https://doi.org/10.5194/nhess-2023-105
Preprint. Discussion started: 18 August 2023

Natural Hazards and Earth System Sciences
Discussions

Regional seismic risk assessment based on ground conditions in Uzbekistan

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Abstract. The assessment of losses from strong earthquakes and the reduction of earthquake consequences are of a great importance in maintaining the seismic safety. Special attention is given to evaluating the magnitude of economic losses caused by earthquakes, particularly the assessment of different levels of seismic risk, in order to protect the population and territories located in seismically active areas. To ensure sustainable development of countries, it is essential to estimate the economic losses that will occur in regions due to strong earthquakes and forecast them within the specified return periods at a given probabilities. Measures can then be implemented to mitigate the consequences of earthquakes.

For the basis of seismic risk assessment, maps of seismic intensity increment and an improved map of seismic hazard have been developed, taking into account the engineering-geological conditions of the territory of Uzbekistan and the seismic characteristics of soils.

For seismic risk map development, databases were created based on GIS platforms allowing us to systematize and evaluate the regional distribution of information on seismic hazards, number of buildings and construction types, coefficient of the seismic vulnerability of buildings, cadastral value of buildings, etc.

1. Introduction

As of January 1, 2022, the permanent population of Uzbekistan reached 35,271,276 people. Currently, approximately half of all Uzbekistan citizens (17.9 million people) live in urban areas and 17.4 million people live in rural areas. At the territory of Uzbekistan and adjacent regions, both during the historical period and recent years, earthquakes with a magnitude of $M \geq 7$ and an intensity at the epicentre I_0 reaching 9–10 according to the MSK-64 scale have been recorded (Table 1). Therefore, the problem of ensuring seismic safety at the territory of Uzbekistan is very relevant. The geological structure of Uzbekistan is very diverse, but the territory basically consists of two tectonic structures of the Tien Shan orogenic region and Turan plate. The current state of relief in the territory of Uzbekistan was preceded by long difficult stages. In the territory of Uzbekis tan, tectonic movements are actively continuing nearly everywhere. In the geological history of Uzbekistan, throughout all stages of development, in particular, in the formation of the modern structural plan, faults, especially zones of deep faults, played an important role. These faults transect the entire Earth's crust, often penetrate into the mantle and are the natural boundaries of large structural elements. These faults influence disaster preparedness and risk reduction activities. One of the challenges in assessing seismic risk is considering the determination of soil conditions in the modification of seismic effects on the Earth's surface. Therefore, one of the tasks of this study is to investigate the geological environment and the patterns of seismic wave propagation through it. This is because this effect is directly dependent on the structure and depth of the geological and lithological differences of the rock formations comprising it.

Table 1. Destructive earthquakes in the territory of Uzbekistan and near its borders. The parameters of these earthquakes are retrieved from the database of the Institute of Seismology, Academy of Sciences of the Republic of Uzbekistan (2017).

№	Date	Name	Latitude	Longitude	M	Depth, km	Intensity, MSK-64
1	1868, August 3	Tashkent	41,2	69,6	6,5	18	VIII
2	1883, November 14	Osh	40,59	72,8	5,5	12	VII
3	1886, November 29	Tashkent	41,4	69,5	6,0	14	VIII
4	1888, November 28	Costakoz	40,2	69,3	5,6	10	VIII
5	1902, December 16	Andijan	40,8	72,3	6,4	10	IX
6	1903, March 28	Aimsk	40,8	72,69	6,1	14	VIII
7	1907, September 15	Kyrkkol	40,3	72,5	5,8	10	VIII

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8	1908, March 24	Namangan	40,9	71,0	5,4	26	VIII
9	1912, January 23	Namangan	41,02	71,7	5,2	12	VII-VIII
10	1924, July 12	Kurshabian I	40,5	73,1	6,4	25	VIII
11	1924	Kurshab II	40,59	73,19	6,5	14	IX
12	1926, May 28	Jalal-Abad	40,9	73,1	5,4	9	VII-VIII
13	1927, August 12	Namangan	41,0	71,6	6,0	14	VIII
14	1929, November 18	Chilean	41,5	63,5	5,2	-	VIII
15	1932, February 10	Tamdybulak	41,3	65,2	6,1	25	VII
16	1935, July 5	Boysun	38,3	67,4	6,2	16	VIII
17	1935, May 31	Bulungur	39,6	67,1	5,4	20	VII
18	1937, December 18	Pskem	42,1	70,9	6,4	17	VIII
19	1942, January 18	Yartepa	41,1	71,6	6,2	18	VIII
20	1946, November 3	Chatkal	41,9	72,0	7,5	25	IX-X
21	1947, June 2	Naiman	40,9	72,3	5,9	9	VII-VIII
22	1955, July 19	Bakhmal	39,7	68,0	5,2	21	VI-VII
23	1959, October 25	Burchmulla	41,67	70,0	5,7	13	VIII
24	1965, March 17	Koshtepa	40,7	69,6	5,5	11	VII
25	1966, April 25	Tashkent	41,33	69,28	5,3	8	VIII
26	1968, March 13	Kyzylkum I	42,43	66,47	5,3	30	VII
27	1968, March 14	Kyzylkum II	42,59	66,45	5,0	30	VII
28	1968, July 8	Baysun	38,11	66,9	5,0	15	VI-VII
29	1970, January 19	Pskent	40,83	69,33	5,0	20	VII
30	1971, October 28	Chatkal	41,95	72,25	5,6	25	VI-VII
31	1976, April 8	Ghazli I	40,33	63,67	7,0	25	IX
32	1976, May 17	Ghazli II	40,28	63,38	7,3	20	IX
33	1977, January 19	Isfara-Batken	40,11	70,79	6,4	15	VIII
34	1977, April 21	Khaidarkan	40,11	70,95	5,7	14	VII
35	1977, December 6	Tavaksai	41,58	69,68	5,1	25	VII
36	1980, December 30	Nazarbek	41,33	69,05	5,5	12	VIII
37	1982, May 6	Chimyon	40,0	71,42	5,5	12	VIII
38	1984, February 17	Papal	40,22	71,5	5,6	14	VIII
39	1984, March 19	Gazli	40,38	63,36	7,2	15	IX-X
40	1985, October 28	Kairakkum	40,28	69,8	5,5	15	VIII
41	1987, March 26	Altyntepa	41,72	70,05	5,0	8	VII
42	1988, December 21	Shamaldysai	41,28	72,19	5,5	15	VI-VII
43	1992, May 15	Izbazkent	40,99	72,4	5,9	25	VIII
44	1999, December 25	Kamashi	38,64	66,42	5,1	12	VII
45	2000, April 21	Kamashi	38,68	66,52	5,0	10	VII
46	2000, January 19	Kamashi	38,66	66,5	5,0	10	VII
47	2007, January 27	Sumsar	41,38	71,31	5,1	12	VI-VII
48	2008, January 1	Gulchin	40,32	72,97	6,0	20	VIII
49	2008, October 28	Jalal-Abad	40,98	73,16	5,1	9	VII
50	2008, August 22	Tashkent	41,3	69,4	5,0	10	VI-VII
51	2011, July 19	Kanskoe	40,16	71,42	6,1	10	VIII
52	2013, May 24	Tuyabogoz	40,89	69,15	5,6	18	VII
53	2013, May 26	Marzhanbulak	39,96	67,34	6,1	18	VIII
54	2017, September 29	Bakhmal	39,75	67,91	5,1	5	VI-VII

Risk assessment is a necessary and important step of any other disaster prevention activity. The urgency of this problem is reflected in numerous publications. The first systematic earthquake risk assessment studies were conducted in the late 1960s and early 1970s. Publications from that period (Cornell, 1968; Algermissen et al., 1972; Keilis-Borok et al., 1973; Whitman et al., 1975; Lomnitz and Rosenblueth, 1976) laid the foundation for future research. activities.

Assessment of risk is a necessary and important first step of any other disaster prevention activities. The relevance of this problem is reflected in numerous publications. The first systematic earthquake risk estimation studies were performed at the end of the 1960s and beginning of the 1970s. Publications from that period (Cornell, 1968; Algermissen et al., 1972; Keilis-Borok et al., 1973; Whitman et al., 1975; Lomnitz and Rosenblueth, 1976) laid the groundwork for future activities. In recent decades, especially during the International Decade for Natural Disaster Reduction (IDNDR, 1990–2000), there has been growing recognition of the problem within the world community. The change in emphasis from hazard to risk, intensified by a sequence of disastrous earthquakes worldwide, has caused the development of procedures and techniques for seismic vulnerability, damage and risk analysis on different geographical scales, e.g., PELEM (1989), Chen et al. (1992, 2002), Papadopoulos and Arvanitides (1996), King et al. (1997), McCormack and Rad (1997), Zonno et al. (1998), FEMA-NIBS (1999), Faccioli and Pessina (2000), RADIUS (2000), Bendimerad (2001), Fah et al. (2001), Coburn and Spence (2002), Lang (2002), Frolova et al. (2003), Giovinazzi and Lagomarsino (2004), Mouroux et al. (2004), Schwarz et al. (2004), Trendafiloski and Milutin (2004), Tyagunov et al. (2006), Di Pasquale et al. (2005), Wang et al. (2005), Alkaz, V.G., et al. (2012) and many others. Different interpretations of the risk concept can be found in different publications, although the general consensus is that risk is a quantified possibility of losses.

