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UTILIZATION OF GIS SYSTEMS FOR FACILITIES PLANNING IN AREAS WITH HIGH RISKS OF EARTHQUAKE

Abstract. Current global urbanization similarly affects cities in Kazakhstan, namely Almaty, whose urban population is increasing year by year. Being a seismically active region, Medey district of Almaty city is one of the densely populated areas, which needs proactive measures in case of disasters such as earthquakes. The average magnitude of the earthquakes in Almaty is between 5-8. Therefore, this paper is going to utilize GIS system and programming tools for mapping simulations of earthquakes in this area and based on that estimate predictive needs. The software combined the GIS data with information from central departments, specifically the number of houses, hospitals or ambulances and fire stations. The Python software was utilized for data analysis. Taking into account the population of more than 200 thousand people there is a need for additional medical and fire station settings in the given region and reconsideration of location of constructed ones.

Keywords: earthquakes, GIS, Almaty, magnitude.

Introduction. Earthquakes are one of the most frequent natural disasters which lead to numerous human, economic and environmental losses. Thus, according to the global statistics within 2 decades more than three million people died and other almost 1 million people suffered from various injuries following earthquakes. The economic losses of this disaster exceeds more than fifty thousand dollars [1]. In this article we are going to discuss one particular region of Almaty city, which is the biggest city with more than 2 million population in Kazakhstan and is periodically exposed to earthquakes.

The national statistical center has published the recent data of the population of Almaty for the beginning of 2020 year, which is 1 million 916 thousand people, comprising almost 11% of the total Kazakhstan population [2]. Moreover, the borders of the city were extended during the last decade as a result of elevated urbanization both in the city and neighbouring districts. Historically, Almaty is referred to the cities with high seismic activity. The main reason is that the city is located in the belt of the Dzhungar and North Tien-Shan mountains, which are one of the highest mountains well-known for their frequently occured earthquakes. Until nowadays the magnitude of the earthquakes varied between 4-8,5 [3]. Due to the growing urbanization the city is widening and most regions which were far away from the mountainous regions became close to the seismically active zones. It has been revealed that earthquakes occur almost with frequency up to 1-2 years with the magnitude from 2 to 5, slowing down to the center of the city [4]. For this reason it is increasingly important to reestimate the probability of the earthquakes in the new resided parts of Almaty city as Medey district. As we assume that improved seismic maps will be an important tool in better preparedness in such a catastrophic natural disaster as an earthquake.

There is likelihood of building damages after the earthquakes which is defined as a seismic risk. However, there is a variety of vulnerability of the seismic activities which can result in many losses, both human and material.

Taking into consideration aforementioned evidence that Almaty city is under the hazard of getting high human and economic losses, we are aiming to develop simulations of the earthquakes happening at each possible magnitude in the Medey district of Almaty city. The literature review has revealed that within the last 2 decades the geographical information systems (GIS) are the most effective tools for the use in these purposes. The GIS was applied in the other seismic countries in the world, such as the United States, China and Japan [5]. Apart from the GIS program, there have been other programs for shelters` evaluation and prediction as SYNER-G and Hazus [6]. In addition, these GIS systems may simulate different scenarios of the earthquakes and demonstrate possible episodes of the disaster using available geographical, geological and spatial databases [7].

Thus, basically the data is directed towards the urban population. Historically, such systems as HAZUS and RADIUS were in use in the other countries, but showed the limited data usage leading to the inappropriate estimations and seismic risk predictions [8]. These systems did not take into consideration historical buildings and construction which lie away from the modern borders of the cities which are now included in the official area of the cities. Additionally, there is a lack of the initial data for those GIS systems about the geological compositions of the grounds and involvement of the engineer-specialists. Other systems use seismic zones and and postseismic estimations data. These GIS systems are a crucial approach in low and middle income countries to lessen the burden of economic losses and overcome the possible negative effects [9].

The initial targets of the usage of this system is by utilizing available geographical and retrospective data of regional earthquakes to develop predictive models of possible earthquakes of the particular districts. Thus, the GIS can demonstrate the possibility of construction damage depending on the magnitude of the earthquake, taking into account the type of the material from which the building was constructed. In this way, such prediction helps authorities to plan strategic action [10]. By action we suppose the use of human and technical resources, which will consequently contribute to minimization of unplanned financial expenditures, which are needed to manage post earthquake damages and losses. There are several crucial services which need to be fully prepared in the case of such disasters as medical staff, hospitals, fire stations and especially shelters [11]. Therefore, this paper will describe the application of GIS for simulation of severity of damages after the earthquake and try to predict the different needs after earthquakes by mapping them in the example of Medey district. The main steps to achieve the aim are:

- Getting the spatial data from reliable source
- Definition of the studying site in seismic region of Almaty city
- Investigate the geological composition of the grounds in the site
- Determining the building types and material of the constructions
- Utilize a seismic activity database
- Combine all databases

- Elaborate the GIS system
- Simulate the possible earthquake magnitudes
- To show the distribution of services at emergencies

Methods.

