, etc.) may participate in the registration and collection of information about events in a person's life. In the absence of a state system for collecting and storing personal information about the population, public or private institutions that need personal information of citizens, begin to collect information themselves and ultimately create personal databases. In this case, the government will be able partially control the acquisition and use of personal data or to ensure the protection of privacy. In cases where a large number of different public or private entities operate separate registries, the government must ultimately determine the authority responsible for verifying and validating personal data. Note that by implementing a single population register system that includes the most relevant information about citizens, using this information together with government or private institutions eliminates the need to maintain multiple databases. Contrastingly, it will result in storage of the same information in different formats in different registers, which will lead to confusion and hinder the further development of the system. Implementation of individual development programs by separate organizations significantly limits the ability to integrate different IT architectures.

Several studies review the analysis of intellectual potential [8–15]. The purpose of the research work is to evaluate the country's intellectual potential on the e-demography platform. For this purpose, in the second section of the article examines the issue of the analysis of the intellectual potential of scientific personnel. The existing models proposed for building a population register and studies on creation of the central register system are analysed. In third section, an overview of the research works conducted in the field of e-demography system formation is taken into account. In fourth section provided an experimental approach for evaluation of scientific personnel intellectual potential of institution. Existing approaches for evaluating the potential of scientific staff are studied on the e-demography platform.

Related works

Conducted studies show that several important researches have been performed in relation to population studies, demographic behaviour, determination of characteristics, use of new information sources

and big data [4–6, 16, 17]. Data collected in public registers, search queries, information on e-services, citizen satisfaction indicators, etc. indicated as the main sources of data for demographic studies. Demographic changes can be analysed and migration processes can be forecasted using the personal data collected on e-demography platform, as well as research of the demographic behaviour of citizens and intellectual potential of the country can be conducted.

Study conducted in recent years mentions that electronic demography tools such as Google Trends can be used to determine, evaluate and forecast migration of health workers from Croatia and Western Balkan countries to Germany and Austria. The objective of the study is to test the usefulness of Google Trends indices for predicting the migration of healthcare workers from Croatia and the Western Balkans to Germany and Austria. Recent trends in mobility of health professionals in Europe are analysed and special attention is paid to patterns of mobility among doctors and nurses using e-demography. The main methodological concept of this approach is to monitor the digital footprint of language searches (for example, “recruitment + doctor”) using Google Trends analytical tool [5]. To standardize the data, the study used data from January 2010 to December 2020 and divided it by keyword frequency for each migration-related query. In order to prove the significance of the results and correlations and to test the predictive potential of the model, the search frequency index was compared with official statistics. The advantage of this method includes reliable estimates that allow better responses to the shortage of health workers and maintain the functionality of the health system.

In the research [17], the importance of demographic methods and perspectives of detailed analysis of population data in improving the systems of civil registration and vital statistics are studied and development of approaches to population dynamics throughout life are reviewed. In that study, emerging problems and future research directions related to population studies and registration of civil status acts for the scientific community, as well as natural population movement statistics systems are discussed [17]. In their study, [18] mentioned the challenges of incomplete and late reporting in South Africa’s national population register (NPR) and death registration register, and demonstrate the ways it is possible to actually monitor the weekly death cases when the population register is systematically renewed through civil register system. The study article uses the last 10 years of available data on recorded deaths, conducts comparative analysis of distribution of death cases in the country, and applies evaluation methods in order to determine underreporting of both adult and child death cases and implement relevant corrections. However, the researchers note a lack of correlation between real-time excess mortality estimates by national and regional authorities. In particular, incorrect birth registration in the early stages of the COVID-19 pandemic ultimately suggests that there are problems with recording child deaths and that they do not reflect reality. Also, in future studies, it may affect the results of specifying the base mortality rate in the regions and monitoring the mortality rate in the local area [18].