The combined aspects of the seismic hazard distribution, seismic vulnerability and exposed assets provide the necessary basis for seismic risk analysis. A similar analysis of the territory of Uzbekistan was the goal of this study, conducted as part of the implementation of the above paragraphs of the Decree of the President of the Republic of Uzbekistan dated July 30, 2020, No.4794, by the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan.

To develop a seismic risk map for the territory of Uzbekistan, databases were created based on GIS platforms allowing systematization and evaluation of the regional distribution of information on seismic hazard, number of buildings and structural types, geographical location of residential buildings, coefficient of the seismic vulnerability of buildings and territories, cadastral building value, etc.

The developed seismic risk analysis algorithm used the capabilities of GIS, combining data on the spatial distribution of seismic hazards, vulnerability of buildings, geographical location of residential buildings, and values, i.e., cadastral value of buildings at risk of damage and loss, in a layer-by-layer manner. Seismic vulnerability analysis was conducted using GESI_Program, which is based on the methodology for the assessment of seismic damage to buildings. At the same time, the existing buildings in the territory of the republic were collected and classified according to the building structural type. There are 5 types of buildings: buildings built using local clay materials, brick buildings, wooden buildings, buildings constructed using a metal frame and reinforced concrete buildings. In previous studies of urban and regional territories, seismic data analysis considered the influence of local soil conditions (microzoning and detailed zoning), inventory of buildings and asset values (element-by-element inventories or based on representative units) (Ismailov, V.A. et al. (2022a), Ismailov, V.A et al. (2022b)).

The developed seismic risk map of the territory of the Republic of Uzbekistan was based on an assessment of probable economic losses within administrative districts combined with seismic hazard factors, seismic vulnerability and concentration of values, ranging from zero to hundreds of trillions of Uzbekistan soms. It is important to emphasize that the level of seismic hazard used in the calculation of physical and economic damage corresponds to a 90% probability of not exceeding seismic impacts over a period of 50 years, which corresponds to an average return period of 475 years. This level of probability is the generally accepted standard in seismic hazard assessment during the design and construction of conventional buildings and structures. Of course, considering a different probability, level of hazard and consequently, the assessment of damage and potential losses may differ from the data presented.

In the development of map of seismic risk for the territory of the Republic of Uzbekistan, seismological and macroseismic databases of the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan, database on the housing stock of Uzbekistan of the State Cadastral Agency under the Tax Committee of Uzbekistan and research experience and publications of the Institute of Seismology and the Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan and JSC ToshuyjoyLITI were considered during the implementation of this research.

The present study is concentrated on the assessment of direct economic losses that may be caused by structural damage to residential buildings as a result of seismic actions. At the same time, given that residential buildings predominate in the development of cities and administrative districts in Uzbekistan, the presented results could serve as a clear reference for a comparative analysis of seismic risk in various administrative districts.

2. Materials and Methods

2.1. Characteristics of the engineering-geological conditions

Based on the analysis of geomorphological and geologic-lithological structure, as well as the peculiarities of groundwater distribution and exogenous geological processes, engineering-geological zoning has been conducted.

The peculiarities of the engineering-geological conditions of Uzbekistan's territory have been identified and described in the works of G.A. Mavlyanov, A.I. Islamov, P.M. Karpov, S.M. Kasymov, R.F. Kirsanova, A.M. Khudaibergenov, M.Sh. Shermatov, K.P. Pulatov and others. Based on their studies, the territory has been divided into 12 regions and each region has

https://doi.org/10.5194/nhess-2023-105
Preprint. Discussion started: 18 August 2023

been further subdivided into separate districts and sections, which are then presented in the form of an engineering-geological zoning map (see Fig. 1).

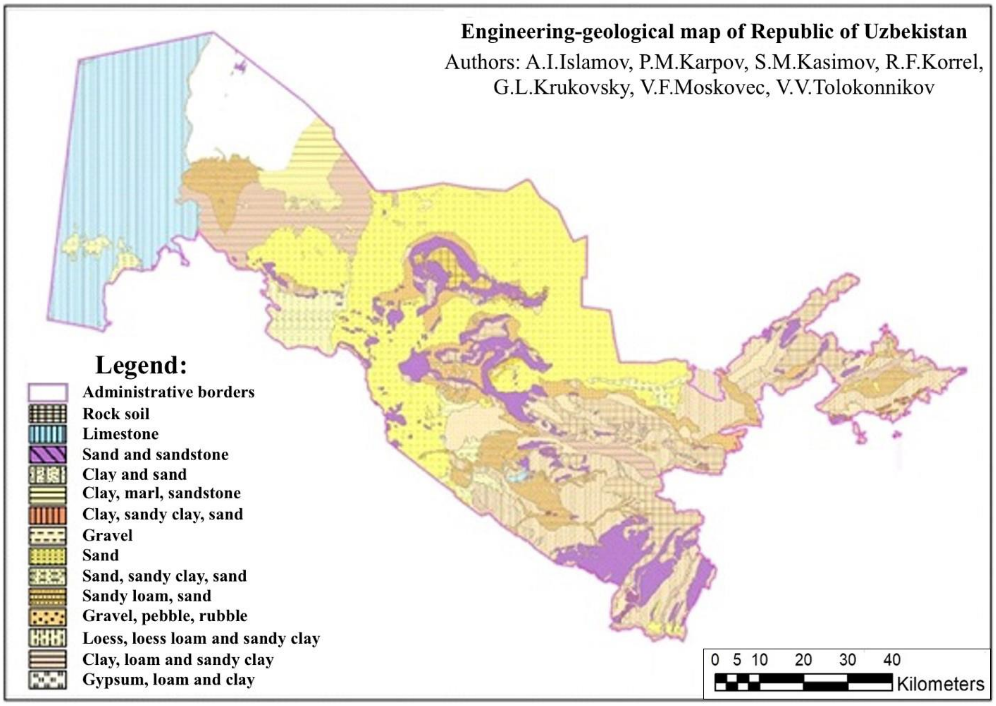

Figure 1: Engineering-geological map of Republic of Uzbekistan.

The complexity of geological structure of the upper soil layers (10-15 m), the diversity of petrographic and lithological composition of soils, the geomorphological characteristics and the unique climate determine the variety of engineering-geological conditions in Uzbekistan's territory. The main features of the republic's orography are closely related to the peculiarities of the geological structure of numerous mountain ranges. Wide plains, intermountain uplifts and depressions are located between the mountain ranges, characterized by an abundance of weathering products.

The complexity and diversity of the engineering-geological conditions in Uzbekistan can be explained by the broad distribution of different geological and lithological strata, which exhibit a certain zoning. While metamorphic, igneous, and sedimentary rocks are developed in mountainous and foothill areas, gravel, pebbles, sands and loamy deposits are prevalent in the vicinity of mountains. Aeolian and alluvial loams, loess soils and sands are widespread in lowland areas.

The first groundwater tables are distributed at various depths depending on the geomorphological structure. The highest groundwater levels are observed in the plains, especially in areas with active agricultural land development. Groundwaters in rock deposits are mainly confined to fractures and fault zones.

Exogenous geological processes are primarily developed in mountainous and foothill plains and are represented by landslides, rockfalls and soil erosion.

2.2. Assessment of Seismic Hazard Considering Soil Conditions

The peculiarities of seismic intensity increment variations across the territory of the Republic have been examined. A methodology for assessing the seismic hazard of the Republic's territory, taking into account the soil category, has been developed. An improved seismic zoning map of the territory of the Republic of Uzbekistan (OSR-2017) has been compiled, considering the soil category based on seismic properties (see Fig. 2).

