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ANNOTATION
on dissertation work

for the degree of Doctor of Philosophy (PhD)
Specialty: 8D10103 – Public Health

Title: “Using Geographic Information Systems to Assess Medical-Social and Infrastructure Barriers to Emergency Medical Services”

Scientific Supervisor:
Assistant Professor, PhD Tuleshova G.T.

Local Scientific Consultant:
PhD Aldyngurov D.K.

International Scientific Consultant:
Assistant Professor, Aušra Beržanskytė

Author:
Chayakova A.M.

Republic of Kazakhstan
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Relevance of the research topic. Emergency medical care is critical to saving lives and providing rapid and effective treatment for serious illnesses and injuries [1-5]. The importance and relevance of research in emergency medical care is confirmed by the continuous increase in the number of accidents, incidents, cardiovascular diseases and other acute conditions requiring emergency intervention [5-7]. CVDs remain the leading cause of mortality and disability in developed countries, accounting for 32% of total mortality [8]. In addition, various epidemics and pandemics (e.g. COVID-19) also emphasise the importance of developing effective emergency medical care for rapid and consistent disease control [9-10].

This study addresses several objectives of the WHO global strategy to achieve health for all in the 21st century: reducing the prevalence of noncommunicable diseases (objective 8); research and health information support (objective 19).

The relevance of the study is determined by the priority of the National Project of the Ministry of Health of the Republic of Kazakhstan 'Quality and affordable health care for every citizen "Healthy Nation", the direction of affordable and quality medical care, task 1. ensuring wide coverage of the population with health care services. Also the direction 2. Formation of a modern system of epidemiological forecasting and response, task 1. Transition to a modern model of epidemiological surveillance of infectious diseases [11].

The authors found that there are few studies to examine the distribution of emergency medical care needs by locality and to explain the specificity of planning emergency medical services according to geographical distribution. The problem of rapid medical vehicle response times has been a persistent issue over the past decade. Moreover, these problems are reinforced by the increasing demand for emergency medical services. The optimum response time of 10 seconds, established by European researchers [12], plays a central role in the ability of the emergency medical service to remain available promptly. Call congestion poses a significant risk to emergency services [13]. Understanding the number of ambulance calls is very important as it affects the response time and standard of ambulance care. Fluctuations in the number of calls may result in more or less ambulance resources being allocated to emergency care, affecting patient outcomes [14].

Currently, methods of modelling and forecasting disease development remain the most relevant issues in epidemiology and public health as fundamental for planning and management of preventive measures [15]. Based on the collected geodata, issues such as determining the spatial distribution of health facilities, assessing the types of demand for health services, and modelling health service areas are addressed. GIS techniques can be applied to the integrated structure of administrative medical and geographical data as a valuable tool to improve the efficiency of health service delivery based on the needs of the population. The results of this study can be useful to senior health managers as an information source for emergency health care decision making. In addition, we found that little research exists at the local level to identify the needs of the

population in EMR conditions of neighbourhoods, which would enable effective response in such situations. GIS is an effective and promising tool for assessing the efficiency, responsiveness and accessibility of emergency medical care, but more research is needed to develop approaches for its use [16-20].

This study allows to develop proposals for practical healthcare, namely for emergency medical services in conditions of density and migration of population in urban environment, to identify the main barriers to emergency medical care, to justify proposals for monitoring and management decision-making in emergency medical care, including for emergency medical services. The use of GIS-technology allows geo-referencing of medical data, which in turn opens up new opportunities for scientific research in the field of emergency medical care. This allows for the analysis of ambulance call protocols, the determination of routes and arrival times, as well as the analysis of data on the condition of patients and the use of resources of medical institutions within the emergency care system. Such studies allow to identify and analyse specific features in the provision of emergency medical care, determine the effectiveness of the measures taken and develop recommendations to optimise the emergency care system.

Purpose of the study.

Justification of a model for assessing medical, social and infrastructural barriers to emergency medical care using geoinformation technology

Objectives of the study:

1. To conduct a comprehensive comparative analysis of international standards for the application of geoinformation technologies in healthcare.

2 Identify the barriers to emergency medical care and their classification.

3. Statistical analysis and modelling of the identified barriers to emergency medical care using geographic information technology.

4. Development of a recommendatory model of emergency medical care taking into account the identified barriers using geographic information systems.

The materials of the study were:

- databases of the automated management system ‘Komek 103’, which has been used at the ambulance station since the end of 2019, and automated information systems ‘ADIS for 2018-2023’;

- data from authoritative databases on scientific research (Web of Science, Scopus);

- GIS-technologies.

Research Methods.