In [19] there are analysed the results of inconsistencies observed in the emigration data to foreign countries of official institutions of Croatia compared to the data of statistical offices of the European Union (Eurostat) and Germany (DESTATIS). In this study, the author presents a descriptive analysis of alternative data sources (big data) that may be useful for identifying, estimating and forecasting migration flows from Croatia to Austria and Germany. To evaluate the model, linear regression was used to determine the correlation between the number of searches confirmed by official statistics and the number of movements (displacement). According to research results, a clear correlation is observed between Google searches related to migration and migration flows from Croatia [19]. As there is a significant increase in internet access in comparison with the establishment of reliable migration monitoring registration systems, the development of statistical tools that combine traditional and new data sources is likely to become an accepted approach for monitoring all types of demographic trends [20].

Currently, use of non-traditional or alternative data (big data such as mobile phone records, social media data, internet-based platforms, etc.) has started in demographic studies, especially to understand migration and displacement processes [4, 21]. [16] explored how big data can help understand the phenomenon of migration. The research work compares the analysis of different stages of migration, traditional and new sources of information and models at each stage in order to study displacement processes. Various datasets and models that can be used to quantify and understand migrant integration were examined [16]. One of the interesting scientific research directions covers the assessment of human resources, intellectual potential of the country, and issues of scientific migration. Given its importance for scientific productivity and education, the study of scientific migration has attracted increasing inte-

rest in recent years. Publications in various scientific fields and the availability of big data describing the careers of scientists create new opportunities for research in this field [16, 22–25].

Understanding the mechanisms that stipulate the decision of scientists to move (migrate) can help institutions and governments manage scientific mobility, make policy decisions to attract or prevent the best scientists from leaving, and thus improve the quality of research [15]. Study of the migration of researchers covers more than a few directions. These include studies on mobility within a country or between universities, the impact of a researcher's mobility on their academic performance, and how a researcher's academic profile influences their decision to relocate.

Centralized population register

Population register systems can have different forms from a structural point of view, but effective models of such systems have the ability to constantly update and ensure security of the data in the register, prevent duplication of data, prevent unauthorized dissemination of personal data and other illegal activities. Different countries have proposed different population register models in accordance with administrative government structures. These models differ from each other depending on how they approach the solution of the following issues [26]:

- division of authorities between central and local government agencies;
- centralization degree of data;
- methods of data transferring from one governance level to another;
- data storage format.

Continuous population migration and changes in civil status acts necessitate the creation of a population register system. This system allows for the effective joint use of data in order to collect new statistical data and update existing data in the register. For example, when a citizen changes his place of residence, the registration authority in both places of residence must make appropriate changes in the register data, and eventually, the current information must be kept. Advantages of keeping register-based population statistics are following:

- significantly reducing respondent load;
- reducing direct costs associated with collection and processing of statistics;
- collecting more detailed statistics due to lack of limitations;
- frequent and timely data transfer;
- higher quality of statistical analysis in many cases;
- including indicators existing in registers, but otherwise impossible to record in traditional census (for example, income);
- availability of potential opportunities for analysis in a certain period by connecting various events in a person's life.

The population register presents the result of an intermittent process, and the initial information about the events in a person's life and place of residence, possibly recorded in different administrative systems, is automatically linked to each other on a permanent basis. It is clear that the management of such a complex system requires the creation of effective mechanisms for the joint use of information, as well as the precise coordination of the activities of competent authorities. One of the most important issues in centralized systems such as population registers is to regularly update data and ensure the accuracy and completeness of registration data [26].

Creation of the population register system is carried out by each country in accordance with the national administrative management principles, procedures, legislation and technical capabilities, as well as human and financial resources allocated to the solution of this issue. Therefore, different mechanisms can be created for the joint use of data by relevant authorities. For example, updating the population register by directly entering data in online mode into the database by registration authorities. Clearly, it is a political decision whether the population register should be under the authority of the central government agency or whether it should be partially or fully delegated to local authorities. In both cases, the legal principles of population registration apply and the duties of all bodies responsible for the register must be clearly defined.

An effective population register relies on the provision of accurate data, dependent on public confidence in the system. To gain public trust, data must be used only for the purpose for which it was originally collected. This basic principle should also apply when personal data is transferred or jointly used by public authorities. During the transfer of data from the population register to another area

(for example, health, education or tax), the purpose of the transfer must be regulated in terms of categories of received and transferred data.