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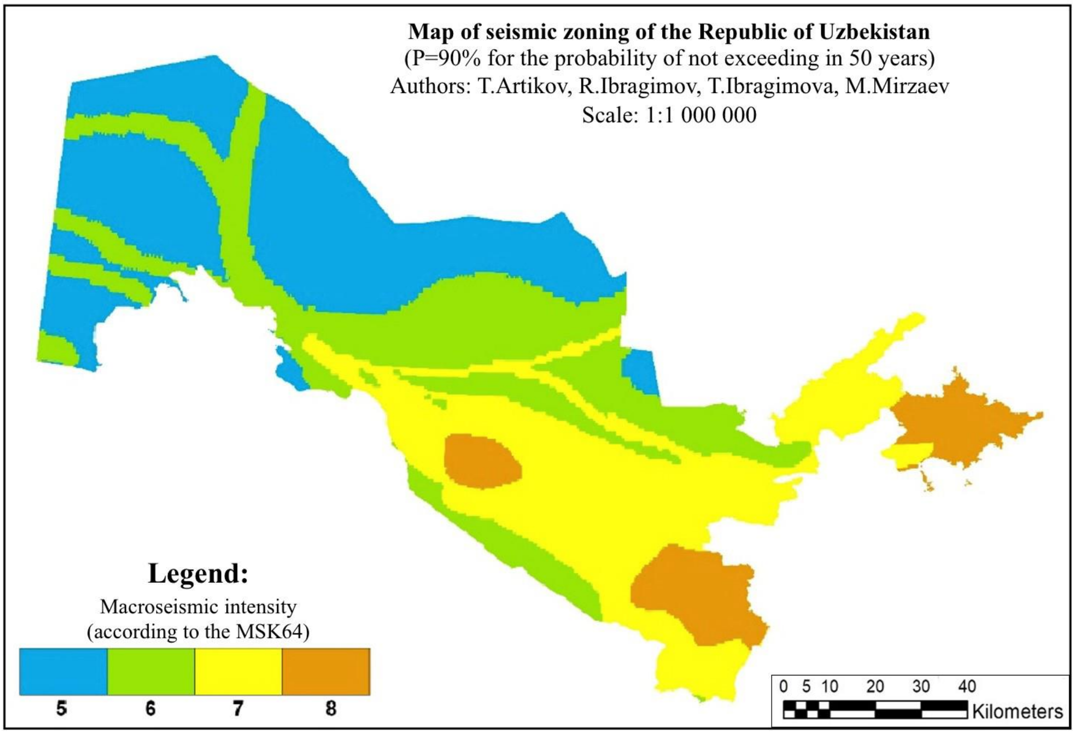

Figure 2: Map of seismic zoning of the Republic of Uzbekistan (OSR-2017).

The assessment of seismic risk in the territory of the Republic of Uzbekistan was conducted taking into account the experience of developed countries such as Germany, Japan, Italy, Russia, Moldova and others. The basis for this assessment was the seismic zoning map for a 90% probability of not exceeding seismic effects over a 50-year period. Therefore, we adopted the seismic zoning map of the territory of Uzbekistan (OSR-2017) (Artikov, T.U., et al. (2020)) for evaluation of seismic hazard of the territory. It is important to note that the seismic zoning map was developed for average soils and did not consider other soil categories.
According to the building code of the Republic of Uzbekistan No.2.01.03.19, all soils are classified into three categories based on their seismic properties and the corresponding increments of seismic intensity are determined for each category. The soil types according to State Standard No.25100-2011 are taken into account in a 10-meter profile. For the 1^{st} Category of soils, the seismic intensity increment is reduced by 1; for the 2^{nd} Category the seismic intensity is as it is; for the 3^{rd} Category of soils the increment is increased by 1 compared to average soils. It should be noted that 1^{st} Category comprised of rock soils, while 3^{rd} Category includes clays, loess and other type soils with low seismic resistance. Based on this, a map of seismic intensity increments has been created with a scale of 1:1000000. The territory of the Republic of Uzbekistan has been divided into zones with increments of seismic intensity of +1, 0, and 1.
Based on the compiled map of seismic intensity increments, adjustments have been made to the OSR-2017 map (see Fig.2). As a result, the seismic intensity for the entire territory of the republic has been determined, taking into account the soil categories based on seismic properties. Fig. 4 shows the map of seismic intensity in macroseismic units developed using a methodology that incorporates soil conditions in assessing earthquake intensity.

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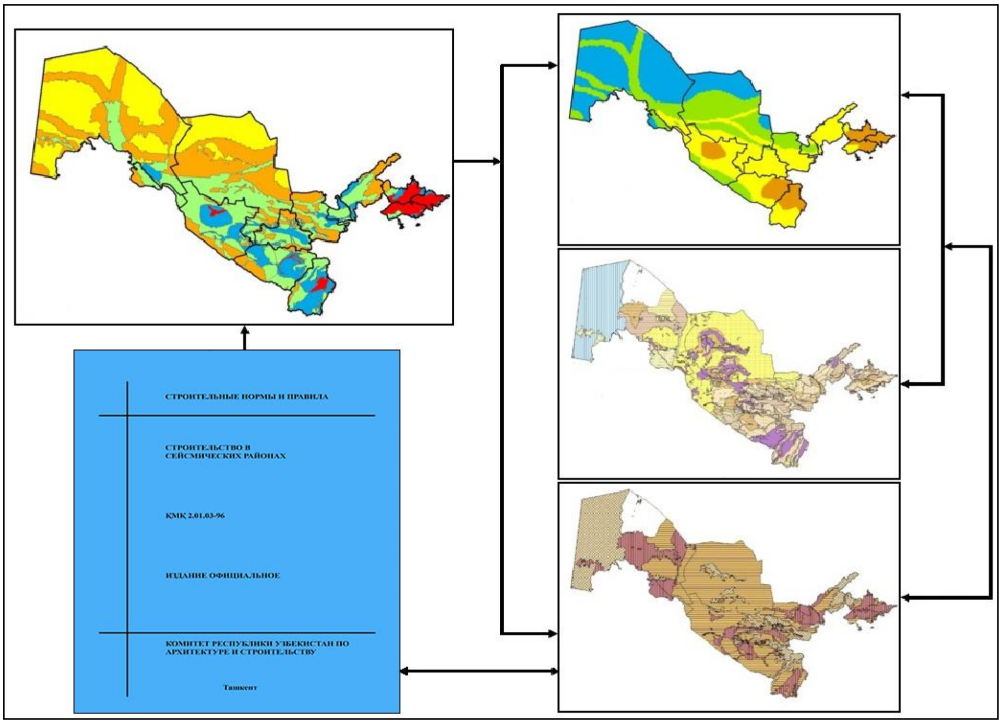

Figure 3: Procedure of compiling the seismic hazard map of the Republic of Uzbekistan (Note: Blue book is Building Code No.2.01.03-96 of the Republic of Uzbekistan).

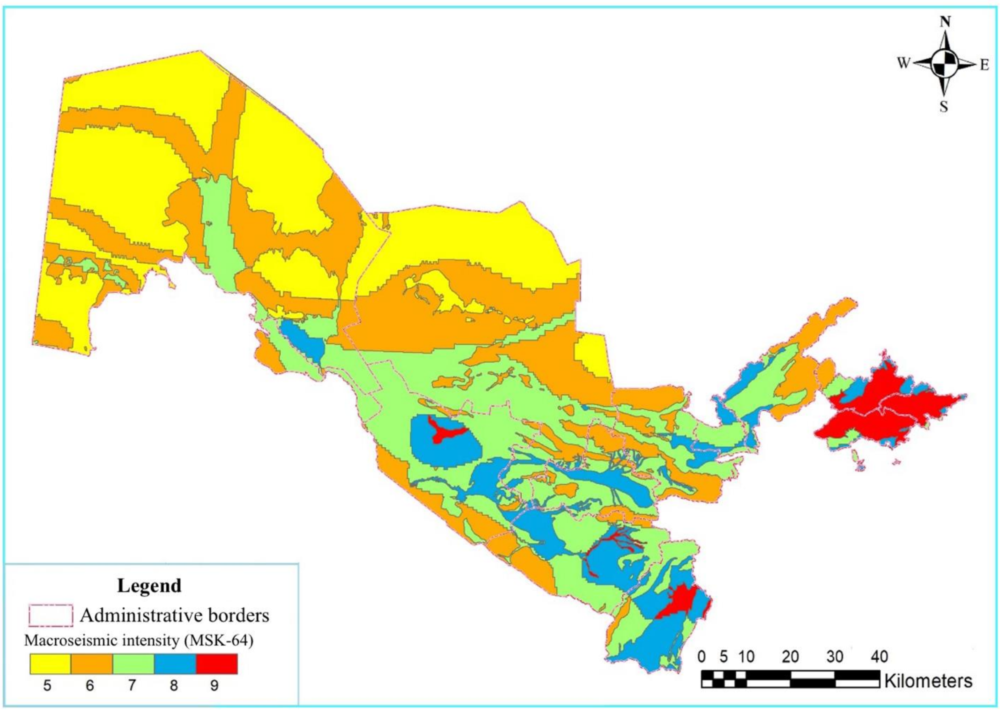

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Figure 4: The schematic map of seismic intensity in the territory of the Republic of Uzbekistan.