Information-analytical, modelling, bibliometric, bibliographic, statistical methods.

Object of study.

Medico-social and infrastructural barriers to emergency medical care.

Scientific novelty of the research results:

1. For the first time, a spatial analysis of the territorial accessibility of emergency medical care in different districts of Astana city was conducted, which allowed to identify the influence of geographical, demographic and infrastructural factors on the quality of emergency care. This approach provided a deeper

understanding of the relationships between the location of medical institutions, transport network and response time of emergency services.

2. For the first time the significant features of COVID-19 pandemic impact on emergency medical care in the Republic of Kazakhstan were studied and identified. The analysis showed changes in the load on emergency services, redistribution of resources, as well as revealed new requirements for efficiency and medical personnel in conditions of increased risk of infection.

3. Models for optimal distribution and routing of emergency medical care based on GIS technologies are developed and proposed. The key components of the model include the analysis of spatial and temporal availability, forecasting the population's needs in emergency care, dynamic resource allocation and route optimisation. The new model makes it possible to automate the decision-making process and significantly improve the efficiency of the organisation of emergency medical care.

Subject of the study.

Emergency medical calls associated with coronary heart disease cases (I20-I25), COVID-19, GIS technology.

Research results and practical significance:

1. A model of emergency medical care using GIS technology has been developed to improve the effectiveness, efficiency and accessibility of emergency medical care based on scientific principles and data analysis.

2. Maps of territorial accessibility of emergency medical care for the population of Astana city have been developed.

3. The needs for emergency medical care before and after the COVID-19 pandemic have been identified.

Basis for conducting the study.

SCP on PCV ‘City Emergency Medical Aid Station’ of the Akimat of Astana city.

Main points to be defended:

1. Based on geospatial analysis and modelling of accessibility zones, it was found that in a number of districts of the city, such as Baikonursky, Saraishyk and Yesilsky, there are calls that go beyond the 10-minute accessibility zone. This indicates critical gaps in the provision of rapid emergency medical care in these districts, which requires improved logistics and reallocation of resources.

2. Modelling showed that the density of calls for coronary heart disease and COVID-19 is concentrated in central and densely populated areas of the city, leading to overloading of health services. The level of accessibility to the SMP and LPU within 3, 5 and 10 minutes shows satisfactory coverage, but a significant number of calls remain outside these areas, which poses a risk to patients with acute conditions.

3. Districts such as Baikonur, Sarayshyk and Almaty are characterised by high call frequency and insufficient access to emergency medical care within 10 minutes. This requires a review of resource allocation strategies and the

location of health facilities to reduce response times and improve the speed of care.

4. The COVID-19 pandemic resulted in a significant increase in the number of calls (56% at the beginning of the pandemic and 7% during the peak), exacerbating the problem of overloaded health infrastructure. Identified call hotspots require the reinforcement of medical staff and technical resources in the most affected areas to ensure timely delivery of care during crisis periods.

5. The developed GIS-data based emergency medical care model showed high efficiency in identifying critical areas with inadequate health service coverage. This confirms the importance of using spatial analysis for more accurate planning and rapid response in the face of increasing pressure on the health-care system.

Approbation and implementation of the research results.

The main provisions of the thesis were reported at international conferences in RK:

- assessment of barriers to emergency medical care using geographic information systems // International Scientific and Practical Conference of Students and Young Scientists 'Medical Science and Education: Youth and Striving - 2019' (Nur-Sultan, 1-2 October 2019);

- demand for the use of geoinformation technologies in emergency medical care // 'Science and Public Health' (Semey, 25 September 2020) ;

- dynamics of emergency calls during the COVID-19 pandemic in Nur-Sultan // scientific and practical conference of students and young scientists 'Insurance Medicine. Science. Education' (Nur-Sultan, 21-22 December 2020).

Certificate of state registration of rights to the object of copyright No. 26453 dated 24 May 2022, IP No. 26453 'Use of geoinformation systems to assess medical, social and infrastructural barriers to emergency medical care' (work of science), (Annex A).

Certificate of state registration of rights to the object of copyright No. 51129 dated 06 November 2024, IP No. 51129 'Trends of emergency medical aid calls before and after COVID-19 in Kazakhstan' (work of science), (Annex A).

Act of implementation of the results in practice of the State Enterprise on PCV 'Emergency Medical Aid Station' UZ Shymkent (Annex B).

Act of implementation of the results of research work of SE on PCV 'Regional station of emergency ambulance' of Aktobe region (Annex B).

Act of implementation of the results of research work of State Enterprise on the Municipal Emergency Medical Station of the Akimat of Astana (Appendix B).

