Geodesy and Geodynamics 11 (2020) 273–292

Contents lists available at ScienceDirect

Geodesy and Geodynamics

journal homepage: http://www.keaipublishing.com/geog

Complex of general seismic zoning maps OSR-2017 of Uzbekistan

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ARTICLE INFO

Article history:
Received 14 May 2019
Accepted 7 March 2020
Available online 26 March 2020

Keywords:
Seismic hazard
Seismic zoning
Seismic sources
Seismic activity
Seismic potential
Seismic load intensity attenuation laws

ABSTRACT

The quantitative assessment of seismic hazard of Uzbekistan has been examined, and new maps of seismic zoning has been developed. Quasihomogeneous seismological areas and seism-generating zones are considered as seismic sources, based on the analysis of seismotectonic data. The seismological parametrization of seismic sources has been carried out, including determination of parameters of earthquake's reoccurrence for different power levels, seismic potential and a predominant type motion in the source of occurring earthquakes. The reoccurrence parameters of seismic sources were both determined by directly from Gutenberg–Richter dependence law and using summation and distribution methods. Setting were conducted separately for a sample of strong ($M \geq 5$) and weak ($M < 5$) earthquakes. The seismic potential M_{max} of seismic active zones was determined by seismological and seismotectonic methods. The predominant type of movement in the faulting for each seismic source is reverse fault. Regional regularities of seismic intensity attenuation with distance of different power levels are determined. The seismic hazard is expressed in points of a macro seismic scale, in velocities and accelerations of ground motions, and it is characterized by calculated seismic intensity with the set probability ($P = 0.9$, $P = 0.95$, $P = 0.98$ and $P = 0.99$) not exceed within 50 years in the constructed maps. In seismic zoning map, the seismic intensity was in average soil conditions. The developed complex of maps considers a number of uncertainties of the input parameters in relation to both incompleteness of initial seismological and seismotectonic data, as well the probabilistic nature of seismic process and seismic intensity. The factors of uncertainty of the input parameters are taken into account by constructing a logic tree. The constructed maps of the general seismic zoning are intended for implementing antiseismic actions in Uzbekistan.

1. Introduction

In Uzbekistan and surrounding regions, there have been several earthquakes with magnitude $M_L \geq 7$ and intensity of ground shaking in epicentral areas I_0 with 9–10 points by MSK-64 scale in historical and modern times. Therefore, maintenance of seismic safety of country is vital.

The major element in a chain of the antiseismic actions, aimed to provide seismic safety, is construction of reliable general seismic zoning maps based on laws of seismic process development, seismic load and forecasting based on reliable and comprehensive seismic hazard research.

The study of seismic hazards of Uzbekistan and its surrounding areas in last two decades has been done within the framework of national programs on reducing consequences of strong earthquakes [1–4] and large international projects [5–9]. These researches have been carried out on the basis of various methodological approaches, using various seismological data and a seismotectonic basis. Several software were used to define quantitative characteristics of seismic hazard. Implementation of these projects has allowed, on one hand, estimating advantages of applied approaches, on the other hand, outlining directions of the

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Peer review under responsibility of Institute of Seismology, China Earthquake Administration.

Production and Hosting by Elsevier on behalf of KeAi

https://doi.org/10.1016/j.geog.2020.03.004

further researches to enrich the methodology of construction of general seismic zoning maps in the future.

The purpose of this work is to examine the assessment of seismic hazard and construct new general seismic zoning maps of Uzbekistan OSR-2017, taking into account the critical analysis of previous researches in this sphere. In new maps, seismic hazard is expressed by likelihood points of a macroseismic scale and in engineering characteristics of seismic load. Quantitative characteristics of seismic hazard are obtained by attraction of several seismic sources, including uncertainty factors of the input parameters used in calculations, based on regional laws of attenuation of intensity of seismic load in space for earthquakes of different energy levels.