Study object and population

The Medey district of Almaty city was chosen as the main study object. This district is located at the foot of the Ile Alatau, which is the part of the Tian-Shan mountains. The height of the mountains varies between approximately 3000-5000 meters, while the highest peak is the Talgar with the height of 5017 meters. All 4 seasons have intrinsic features with hot summer months and snowy winter months. Medey district occupies almost 37% of the total area of the city and it is a dwelling place for almost 300 thousand residents [12].

Data preparation and analysis

The GIS system was used to perform maps of the location of medical settings and fire stations in the Medey district of Almaty city. The software combined the GIS data with information from central departments, specifically the number hospital or ambulances and fire stations. The Python software was utilized for data analysis. To get the outcomes and data visualization the plotly and mapbox libraries were used. The databases were uploaded to the GIS system and processed using the information about the ground composition, morphology, number of residential sites, their density, slopes and altitudes. After which each seismic zone was divided by the layers corresponding to the severity of damage following the predicted earthquake at a given magnitude.

Results. Having been the largest city, Almaty occupies more than 804 thousand square kilometers. There is a map of the city in the Figure 1, which shows its borders with other neighboring cities and the part of the mountainous region in the southeastern side.

Figure 1. The area of Almaty city

The highest points of the earthquake magnitudes are presented in Figure 2, showing the location of main seismic sites in the Medey district. Red dots on the picture demonstrate that the possibility of the earthquake is high and damage could exceed minimal threshold in those areas. Additional analysis shown in Figures 3-7.

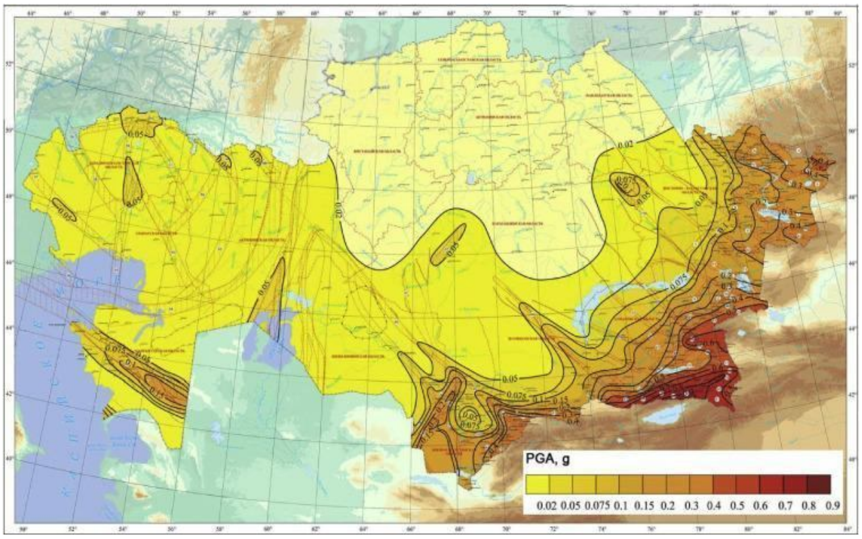

Figure 2. The points of high earthquake magnitude in the Medey district

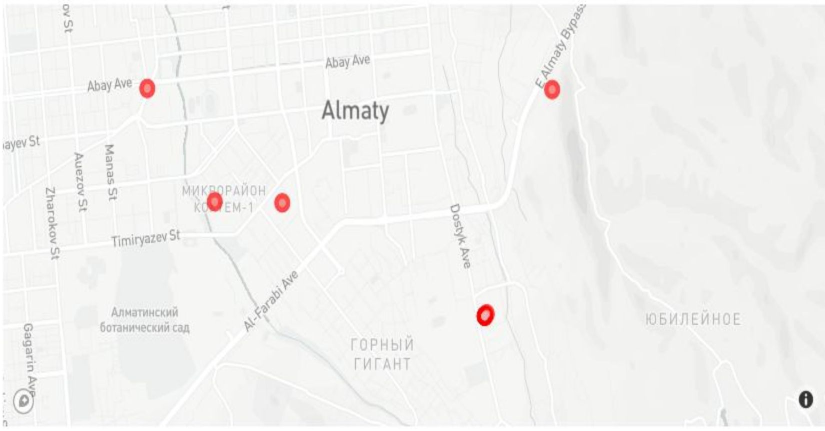

Figure 3. The map of general seismic zoning of the territory of Kazakhstan (Almaty) in PGA for probability of exceeding 2% during 4 years