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There are some differences in values and established boundaries of seismic hazard zones between the OSR-2017 map and the compiled map of seismic intensity in the territory of the Republic of Uzbekistan. These differences are due to the delineation of different zones based on seismic intensity parameters, related to the distribution of soils of Categories I and III. For example, in the OSR-2017 map, the zone with I=7 is subdivided into zones with intensities of 6, 7, and 8 on the seismic intensity map, depending on the soil conditions. However, the entire territory of the republic is divided into zones with seismic intensities of 5, 6, 7, 8, and 9.

2.3. Seismic vulnerability

Seismic vulnerability of buildings is to the ratio of expected costs of restoring structures that may be subjected to destructive seismic events of a given intensity, to their initial cost. Vulnerability ranges from 0 (no damage) to 1.0 (unrepairable). By knowing the current value of a structure, the monetary damage can be determined. The relationship between vulnerability and seismic impact (e.g., in degrees) is referred to as the vulnerability function. Vulnerability functions play a central role in regional seismic loss assessment.
A vulnerability function represents the relationship used to forecast statistics (such as mean value or standard deviation) of seismic losses distribution. It predicts the extent of damage that a structure (e.g. residential building or bridge) will experience under probabilistic seismic events. It should be noted that vulnerability functions are calculated separately for each type of building listed in the cadastre.
Vulnerability functions for the identified structural building types within the territory of the Republic of Uzbekistan were developed using the "GESI_Program", which is a computer program based on the assessment of structural damage under specified seismic events (see Fig. 5). This software was developed as part of the United Nations' Global Earthquake Safety Initiative (GESI) Pilot Project in 1999-2001. The primary data used for the program's development were collected within the framework of the international RADIUS project (Risk Assessment Tools for Diagnosis of Urban Areas against Seismic Disasters), conducted by the UN-IDNDR Secretariat in 1998-1999. The vulnerability function used to assess seismic risk was created in an experiment involving cities such as Addis Ababa (Ethiopia), Antofagasta (Chile), Bandung (Indonesia), Guayaquil (Ecuador), Zigong (China), Izmir (Turkey), Skopje (Macedonia), Tashkent (Uzbekistan) and Tijuana (Mexico). The experiment utilized identical building materials in the respective cities. The vulnerability index for the city of Tashkent in the experiment did not exceed 10% of the total.
In Fig. 5, in addition to the vulnerability functions, the boundary conditions of damage are also presented, characterized by the overall direct costs of restoring buildings to their initial condition.

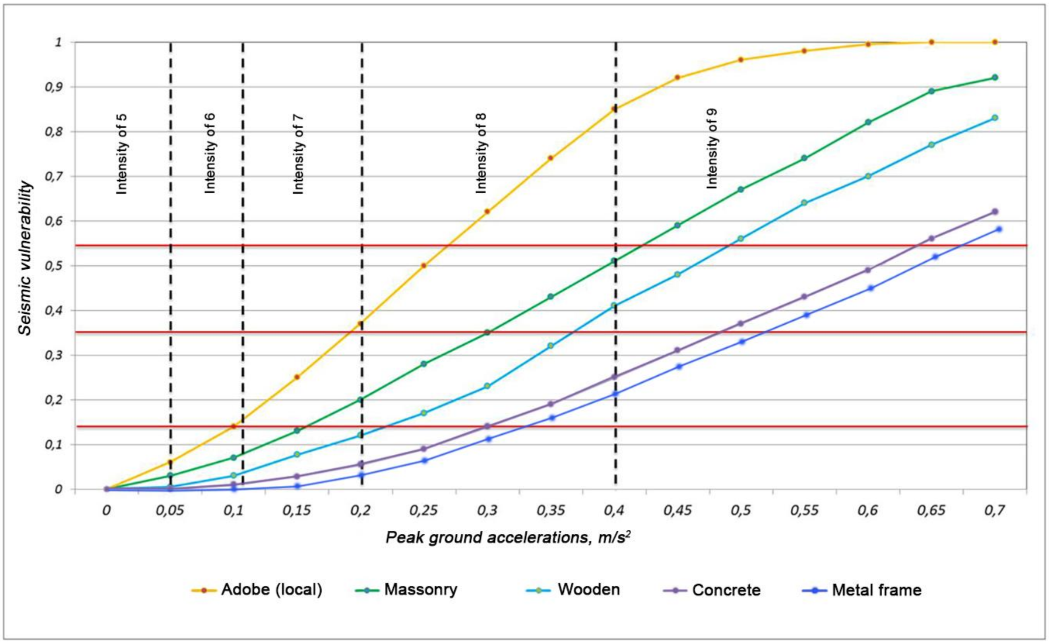

Figure 5: Vulnerability function for the different building types.

Buildings built using local materials (adobe, guvalyak, pakhsa and raw bricks); masonry buildings; wooden (chopped or panel) residential buildings; concrete (panel, large-panel, monolithic and reinforced concrete) buildings; and buildings with a metal frame or a frame with diaphragms (ties).

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As of February 1, 2021, at the republican level, 7,135,881 residential buildings were analyzed and systematized with a total area of 4.4 billion square meters. These buildings were categorized by their structural types and aggregated by administrative regions.

Table 2. Residential buildings by their structural types within zones of different seismic intensities

Seismic intensity zones	Total	Residential buildings by structural types				
		RC	Wooden	Masonry	Metal frame	Local adobe materials
5	6031	758	1	2933	0	2339
6	398838	24431	3323	62787	126	308171
7	1956323	176113	10029	338873	3292	1428018
8	2960146	169079	31954	985165	6318	1767630
9	1819597	133535	23030	217787	3025	1442220

The vulnerability function for each structural type of buildings was determined using the GESI_Program, which served as the basis for calculating seismic vulnerability by administrative regions. For aggregation of values of seismic vulnerabilities of buildings, the equation proposed by Tyagunov, S.A. et al. (2007) was used.

$$MRV = \frac{\sum_{i=1}^{n} N_i \cdot MVR_i}{\sum_{i=1}^{n} N_i}$$

Here, MVR represents the average value of seismic vulnerability for the territory of the district, MVR_i represents the average value of seismic vulnerability for the identified structural types of buildings and N represents the number of buildings by structural types within the administrative district.

Thus, administrative districts with seismic vulnerability values of 0-0.15, 0.16-0.3, 0.31-0.45, 0.46-0.6 and 0.61-0.75 were identified. These values were aggregated to create a schematic map of seismic vulnerability for the administrative districts of the Republic of Uzbekistan (see Fig. 6).

The schematic map of seismic vulnerability is the basis for the assessment of possible damage at given values of seismic impacts.

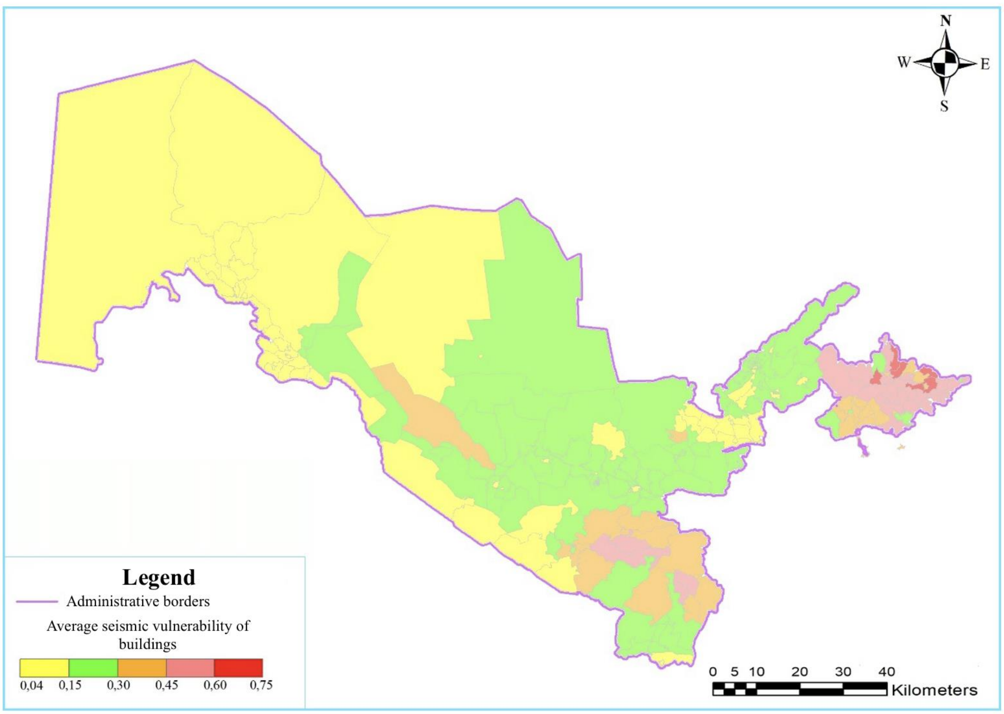

Figure 6: Map of average values of seismic vulnerability of buildings by administrative districts of the Republic of Uzbekistan

The GESI_Program consists of five sets of input parameters that characterize the type of structure, design features, quality of construction, quality of building materials and level of seismic impacts in the peak acceleration process. Based on these input parameters, a damage diagram and building vulnerability function are constructed. Damage to buildings is rated at four levels: light, moderate, heavy and very heavy.