Publications on the subject of the thesis. On the subject of the dissertation published 9 publications, including 4 in publications recommended by the Committee for Control in the field of education and science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 3 speeches and publication in collections and materials of international scientific and practical conferences in Kazakhstan; 2 articles published in the Open Access Macedonian Journal of Medical Sciences (SJR 0.288 in 2020, percentile on Citescore - 48%)

and ‘Georgian medical news’ (SJR 0.139 in 2023, percentile on Citescore - 31%).

Scope and structure of the thesis. The thesis consists of a table of contents, a list of notations and abbreviations, an introduction, a literature review, materials and methods of research, 4 sections of the results of own research, a discussion of the results obtained and a list of literature sources used. The total volume of the thesis is 99 sheets of computer text. The list of used sources contains 124 sources. The thesis is illustrated with 38 figures and 17 tables.

Personal contribution of the doctoral student. The dissertation of Chayakova A.M. is a completed independent work performed at a high scientific and methodological level. The author personally developed a model for assessing medical, social and infrastructural barriers to emergency medical care using geoinformation technology. The author directly participated in the collection and analysis of initial data, approbation of the research results, preparation of publications on the completed work, presentations at international conferences, preparation and receipt of author's certificates.

Results:

The study confirmed the importance of using GIS to assess and overcome health, social and infrastructural barriers to emergency medical care. Analysing spatial data with the help of GIS made it possible to identify areas with insufficient accessibility of medical services, as well as to identify key factors affecting the efficiency of emergency medical care.

Health and social factors such as population density, age structure showed a significant impact on the need for emergency medical care and its availability. Infrastructural barriers, including the location of health care facilities and availability of necessary resources, proved to be critical for timely delivery of care.

The use of GIS technologies has contributed to the creation of visual maps and models reflecting the current situation in the health care system, which will allow health care authorities to make more informed decisions on optimising ambulance routes, locating new medical facilities and redistributing resources.

The results of the study suggest that the integration of GIS into the planning and management of emergency medical care can significantly improve its efficiency and accessibility. It is recommended to continue the development of GIS tools for continuous monitoring and analysis of medical, social and infrastructural factors affecting the health care system. This study allows to develop proposals for practical health care, namely for emergency medical services in conditions of density and migration of the population of urban environment, to identify the main barriers to the provision of emergency medical care, to justify proposals for monitoring and management decision-making emergency medical care, including for the services of emergency medical services. The use of GIS-technology allows geo-referencing of medical data, which in turn opens up new opportunities for scientific research in the field of emergency medical care. Such studies make it possible to identify and analyse peculiarities in the provision of emergency medical care, to determine the effectiveness of measures taken and to develop recommendations for optimising

the work of the emergency care system.

The following **conclusions** are drawn on the basis of the research conducted**:**

1. Analyses of international standards and experience with GIS applications have established that GIS offer a rich set of methods and technologies that go well beyond the creation of digital maps. The use of GIS in health care contributes to improving the quality of care and optimising its accessibility by providing tools for spatial data analysis and administrative health data integration. GIS can be powerful tools for early identification of problems and for improving the planning and delivery of population-based health services. The results of the study confirm that GIS is useful for management decisions in emergency medical care, but more in-depth study and adaptation of approaches are needed for effective use at the local level.

2. The identification of barriers in the provision of emergency medical care found that the arrival time of ambulance crews increased during the analyzed period: from 15 minutes 5 seconds in 2020 to 16 minutes 56 seconds in 2024. The time from receiving a call to hospitalization in 2020 was 1 hour and 3 minutes, then decreased in 2021 and 2022, but increased again in 2023 and 2024, which may be due to increased load on the EMS system. It was found that the arrival time of ambulance crews increased on average during the study period. The time from receiving a call to hospitalization decreased in 2021, but then increased again in 2023-2024, which requires an analysis of the reasons for the slowdown in logistics and the reallocation of resources. During the study period, it was revealed that men were more likely to seek medical help for coronary heart disease, but the average age of women remained higher. A significant increase in calls among the 65+ age group indicates the need for increased attention to elderly patients. It was found that Monday is the day of the greatest workload: the analysis of calls showed that Monday is consistently the day of the greatest number of calls, which indicates the need for increased attention and resource optimization at the beginning of the week. An analysis of the time of emergency medical care for coronary heart disease found that the number of calls for coronary heart disease (I20-I25) has a pronounced seasonal variability. The largest number of calls is observed in the winter months (December, January, February). It was found that the most intense periods of calls occur during the daytime, especially from 10:00 to 11:00, which reflects the physiological rhythms and activity of patients. During the night hours (00:00-06:00), the number of calls is minimal, but remains consistently high for emergency medical care. This requires optimizing the allocation of resources and scheduling the work of ambulance crews depending on the daily peaks of activity.