Transferred data within the population status acts system can include name and surname or address and transfer is performed without any special limitations. Other special category data, including personal identification number, place of employment etc., can be only be transferred when purpose of use of transferred information is known and transferred is provided by law.

Population registers are often confused with registers created by the authorities responsible for civil status acts. However, civil registration differs from population registration in the fact that registration of information about citizens is usually limited to important demographic events, such as births, deaths, marriages, and divorces. Although this is considered an important component in the establishment and updating of the population register, it is not sufficient for the establishment of the population register. Creating and maintaining a population register requires at least three additional components [7, 27]:

- first of all, primarily, certificates containing a separate event (birth, marriage, etc.) for a person must be collected in a general form, i. e. under the name of the person concerned;
- second, since the population register concerns each person residing on a certain territory or a country, it must include information about change of address;
- third, initial registration of the population living in the area must be generally performed through a census [27].

Population registers are by no means universal in terms of monitoring a person's identity, citizenship status, place of residence, as well as life events. For this purpose, it is very important to develop an integrated register i. e. e-demography system. Currently, population registers can be created in different structures depending on the purpose and can be used completely differently in practice. Experts demonstrate 5 main approaches or models of population registers in conducted studies [28]. Studies show that similar models for population registers are used in certain geographic regions, although not always. It is partly due to the fact that countries in the same geographical areas have similar development trends in their administrative and institutional systems.

Below is a brief description of 5 different conceptual approaches or traditions to population registers based on international practice. However, it must be noted that this classification serves to describe some basic conceptual approaches to collecting and registering data on larger population and is by no means fully comprehensive [28].

Integrated system based on social foot printing – this system is based on citizen identification using several organizational sources, i. e. social security registers, taxes, credit cards and banks can be used to collect personal information about an individual. By integrating data from many organizations, a social footprint is created for a citizen (resident). Their personal data is collected and their identity is confirmed due to the actual existence of the resident and their use of different government, as well as commercial services. Such systems can be available in many countries including the USA, Canada, United Kingdom, Ireland, Australia and New Zealand.

A community based model – this model to be dominant in Russia and many Asian countries. This model does not constitute a centralized population register. Personal information is collected and stored locally or regionally, depending on the country in question.

Central population register – this model is more prevailing in Europe, some countries of Central and South America. Personal data is stored on a central level, however, details can be collected on local, regional or centralized level. However, currently, many countries are implementing purposeful works in order to transfer to centralized population register.

Biometric model – this practice is available in India; biometric data of population is stored in government agencies. Stored biometric data, i. e. biometric photo or finger print can be used as personal identification and confirmation of identity of the resident.

Limited public registration model – this model can be significantly different. Countries with limited government registration is characterized by systematic collection of a little or structured data. Historically, national registers were non-existent for residents in many African countries. Incomplete coverage of citizens in some countries, for example, lack of data about children and child death is a serious problem. Besides, African countries such as Kenya and Nairobi have succeeded in developing a population register systems using digital technologies.

There are different forms of population registers and there can be significant differences in data entered into different registers. Obviously, population registers do not operation as a single system.

In many cases, other registers and databases in the country are integrated and this makes the population registers a part of a wider population data system. It is important to mention the relation of population registers with other systems. For example, national population register of the Netherlands is one of the 10 other national data bases and forms a more broadly coordinated information system [28].

Certainly, development and updating of the population register and the detailing of available statistics require the integration of various data sources. In this context, development of e-demography system creates new opportunities towards conducting population studies. Principal functional objectives of e-demography system include collection of administrative data, primarily personal identification and collection of population data. Functional capabilities of e-demography system include following:

- uninterrupted updating of the system, population relocation, tracking migration processes;
- collecting more detailed information related to personal characteristics;
- development of a register-based system and conducting population statistics;
- conducting more detailed statistical analyses with large-scale selective or thematic selective queries;
- obtaining comprehensive statistics about separate individuals or households based on information collected in different registers;
- monitoring of population data on different levels and sections;
- online census and conducting different social-demographic studies on macro, regional and individual levels.