Damage characteristics of buildings:

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Grade 1. Minor damage
- light non-structural damage, including cracks in plaster (up to 0.5 mm wide), chipping of small plasters from walls and frame elements, and thin cracks in partitions, cornices and floor screeds;
- light structural damage (complete or almost complete absence). Minor damage requires maintenance costs. According to norms, the cost can reach up to 15% of the book value of the object.
Grade 2: Moderate damage
- moderate non-structural damage, including chipping of rather large pieces of plaster, falling roof tiles, cracks in chimneys, falling parts of chimneys, through cracks in partitions and lintels above openings, cracks in the masonry of gables and parapets, and their partial displacement;
- light structural damage, including small cracks in walls, between prefabricated floor panels, along the counter of large blocks, and in the load-bearing elements of frames. Overhaul costs are calculated based on damage to the building, ranging from 15–35%.
Grade 3. Severe damage
- severe non-structural damage, including falling chimneys, gable wall parapets, collapse of individual or many load-bearing and self-supporting elements, and destruction of lintels over openings;
- moderate structural damage, including large deep and through cracks in walls, loss of connections between structural elements and separation of longitudinal walls from transverse ones. In the case of severe damage, the restoration costs are determined depending on the nature of the damage and are decided by an expert commission. Restorative repair is determined depending on the damage, ranging from 35% to 55%.
Grade 4: Very severe damage
- non-structural destruction, including the collapse of individual sections of internal walls and collapse of partitions;
- structural destruction, including delamination of the masonry of load-bearing walls, gaps in walls, destruction of connections between individual parts of the building, and rupture of the joints of prefabricated structures. In case of damage to the building of the 4th degree, the building is subject to demolition.

The seismic vulnerability is estimated as a percentage of the damage due to peak acceleration.

According to the definition, the vulnerability of buildings is considered a property of a given structure capturing the loss of qualitative or quantitative indicators of reliability and safety due to any impact. The vulnerability ranges from 0 (no damage) to 1 (unrepairable). The dependence of the vulnerability on seismic impact (for example, in intensity) is denoted as the vulnerability function.

The vulnerability function relating the degree of damage to the level of seismic impact, given in intensity is usually determined empirically.

For a detailed assessment of the damage to buildings under different intensities of seismic impacts and to compile vulnerability functions for specific structural types of buildings, calculations were performed in the GESI_Program.

A comparison of the results revealed (Fig. 7) that macroseismic observations (Usmanova et al., 2019) of the damage to the buildings under consideration greatly differ from the calculation results obtained with GESI_Program, but at the intensity of 7.3 the observations and calculation results coincide. Closer matches are shown in graphs obtained via calculation using GESI_Program and experimental data of Sh. Khakimov. Based on these data, it can be assumed that the use of GESI_Program in the assessment of the vulnerability of various construction types of buildings yields better results, at least excluding subjective opinions when comparing the vulnerability of buildings.

The vulnerability function, which relates the degree of damage to the level of seismic impact, given in MSK-64 intensity or peak ground acceleration values, is usually determined empirically or via calculation methods. When studying the engineering consequences of strong local earthquakes, world statistics of damage data for classes of objects located in the study area under similar seismogeological conditions are involved. To date, the Institute of Seismology of the Academy of Sciences of Uzbekistan has accumulated a large amount of data on the consequences of strong earthquakes. However, the range of observed intensities remains insufficient to obtain full-fledged regional loss matrices. Therefore, at this stage, we limited ourselves to using the GESI_Program, which, at the moment, is the best way to model and evaluate the relationship between the degree of damage and level of seismic impact.

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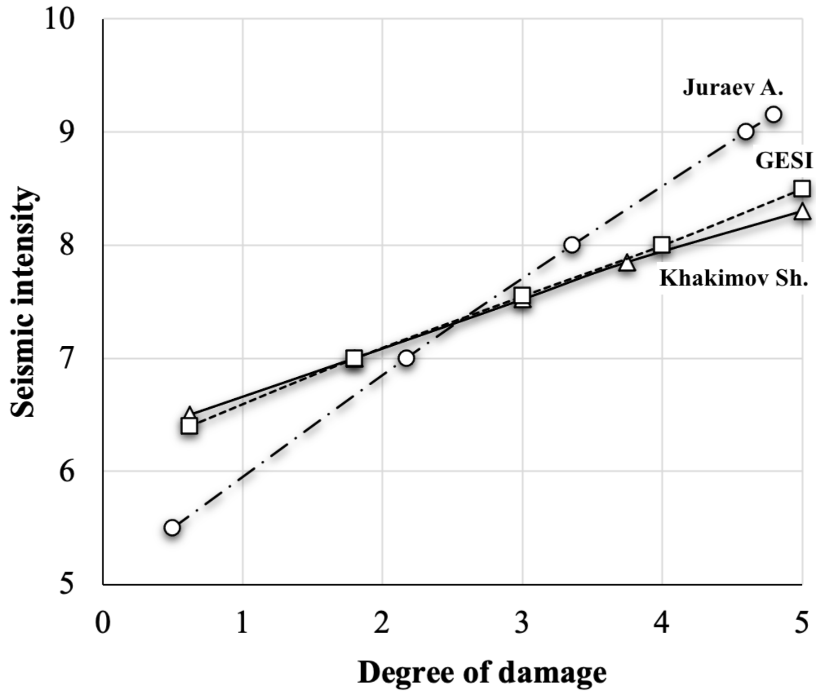

Figure 7: Graph of changes in the average degree of damage to individual mudbrick houses depending on the seismic intensity according to different authors.

This paper represents the first attempt to compile an extensive database of residential buildings in Uzbekistan and involves significant efforts to include the most at-risk assets in the territory. At the same time, a database of the housing stock in the republic was formed based on the database of the State Cadastral Chamber of the Cadastral Agency under the Tax Committee of Uzbekistan.
Residential buildings in the territory of Uzbekistan could be divided into 5 main types of structural systems:

1. Type A: local adobe materials (guvalyak, pakhsa and raw bricks);
2. Type B: masonry;
3. Type C: wooden (chopped or panel);
4. Type D: concrete (panel, monolithic and reinforced concrete);
5. Type E: metal frame or a frame with diaphragms (ties).

These 5 types of buildings could be subdivided into 24 different subtypes according to their structural features and year of construction (Table 3). These classification of the buildings is typical not only for Tashkent, but also for other cities in Central Asia. The buildings were also classified according to the number of storeys and type of material of the supporting structures.

Table 3. Classification of buildings in Tashkent according to the vulnerability index (Khakimov Sh.A., 2000)

No.	Building types and their structural types	Average damage index
1	Residential buildings constructed from local low-strength materials (without anti-seismic measures)	3.95
2	One-story clay walls of the guvalyak and pakhsa types	3.68
3	Three- to five-storey frameless brick buildings with wooden floors constructed until 1958	3.84
4	Prefabricated reinforced concrete frame made of linear elements with a welded joint in the zone of maximum effort, or the same with stiffening diaphragms in one direction (framework III of the IIS-04 series and their modifications)	2.96
5	One- to two-storey frameless brick walls with wooden floors	3.15
6	Crossbarless frames or buildings erected by raising floors (crossbarless frame with stiffening core)	2.75
7	Buildings with a flexible ground floor and rigid upper floors	2.7
8	Walls made of bricks, small concrete or natural stones; ceilings - prefabricated reinforced concrete	2.62
9	Large-panel walls without anti-seismic measures	2.61
10	Buildings with external load-bearing brick walls; internal - reinforced concrete frame elements	2.58

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11	Prefabricated frame of flat reinforced concrete cross or H-shaped elements with monolithic nodes	2.56
12	Monolithic reinforced concrete frame	2.55
13	Walls made of large blocks (concrete, vibro-brick, or reinforced vibro-brick panels)	2.5
14	Reinforced concrete frame with brick filling	2.41
15	One- to two-storey wooden frames filled with raw bricks (sinch)	2.37
16	Walls of complex construction (with reinforced concrete inclusions); ceilings - prefabricated reinforced concrete	2.33
17	Prefabricated reinforced concrete frame-braced frame with monolithic nodes, with stiffening diaphragms in two directions or stiffening cores	2.22
18	Frame made of spatial elements (volumetric cross) with monolithic knots	2.17
19	Large-panel buildings with brick exterior walls	2
20	Monolithic walls	1.86
21	Large panel walls	1.73
22	Volumetric blocks per room	1.67
23	One- to two-storey wooden houses (chopped or panel)	1.16
24	Metal frame or frame with diaphragms (bonds)	1.16

Notes:
1. The table provides average values of the damage index.
2. The first column of the table indicates the degree of vulnerability in the ascending order, the most vulnerable to the least vulnerable structural types.