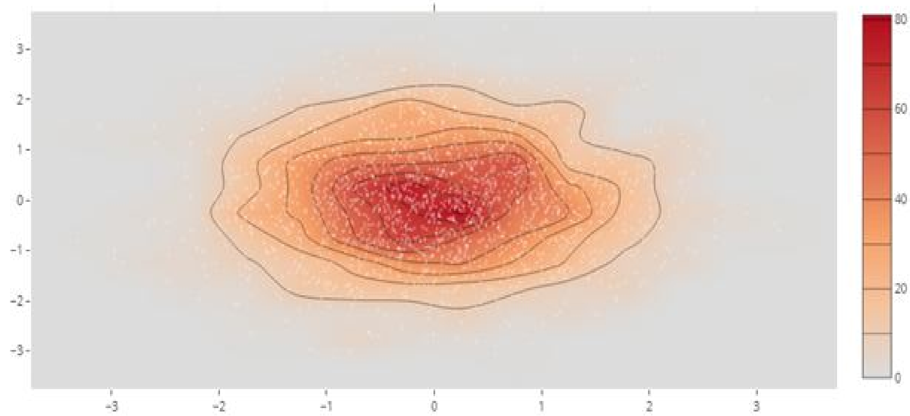

Figure 4. Clipping from the map of seismogenerative zones of Kazakhstan's Earth crust The rectangle outlines the seismic sources considered in the analysis. The contour of Almaty (Medeu District) is shown in the center

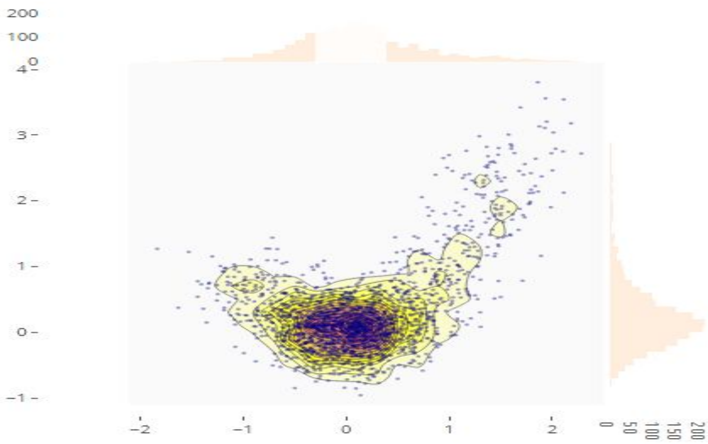

Figure 5. The distribution of epicenters of earthquakes with $M \geq 3.0$ from historical time to 2019. The inset shows earthquakes with energy classes of 4–12 occurred near Almaty in 2015–2017. The rectangle outlines the area considered in the analysis

Figure 6. Histograms of the earthquake number distribution by magnitude (red) and depth (green) in the declustered catalog used to determine the recurrence parameters(Almaty, Medeu District)

Based on the analysis from the Figure 6, it is seen that distribution of epicenters with a magnitude higher than 3.0 within given years is since July 2016 and in the beginning of the 2017 year it is reaching the highest point. Therefore, based on the availability of the data it is assumed the elevating trend of the high epicenters in the Medey district up to these days.

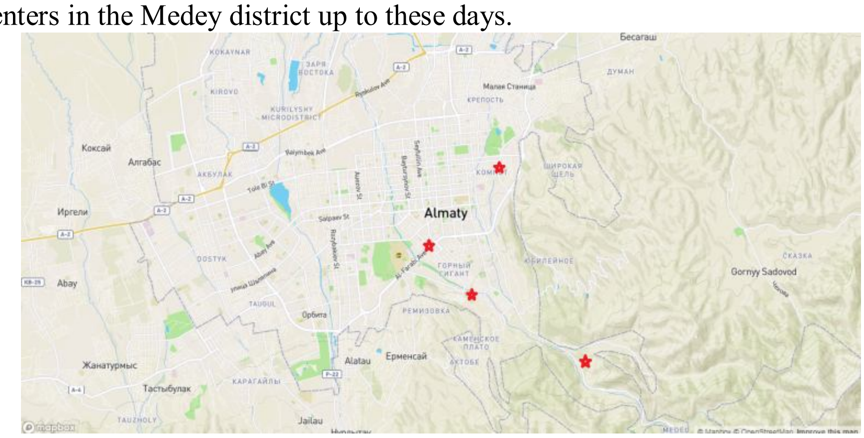

Figure 7. The distribution of fire stations in Almaty city

According to the demonstrated map, most of the fire stations are situated in the southeastern part, but there is a lack of them in the south part, where the main Alatau belt lies. This approach is essential in the emergency situations when substantial technical resources are needed to reduce losses from fires resulting from mountainous earthquakes.