Data integration (gathering data from different available sources in one place) creates opportunities to obtain more data and statistical information, conducting higher frequency and more detailed processing of data and statistical analyses. Before integrating different data sources for population registration, initially, all discrepancies must be solved and mechanisms must be developed for their elimination. This process can be difficult and time-consuming, besides, participation of interested parties must be provided. At the same time, personal identification number must be assigned at birth for effective use of population registers. Approximately 70 countries assign a PIN number at a certain stage of life of a citizen or a resident [29]. Difficulties arising during integration of government registers into a single platform are following:

- use of different platforms and software while creating separate government registers;
- non-use of personal identification number in all registers;
- risks related to provision of security of personal data;
- concerns regarding inviolability of personal life;
- violation of privacy and confidentiality in the process of data integration from various sources;
- inconsistencies in register data, presence of errors, various errors;
- problems related to updating data, as well as provision of accuracy and completeness of registration data.

Recently, countries in some cases refuse to use a single number in all systems. Current best practice is to use other tools to link data, such as an encrypted number [30]. The use of PIN in the future is likely to focus on the implementation of electronic unique keys, which are different for each individual and application, facilitate the separation of more complex data, and are considered more secure in terms of security [29, 31]. It must be noted that, despite its application in most systems, international standards for PIN have not yet been developed.

Provisions for protecting confidentiality and guaranteeing privacy should be taken into account when creating, updating and using population registers. A more flexible and reliable infrastructure must be built, and controls for the elimination of errors and inconsistencies must be implemented and supported. In the process of data integration from different sources, proactive measures should be taken and flexible measures should be taken in cases of privacy and confidentiality violations [32, 33]. Overall, in order to present any integrated system to the government, as well as render effective e-services it is required to continuously clear, update and monitor data.

Evaluation of scientific personnel intellectual potential

The impact of investments aimed at the development of intellectual potential on obtained economic results and future development must be positively correlated. At the same time, conducting complex research on the impact of human capital on social and economic development requires a multidisciplinary

approach. Studies show that intellectual potential is viewed and analysed from the standpoint of the following components: demographic (social, human) potential, human capital, and a set of organizational and economic resources aimed at the development of human capital [12].

Demographic (human) potential is a set of quantity and quality of human resources. Human capital is a set of knowledge and skills used to meet the various needs of a person and society as a whole [9, 13]. Thus, the innovative economy is interpreted as an economy based on new knowledge and intellectual potential [34].

In order to determine the factors affecting the low intellectual potential of a number of countries, including developing countries, it is important to analyse trends in demography and economic activity of the population, education level, personnel training system and its financing. Methodological approaches for evaluating the efficiency of using the university's intellectual potential have been investigated in conducted studies [8, 10]. The authors identified the specific features of the development of the intellectual potential of the university and proposed conceptual approaches. Study proposes instructions regarding organization of monitoring for evaluation of usage efficiency of university's intellectual potential, as well as system of indicators and methods. Proposed evaluation methodology can be applied globally as it is universal [10].

National Information System "Scientific Personnel" was created by Institute of Information Technology in 2018 [35]. Purpose of project implementation is to create a single electronic information system for scientific personnel that monitors and forecasts scientific activities in the ANAS according to the current potential, conducts analytical and statistical analyses, prepares electronic report forms and ensures the availability of scientific information. Main functions of "Scientific Personnel" National Information System include following:

- improvement of management and regulation in the field of evaluation and monitoring of scientific activity;
- creation of a database about scientific researches and provision of accessibility of scientific information;
- also, creation of an integrated electronic database in order to improve the quality of analytical, statistical analyses and reports.

Structural model of scientific personnel management system is provided in Fig. 1. As shown in Fig. 1, future expansion of the system and coverage of universities, scientific-research institutes and other scientific institutions country-wide is planned.