3. Results and Discussion

3.1. Asset values

According to cadastral data, as of February 1, 2021, the housing stock in Uzbekistan consists of 7135881 houses and apartments.
Depending on the demographic situation, the number of residential buildings in the territory of the republic exhibits a very uneven distribution. The housing stock in Uzbekistan is divided in 2 main types: individual houses (80.1%) and multi-storey residential buildings (19.9%).
It should be noted that in the housing stock of the republic, there are 44827 multi-storey buildings, where there are 1375623 apartments, which are also considered when compiling the residential building database.
These types of buildings are distributed unevenly in quantitative terms and spatially, so among these buildings, buildings built using local materials are the most widespread. These buildings are highly represented in rural areas (settlements, towns, cities, etc.) and comprise about 70% of the total number of residential buildings in the Uzbekistan. The buildings built of wood (including panel houses) or metal frames, comprise less than 1% of the total number of residential buildings. Figure 8 shows the distribution of residential buildings by the structural type.

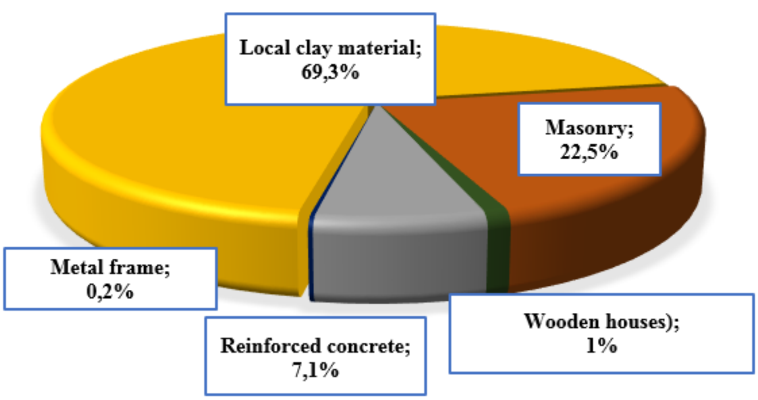

Figure 8: Distribution diagram of the number of residential buildings by design types.

Analysis of statistical data demonstrates a large spread in the number of buildings by structural types. For example, in the Kashkadarya region, the share of buildings built from local clay material exceeds 83% of the total number of residential

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buildings; in the Samarkand and Andijan regions, the share is 82%; and in the Tashkent region, 48.3%. In large cities, the percentage of adobe residential buildings is smaller and ranges from 13% to 27%. This circumstance must be considered when assessing the seismic risk, since the amount of damage due to an earthquake in the selected territorial units depends on the proportion of the specific structural types of buildings.

The number of residential buildings located in the territory with different seismicity values, expressed by peak ground accelerations is shown in Figure 9. This diagram shows that a large number of buildings, approximately 31% of the total number of residential buildings are located in the territory with PGA ranging from 100 to 150 cm/s^2, 27% of the buildings are located in areas with PGA of 150–200 cm/s^2 and more than 30% are located in areas with peak accelerations higher than 200 cm/s^2, representing the zone with an intensity of 8 (according to EMS-98).

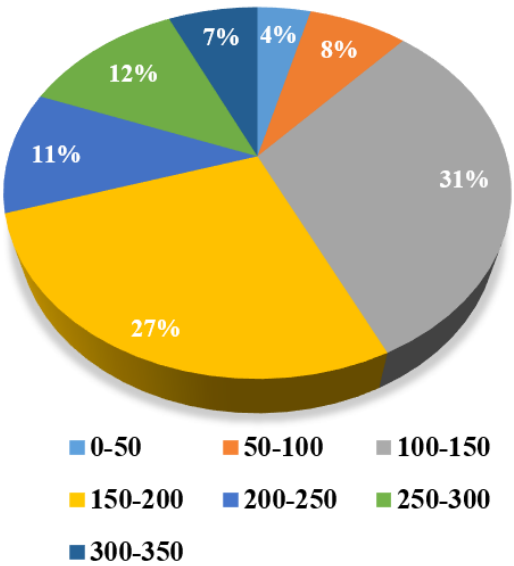

Figure 9: Distribution of residential buildings in areas with different seismic effects (values of the peak ground acceleration are given in cm/s^2).

Information on the distribution of residential buildings by structural types depending on zones with different seismic effects is given in Tables 3 and 4.

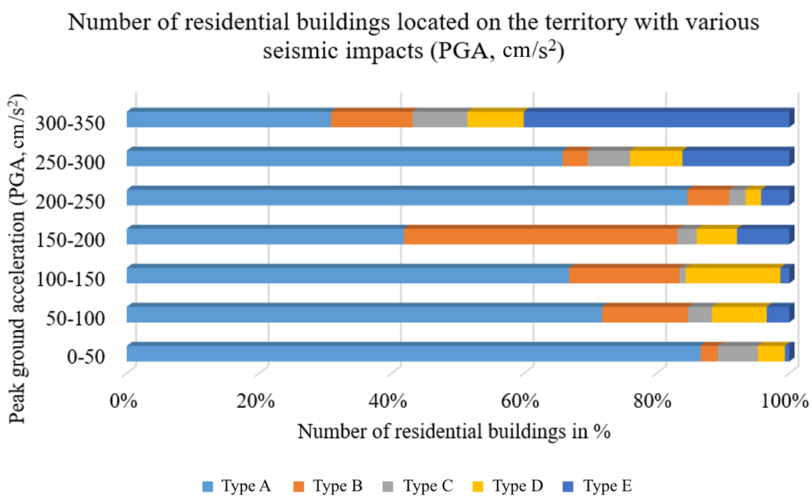

Figure 10: Number of residential buildings by structural types located in the territory with different seismic effects (PGA, cm/s^2).

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Table 4. Distribution of residential buildings in Uzbekistan depending on the structural types of buildings (as of February 1, 2021)

Structural type of the building	Total, %	including (%)	
		in cities	in rural areas
Type A	69,2	27,2	84,8
Type B	22,5	54	10,9
Type C	1	0,6	1,1
Type D	7,1	18	3,1
Type E	0,2	0,2	0,1

To assess the seismic risk within the context of the administrative districts of the Republic of Uzbekistan, it is necessary to take into account the share of the housing stock across all administrative districts, considering the different intensity zones. Figure 10 shows the share of residential buildings located in the territory with different parameters of seismic vibrations (based on the OSR-2017 map with a probability of 90%).

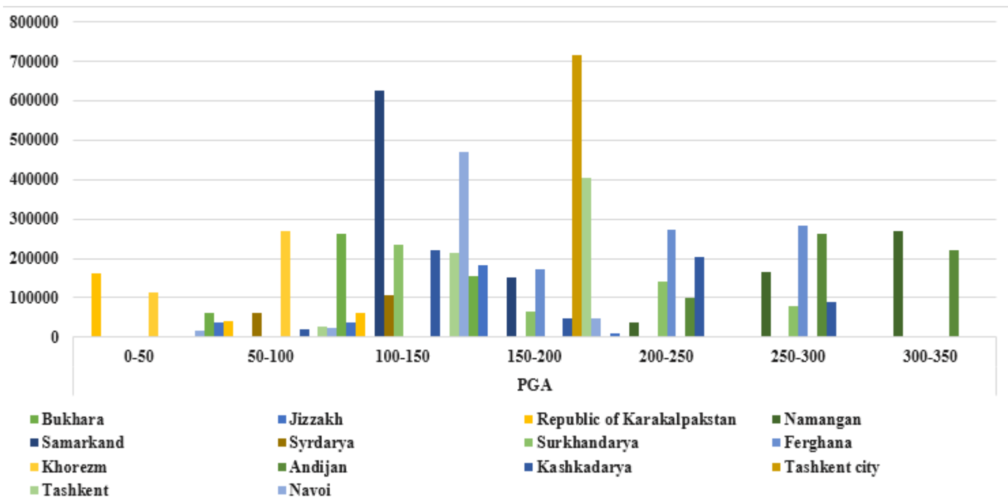

Figure 11: Distribution of residential buildings in the territories with different seismic effects within the administrative regions in Uzbekistan.