In the Figure 8 is shown the location of local medical settings which are located sparsely in the city. It is seen that their numbers are in the belt of the mountains, which could put them under the thread of destruction as a result of earthquakes` activities. Therefore, the relocation and proper management of this question needs further investigation.

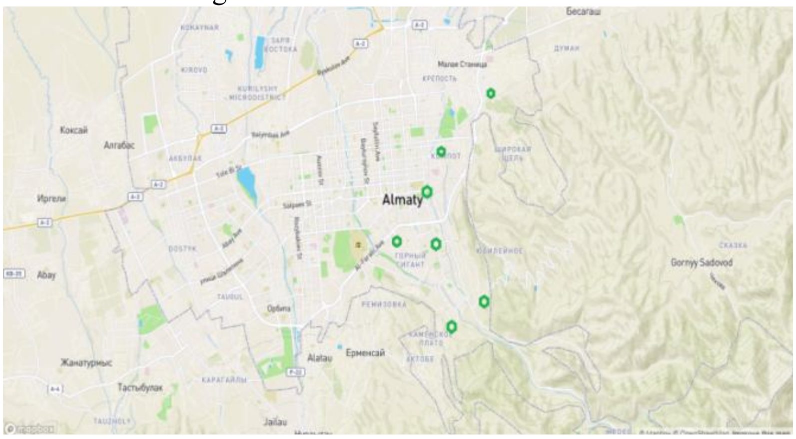

Figure 8. The distribution of medical settings in Almaty city

Conclusion. The main question in this natural disaster is the optimal way of risk assessment based on the modern approaches of probability assessment of the earthquakes in different magnitudes to make consequent losses and damages of the event as less as possible, especially minimize the losses of human resources. From analyzed maps it was observed that nowadays most of the mountainous regions of the Medey district in Almaty city are densely populated and those areas are at high risk of highest damages in case of the earthquakes. Taking into account the high number of the population this issue needs a proper solution and preparedness plan [13]. Utilized GIS system mapping and simulations in this study showed that Almaty city is under the high risk of earthquakes year by year. Since there is an elevated trend of seismic vulnerability in the region standardized measures have to be taken to start planning proactive activities. One of the main advantages of this system is comprehensive usage of the big statistical databases as well as available high quality spatial resources which enable the the actors of this problem to have easy-to-use and take needed measures in the short period of time. The Probabilistic Common Seismic Zoning maps of the region of Kazakhstan and the large-scale maps of the city of Almaty are developed and arranged for consideration in administrative archives. The latter ones will be utilized as foundation maps in seismic microzoning of Almaty that's beneath development. The information utilized to create the simulation maps in Almaty consists of an upgraded database of all accessible data, e.g. updated seismic tremor catalogs, reexamined outline of seismic source model and advanced ground movement expectation equations. More importantly, once a GIS based approach is adopted, the danger investigation can be expanded to multiple scenarios, the input factors can be overhauled and adjusted, and the demonstration can be robotized in an expert systems technique so that it can be utilized on a routine premise without coordinate master input [14].

The elaborated GIS system is able to analyze retrospective data for better prediction of seismic activities for 2 objectives 1) simulation and 2) showing risk scenarios. Therefore, based on the GIS system, the constructions in the Medey district have to follow strict rules which will guarantee the protectiveness in the earthquakes of the average magnitude in the district. The system can give a chance to geologists and other specialists involved in this domain to divide the residential sites to high, moderate and low risk of damage after the event. Moreover, simulations which show the destruction of those residential buildings will give the information about the necessary shelters in case of high magnitude earthquakes. Thus, the stakeholders will be able to calculate costs of the losses and predict the necessary amount of budget to cover them. The complex scenario demonstrated in the simulation will give an opportunity to be prepared in possible emergency conditions. The GIS system additionally is an irreplaceable tool which is able to continuously update the spatial information and connect other necessary data in emergency [15].