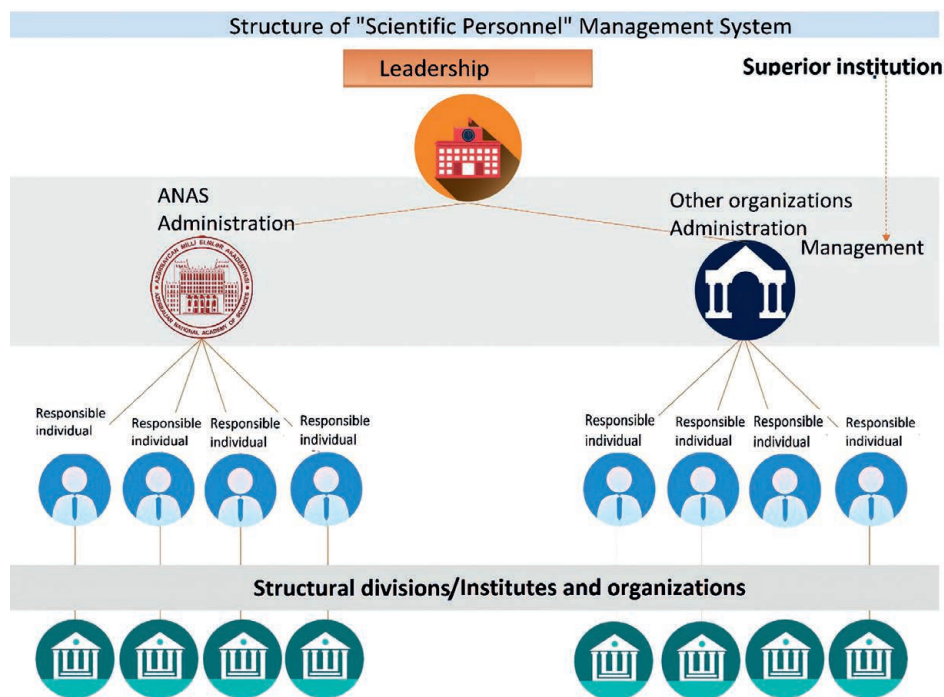


Fig. 1. Structural model of scientific personnel management system

Institute of Information Technology prepared the concept of the system and developed the software. Responsible individual was appointed at scientific institutions and organizations in order to provide control over accuracy of information entered into the system. As a pilot project, developed information system was initially successfully implemented at Institute of Information Technology. Registration of scientific personnel in the system is performed based on scientific structures and institutes, online through the website [36]. Currently the system contains profiles of over 4.000 scientific personnel. Information on more than 110 indicators, including 10 sections overall, was included in the scientific personnel profile. Scientific personnel profile includes information such as personal information; scientific works (articles, conference materials), books, monographs, textbooks and teaching aids; scientific expertise activity; patents and inventions; participation in grant projects; staff training; representation in the scientific institutions of the republic, international and foreign countries and contact information.

In the study, the issue of demographic indicators of scientific personnel is analysed based on the data of the National Information System “Scientific Personnel”. Profile data of 50 scientific personnel were anonymized and used for research purposes for experimental evaluation. Tab. 1 shows a fragment of data on the scientific personnel profile.

Table 1. Scientific personnel data (as an example)

PIN	Age	Gender	Academ.deg	Specialty	Publication	Articles in WoS/Scopus	University
4579951	35	Male	PhD	Chemistry	20	5	BSU
4579952	24	Female	None	Geography	7	1	BSU
4579953	78	Male	Dr.Sc.	Computer science	61	23	ASOIU
4579954	65	Female	Dr.Sc.	Philology	78	25	BSU
4579955	43	Female	None	Geology	8	0	AzTU
4579956	36	Male	PhD	Applied mathematics	26	6	BHOS
4579957	32	Female	PhD	Sociology	30	8	BSU

Collected dataset was analysed and Fig. 2 demonstrates a distribution diagram of personnel based on gender and academic degree.