3.2. Inventory of existing buildings and compilation of the database

The assessment of social and economic consequences of earthquakes is primarily based on the assessment of physical damage to buildings, life support systems and transportation facilities. Therefore, the inventory of all engineering structures is the most important task in identification of seismic risks. When performing an inventory of structures and assessing possible physical damage to strong earthquakes, the inventory database should contain structural parameters reflecting the characteristic response of structures to strong ground vibrations. To address this issue, the inventory should reflect those characteristics of buildings that may be relevant to their response to severe ground motion. Typically, these characteristics involve the structural types, material and year of construction, construction, quality and maintenance of buildings.
In the database of the State Cadastral Chamber, the data of the Republican Fund (in *.xlx format) are as follows: region, district, cadastral code, spatial coordinates, types of objects (individual and multi-storey building), real estate (address), actual cost, land area, area of the land plot under construction, total usable area, new cost, number of storeys, year of construction and materials.
Based on analysis and systematization of the collected housing stock data, i.e., geometric parameters of registered objects in *.xlx format, a database was created in *.mdb and *.shp formats. Figure 12 shows a fragment of the geographical location of the registered residential buildings in the Pap district of Namangan region in *shp format.

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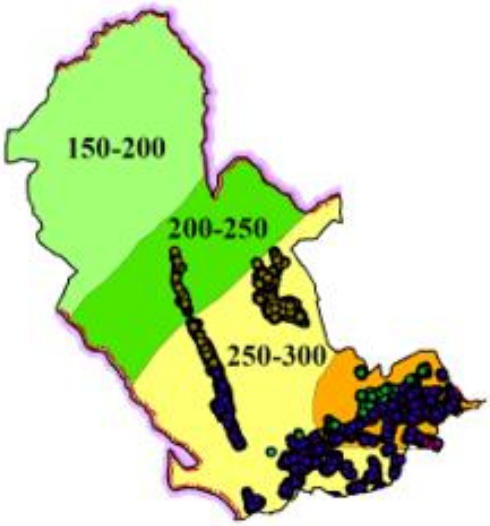

Figure 12: Geographic location of the registered residential buildings in the Pap district of the Namangan region in *shp format.

Figure 13 shows the sequence of object registration (a specific building - a building site - the territory of the administrative district - the territory of the region) in *shp format.

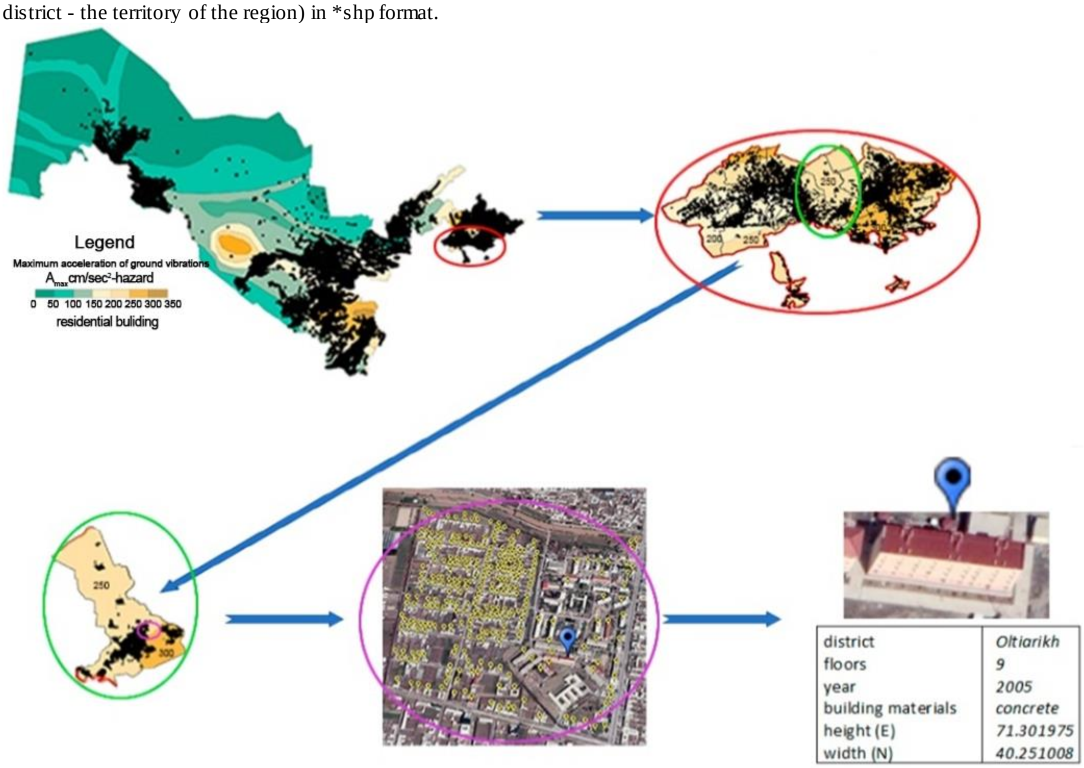

Figure13: Sequence of registration of housing stock.

With the use of the created database, the total cadastral value of the housing stock within the administrative regions of Uzbekistan was determined, which is measured in trillion soms (in March 2021 prices) (see Fig. 14). The presented map is essentially a map for the assessment of the value of Uzbekistan's territory.

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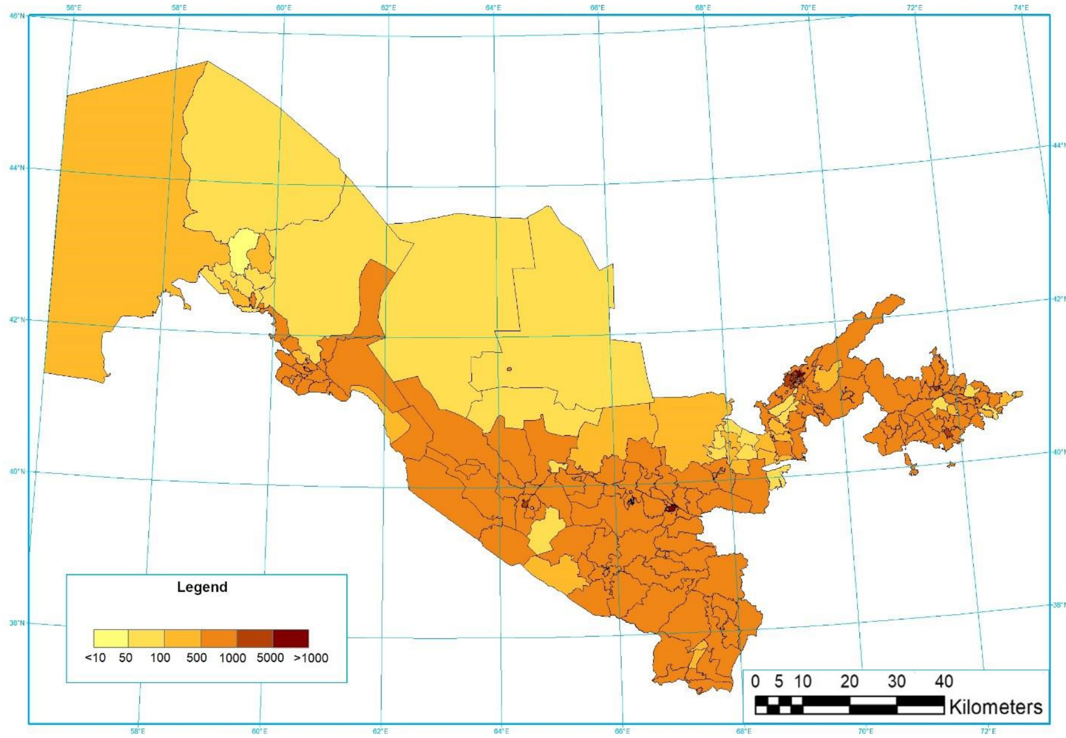

Figure 14: Map of the total cadastral value of the housing stock within the administrative regions of the Republic of Uzbekistan.