3. Statistical analysis and modeling of barriers showed that 1.74% of calls are outside the 10-minute availability zone of the EMS. These areas are characterized by a high population density, which leads to an uneven distribution of the burden on emergency services. Cluster analysis showed statistically significant areas with an increased frequency of calls, confirming the presence of "hot spots" in central areas. Correlation analysis between population density and

the frequency of CHD calls revealed a positive relationship (Pearson correlation coefficient $r > 0.7$), which indicates the influence of demographic factors on the workload of EMS services. Regression models for predicting the arrival time of ambulance crews have shown that in areas with high call density, response time increases by 15-20% compared to the city average. It was found that the pandemic had a significant impact on the increase in the number of EMS calls, especially in 2021. Diseases caused by COVID-19 have contributed to an increase in referrals in the central and densely populated areas of the city, which underscores the importance of the EMS system's preparedness for such crises. The COVID-19 pandemic has significantly increased the burden on the healthcare system, which has resulted in an increase in the average response time of the EMS and the time from call to hospitalization. There has been an increase in the number of calls, especially during the winter months, which requires optimizing the allocation of resources on a seasonal basis. The calls that did not fall within the 3, 5, or 10-minute accessibility zones to the medical facility were highlighted - 469 out of 38333 (1.22%) such calls are located in the following districts of the city: Baikonur district, Saraishyk district, and Saryarkinsky district.

4. The development of an advisory model for emergency care, taking into account the identified barriers, has established that most of the calls fall within the 10-minute availability zone from the MPI and medical institutions. However, a certain percentage of calls go beyond this area, which requires improvements in the allocation of resources and logistics of emergency care. It was found that the call density for coronary heart disease was higher in the old districts of the city (right bank), which is related to the age structure of the population and the density of buildings. In the new areas, there was a lower call density, which is associated with a younger population. It has been established that areas with insufficient emergency coverage have been identified in the Baikonursky, Saraishyk and partially Yesilsky districts, which requires a review of logistics and the reallocation of resources to reduce response time. The new model provides analytical data for making decisions on the location of new ambulance and medical substations at strategic locations based on the projected needs and demographic characteristics of the areas. The introduction of new EMS and medical treatment facilities made it possible to achieve a significant reduction in the average transportation time: the time from the EMS to the call addresses decreased by 6.66 p.p. The time from addresses to medical facilities decreased by 4.51 p.p. The analysis showed that the placement of new facilities is especially effective for addresses with initially high arrival times. The creation of new MPIs reduced the number of such calls by 10-20 percentage points, and for medical institutions the improvement was 2-6 percentage points. Based on the simulation results, it is recommended to implement the priority placement of EMS facilities in the areas of Lesnaya Polyana – Kosshy, Talgat Nigmatullin and Polet streets. For medical institutions, the priority areas are No. 229 Street, Bypass Road and Dzhunusova Street. Continue monitoring the logistical efficiency of routes and accessibility zones using geographic data.

Practical recommendations:

1. Use geographic information systems (GIS) for continuous monitoring and analysis of ambulance calls in order to efficiently allocate teams and resources. Regularly update availability zone models to improve planning and minimize arrival time at the call location.

2. Based on the analysis of call density and arrival time, it is recommended to review the current location of emergency departments in Astana. Additional units should be created or existing ones reorganized in areas with increased workload, such as Baikonur and Saraishyk and Almaty districts, in order to reduce response time and increase the responsiveness of assistance.

3. Create rapid response plans for emergency situations, such as pandemics or natural disasters, with a clear allocation of resources (additional teams, transport, equipment) depending on population density and territorial specifics.

4. During crises such as the COVID-19 pandemic, provide temporary mobile emergency centers in areas with high call density (for example, Baikonur and Almaty districts) in order to reduce the burden on inpatient hospitals and speed up hospitalization.

5. In order to reduce critical response times, medical infrastructure should be strengthened in peripheral areas, especially in high-risk areas such as the Esil district. This may include the creation of mobile ambulance stations, as well as more dense coverage of territories with stationary points.

6. Based on the analysis of the call density by time of year and day, it is recommended to develop a forecasting and warning system. Such a system will make it possible to predict in advance the peak load on the EMS services, especially during the winter months and on Mondays, which requires the training of additional teams and resources.

7. Using the results of modeling accessibility zones to medical facilities, it is necessary to optimize the routes of delivery of patients, especially with coronary heart disease.