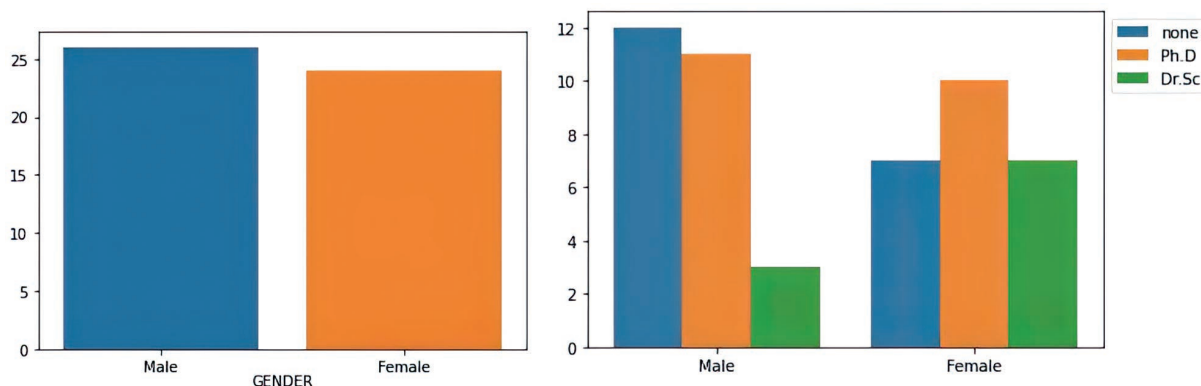


Fig. 2. Distribution of scientific personnel based on gender and academic degree

Dataset on scientific personnel was clustered and analysed according to age groups, academic degree and scientific publications using the k-means clustering method, which is a popular machine learning algorithm. Analyses were performed on Jupiter Notebook 6.1.4. platform using Python programming language. Elbow and Silhouette methods were used in order to find the optimal number of clusters in k-means clustering. As shown on Fig. 3, selection of 4 clusters is considered optimal based on Elbow and Silhouette index values.

As shown on Fig. 4, scientific personnel were clustered based on age groups and number of publications.

On Fig. 5 scientific personnel are clustered based on age groups and number of articles in WoS/Scopus database.