According to the previous research findings and guidelines, the most important services which have to be planned in seismic areas are hospitals, fire stations, shelters and the number of transportation. The main aim of all medical units is to be able to provide medical care to those who are in demand within 24 hours, but not later than 72 hours [16]. In accordance with the epidemiological data the mortality and acute morbidity is higher in the regions where emergency medical care is delayed. Firstly, all medical buildings are needed to be spread based on the triage system. The triage system is a location of the constructions on the rationale of their need. Thus, there should be an additional 2 medical settings for sufficient provision of medical services in the Medey region to more than 200 thousands residents. There have to be 3 physicians per every medical center, who work for 12 hours as a 1 shift. Additionally, in the nearest safe area should be separated the place for the helicopter, which will provide transportation in case when roads are unavailable or fire is present [10-11].

Another important facility is the fire stations. The fire itself may cause more losses than the earthquakes, leading to the high cases of death and being a reason of inability to provide any other help because of the inaccessibility of the roads.

The earthquakes as a natural occasion will remain actual at any time. Therefore the level of preparedness is a key to prevent any losses and especially human resources. The application of the GIS system will help to save time and react in a proper way with sufficient amounts of care or facilities. As such disasters need the intersectoral collaboration, the GIS system will be an irreplaceable tool for better understanding in a visual way for actors in this emergency situation. GIs modeling gives a really helpful stage for the assessment of seismically actuated avalanche hazard. The advantage of this approach is that regional geological, geomorphological, and height information can be promptly combined inside the GIS model and then can be analyzed employing a pseudo-static seismic slope stability investigation, a ground shaking constriction demonstration. Then again, it can be easily modified and acknowledge unused, user-specified capacities, e.g., different constriction laws for seismic risk appraisal or different powerlessness capacities, to meet wants and requirements pertinent in other districts.

The recommendations consequent of this study are the followings:

- to use this tool in other seismic regions and connect them with governmental control systems, who are responsible for decision-making processes;

- to share the predictive simulations to all actors involved in the emergency situations;

- to be close with geological organizations who provide up-to-date information of changes about the ground;

- to use by the stakeholders who responsible economic questions in emergencies;

- To give access for the other scientists who are interested in the further improvement of this problem at high magnitude.

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ИСПОЛЬЗОВАНИЕ ГИС-СИСТЕМ ДЛЯ ПРОЕКТИРОВАНИЯ ОБЪЕКТОВ В РАЙОНАХ С ВЫСОКИМ РИСКОМ ЗЕМЛЕТРЯСЕНИЯ

Аннотация. Глобальная урбанизация затрагивает и города Казахстана, в частности город Алматы. Будучи сейсмически активным регионом, Медеуский район города Алматы является одним из густонаселенных районов, который нуждается в активных мерах в случае таких стихийных бедствий, как землетрясения. Средняя величина землетрясений в Алматы составляет 5-8 баллов. Поэтому в этой статье будут использоваться система ГИС и инструменты программирования для составления карт моделирования землетрясений в этой области и на основе этой оценки прогнозируемых потребностей. Программное обеспечение объединило данные ГИС с информацией из центральных департаментов. Программное обеспечение Python было использовано для анализа данных. Для получения результатов и визуализации данных использовались библиотеки plotly и mapbox.

Ключевые слова: землетрясения, ГИС, Алматы, магнитуды.

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ЖЕР СІЛКІНІСІ ҚАУПІ ЖОҒАРЫ АУДАНДАРДАҒЫ НЫСАНДАРДЫ ЖОБАЛАУДА ГАЖ ЖҮЙЕЛЕРІН ҚОЛДАНУ

Аннотация. Жаһандық урбанизация Қазақстанның қалаларына, атап айтқанда Алматы қаласына әсер етуде. Алматы қаласының Медеу ауданы сейсмикалық тұрғыдан белсенді аймақ бола отырып, халық тығыз қоныстанған аудандардың бірі болып табылады. Алматыдағы жер сілкінісінің орташа күші 5-8 баллды құрайды. Сондықтан, бұл мақалада жобалау қажеттіліктерін бағалау негізінде осы аймақтағы жер сілкінісін модельдеуді картаға түсіру үшін ГАЖ жүйесі мен бағдарламалау құралдары пайдаланылады. Бағдарламалық жасақтама ГАЖ мәліметтерін орталық бөлімдердің ақпараттарымен біріктірді. Python бағдарламалық жасақтамасы деректерді талдау үшін пайдаланылды. Нәтижелер алу және деректерді визуализациялау үшін plotly мен mapbox кітапханалары пайдаланылды.

Тірек сөздер: жер сілкіністері, ГАЖ, Алматы, магнитуда.