3.3. Probable seismic damage and seismic risk

Seismic risk maps of the territory of the Republic of Uzbekistan were compiled based on an assessment of the 90% probability of not exceeding seismic impacts for 50 years and the seismic vulnerability of buildings within the administrative regions of Uzbekistan. In this case, the cadastral database of the housing stock of the republic was used.
To develop a map of seismic risk of the territory of the Republic of Uzbekistan, several databases based on GIS platforms were created allowing systematization and evaluation of the regional distribution of information on seismic hazards, number of buildings and their structural types, coefficient of the seismic vulnerability of buildings and built-up areas, cadastral value of buildings, etc.
The seismic risk analysis algorithm used the capabilities of GIS, combining data on the spatial distribution of seismic hazards, building vulnerability and values, i.e., cadastral value of the buildings at risk of damage and loss, in a layer-by-layer manner. Seismic vulnerability analysis is performed using GESI_Program, which is based on the assessment of seismic damage to buildings. At the same time, the existing buildings in the territory of Uzbekistan were collected and classified according to their structural types. There are 5 main types of structures: buildings built using local clay materials, masonry buildings, wooden buildings, buildings constructed using a metal frame and reinforced concrete buildings.
The developed map of seismic risk of the territory of Republic of Uzbekistan is based on the assessment of probable economic losses within administrative regions, depending on the combination of seismic hazard factors, seismic vulnerability and concentration of values, ranging from zero to hundreds of trillion soms. It is important to emphasize that the level of seismic hazard used in the calculation of physical and economic damage corresponds to a 90% probability of not exceeding of seismic impacts during 50 years, which corresponds to an average return period of 475 years. This level of probability is generally accepted standard in seismic hazard assessment during the design and construction of conventional buildings and structures. Of course, considering a different probability, the level of danger and estimates of damage and potential losses may differ from the data presented.
When developing a seismic risk map of the territory of Uzbekistan, seismological and macroseismic databases of Institute of Seismology of the Academy of Sciences of Republic of Uzbekistan, data on the housing stock of State Cadastral Chamber of the Cadastral Agency under the Tax Committee of the Republic of Uzbekistan and scientific developments of the Institute of Seismology and the Institute of Mechanics and Seismic Resistance of Structures of the Academy of Sciences of the Republic of Uzbekistan and JSC Toshuyjoy LITI served as a basis during the implementation of state scientific and technical programs.
The present study covered only the assessment of direct economic losses that may be caused by structural damage to residential buildings as a result of seismic events. At the same time, given that residential buildings predominate in the development of cities and administrative districts of the Republic of Uzbekistan, the presented results could serve as a clear reference for a comparative analysis of the seismic risk in various administrative districts.
Below is a small-scale map of the seismic risk in the territory of the Republic of Uzbekistan with an assessment of the probability of economic damage (see Fig. 15) within the administrative districts at the maximum level of seismic impacts for the return period of T=475 years.

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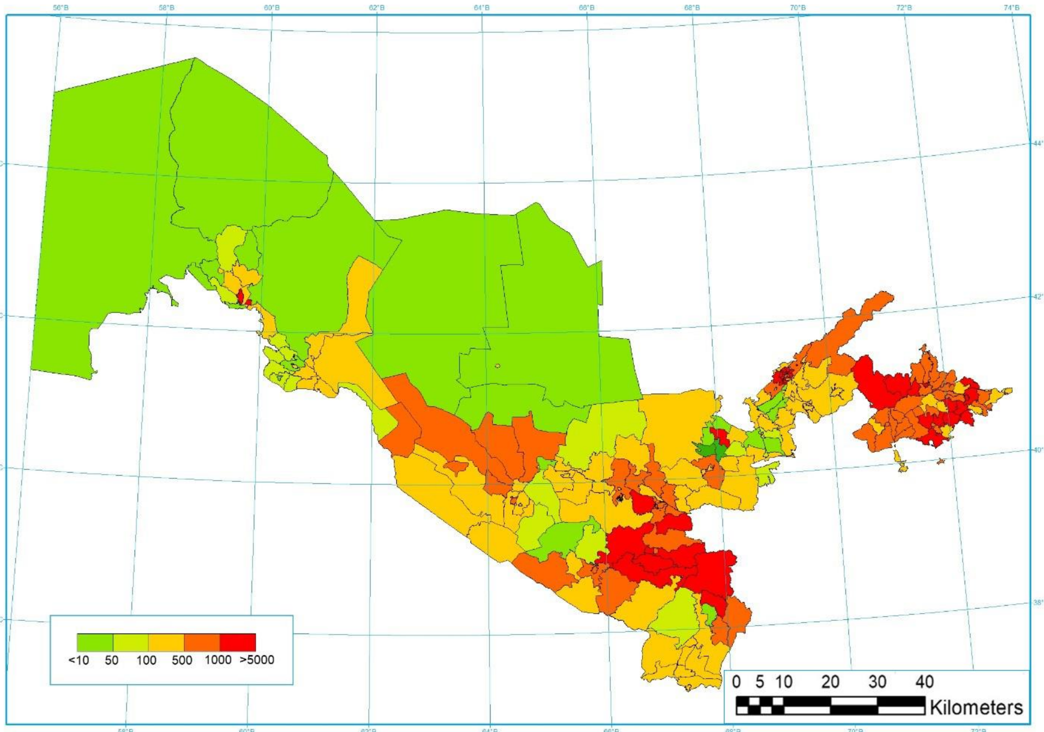

Figure 15: Estimated distribution of seismic risk (billion soms) in administrative districts of the Republic of Uzbekistan with a probability of not exceeding 90% in 50 years.

4. Conclusions

Based on the study of geomorphological and geological structures and changes in the composition of rock formations at a depth of 10 meters, peculiarities of changes in engineering-geological conditions and seismic stiffness within administrative districts have been identified. Additionally, for the first time in Uzbekistan, a seismic intensity increment map has been compiled with a scale of 1:1000000.

Using the seismic zoning maps of the country (OSR-2017) for a 90% probability of not exceeding seismic effects over a 50-year period and seismic intensity increments, a small-scale (1:1000000) schematic map of seismic intensity for the territory of the republic has been developed. The seismicity of the territory has been refined based on the soil categories and their seismic properties.

At the national level, as of February 1, 2021, a systematic electronic database has been created, containing information on 7135881 real estate properties, specifically residential buildings. Each property has been grouped based on its construction type and coordinates in relation to administrative districts. This comprehensive database has been established to facilitate the quantitative assessment of potential building damage during strong earthquakes, enabling the identification of preventive measures to mitigate possible losses.

Based on the compiled schematic map of seismic intensity for the territory of Uzbekistan and the vulnerability functions established for each construction type, the seismic vulnerability of the developed areas within the administrative districts has been determined. The values of seismic vulnerability for the administrative districts fall within the following ranges: 0-0.15; 0.16-0.3; 0.31-0.45; 0.46-0.6; 0.61-0.75.

Comparison of the calculations and observational data for the damage caused by real past earthquakes reveals a suitable agreement, indicating the correctness of the developed models and the efficiency of the calculation algorithms, which, in combination with operational seismological information, could also be used to estimate losses due to earthquakes occurring in real time.

Seismic vulnerability analysis and assessment were conducted using GESI_Program. Vulnerability models built depending on the construction types of residential buildings characterized the vulnerability of residential buildings in all administrative regions of Uzbekistan, which are subsequently considered as calculation cells. To assess the magnitude of potential damage in monetary terms, cost indicators of the restoration of residential buildings were used. Seismic impacts were considered within the framework of the project in the form of a probabilistic seismic hazard map. This approach made it possible to conduct a comparative analysis of seismic risk distribution throughout the Republic of Uzbekistan.

When compiling a seismic risk map of the territory of the Republic of Uzbekistan, an administrative region was chosen as the territorial unit. This occurs because the scale of the study (1:1000000) does not allow for a detailed presentation of the existing database related to seismic hazard assessment, distribution of typical buildings, vulnerability assessment, etc.
The results obtained are presented in the form of maps showing the spatial distribution of possible damage to residential development and direct economic losses caused by this damage in all administrative regions of the Republic of Uzbekistan.
The territory of the Republic of Uzbekistan is characterized, on one hand, by a relatively high level of seismic hazards and on the other hand, by a relatively high concentration of residential buildings with low seismic resistance. Thus, possible future seismic events in the territory represent a typical high-probability problem with a potentially high level of losses. The obtained results and map of seismic risk could serve as a basis for the development of plans and measures to reduce the existing level of risk and prevent the catastrophic consequences of future earthquakes.
The present study covered only the estimation of direct economic losses of residential buildings in the Republic of Uzbekistan. At the same time, given that residential buildings predominate in the development of cities and towns in Uzbekistan, the presented results could serve as a clear reference for a comparative risk analysis throughout the Republic of Uzbekistan.

Author contributions

All of the authors contributed to the process of writing and verifying the research work and analyzed the results.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Acknowledgements

This work was funded by the Academy of Sciences of the Republic of Uzbekistan and Project "Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia" EU-funded Program "Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia" (SFRARR) was funded by the European Union and implemented by World Bank. We sincerely thank all the project team members, in particular Dr. Sergey Tyagunov and Dr. Paola Ceresa and the World Bank specialists, in particular Stuart Alexander Fraser and Madina Nizamitdin, for their constructive contribution to the project.

Financial support

This project was developed by the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan at the request of the Academy of Sciences of the Republic of Uzbekistan

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