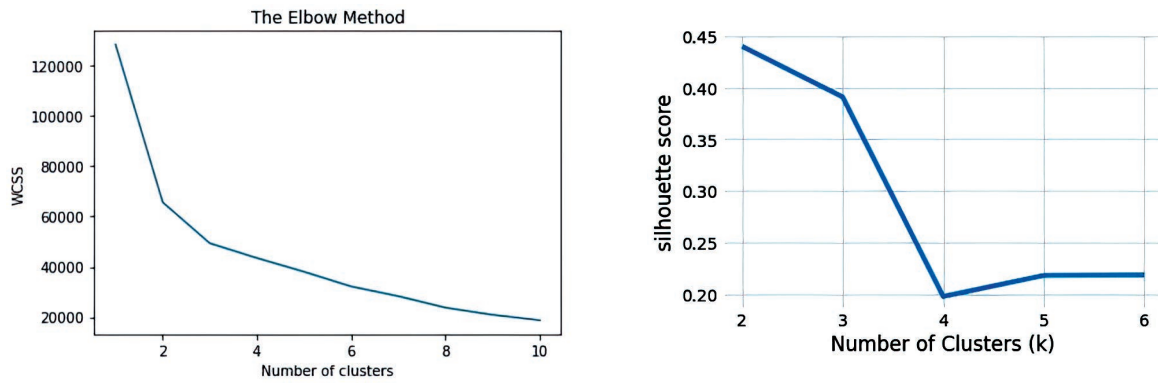


Fig. 3. Elbow and Silhouette index values

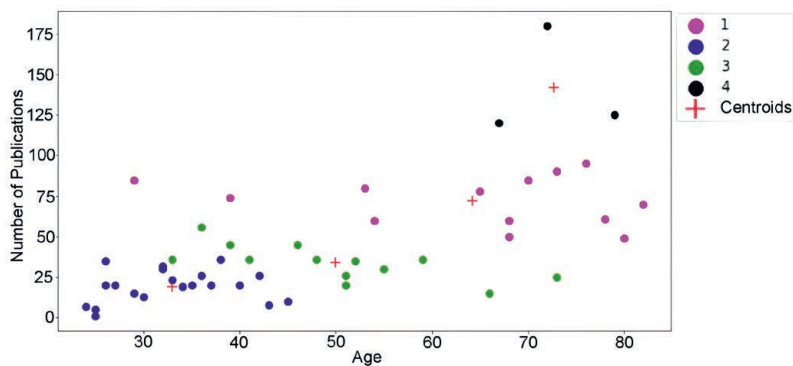


Fig. 4. Clustering of scientific personnel based on number of publications

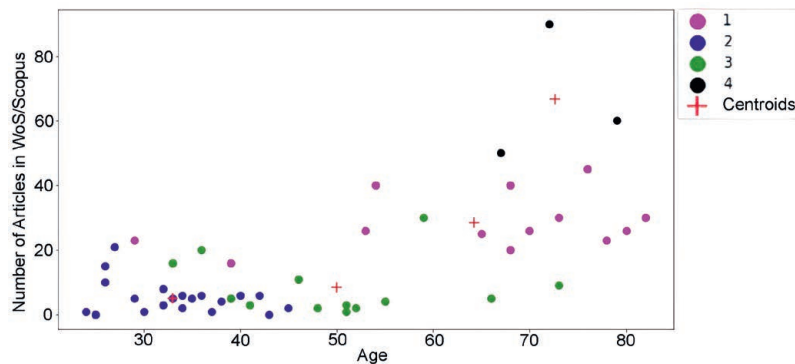


Fig. 5. Clustering of scientific personnel based on number of articles in WoS/Scopus

Based on obtained results, it is possible to conduct analyses and make conclusions on age groups, scientific productivity, fields of science, and universities. Currently, the availability of publications in various scientific fields and big data describing the careers of scientists create new opportunities for research in this field. Investigating the factors affecting the productivity of scientists, analysing factors that determine the migration of researchers, can help evaluate the intellectual potential at university and national level, manage scientific mobility, prevent migration of young, promising researchers, and take stimulating measures to increase the quality of conducted research. Note that monitoring and forecasting the scientific activity of institution in accordance with its potential, conducting analytical and statistical analyzes, preparing electronic reporting forms, ensuring the availability of scientific information and other issues made it necessary to create a unified electronic information system for scientific personnel.

Conclusion

1. Currently, the analysis of intellectual potential and the study of its impact on the socio-economic development of countries is one of the most topical issues. This article studies the analysis of the country's intellectual potential on the e-demography platform. The article studies the creation of a centralized population register, integration problems of various public registries, formation of e-demography sys-

tem, and scientific research conducted in this field. We must note that building and updating the population register and detailing of accessible statistics require integration of various information sources. In this context, formation of an e-demography system creates new opportunities for population research. Difficulties encountered when integrating public registers into a single platform include non-use of personal identification number in all registers; risks related to ensuring the security of personal data; privacy and confidentiality violations; inconsistencies in register data, errors, various inaccuracies, etc. This article reviews analysis of demographic indicators of scientific personnel on e-demography platform. In this study proposed conceptual model of scientific personnel management system. Main scientific result is study conceptual bases of register-based approach to develop unified state system. An integrated information system on scientific personnel has been developed for monitoring and forecasting of scientific activity in ANAS in accordance with existing potential, and performing analytical and statistical analyses.

2. Data on 50 scientific personnel members were analysed and clustered using *k*-means clustering algorithm and analysed based on age groups, academic degrees and publications. Distribution of scientific personnel based on age groups, division of highly qualified personnel, clustering of scientific personnel according to gender composition and publications in reputable scientific bases are presented. According to obtained results, the proposed system can be used to study the intellectual potential of the country and research the demographic profile of scientific personnel. The main advantage of the register-based approach is collection of more detailed statistics, improvement of management and regulation in field of evaluation and monitoring of scientific activity, assessment of intellectual potential and investigation of scientific migration processes, as well as improvement of the quality of analytical, statistical analyses and reports.

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Author contribution

Yusifov F. F. carried out the task setting for the study, formulated the structure and prepared the manuscript of the article.

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