2. Seismic sources

Quantitative assessments of seismic hazard of active seismic regions is based on two interdependent models of seismic process: models of seismic sources and model of seismic effect from the selected set of sources of earthquakes. In implementation of OSR-2017 project, the two types of seismic sources (Fig. 1) have been considered:

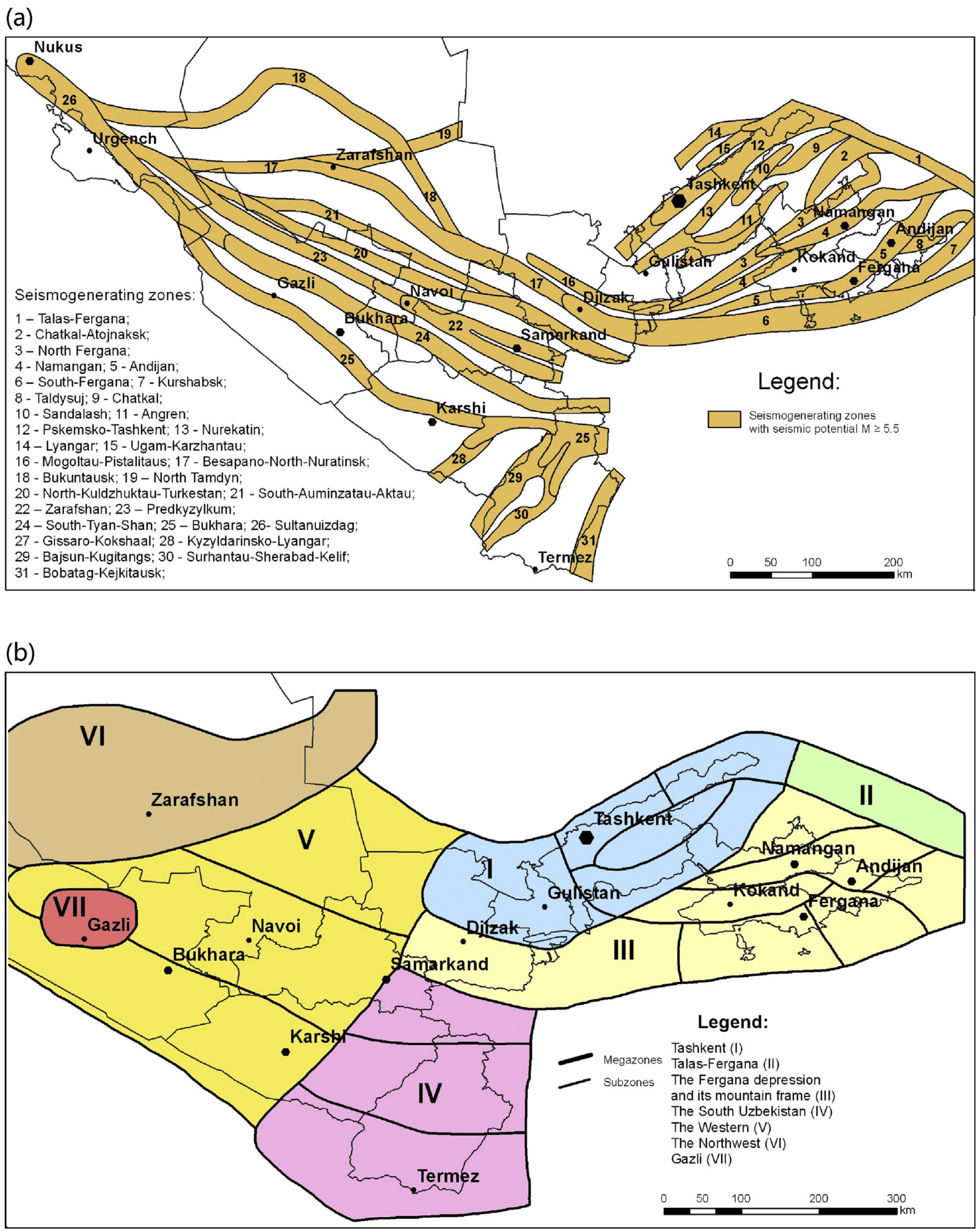

Fig. 1. The seismic sources used for seismic zoning of OSR-2017 in Uzbekistan: a) seismo-generating zones; b)- areas sources.

- linear sources, representing active fault's buffer zones – seismic generating zones;
- the space sources - quasi-homogeneous seismological provinces.

The seismic generating zone is an area of active dynamic influence of a large fault or system of closely located and equally directed rupture of earth crust, which is at a stage of tectonic activity of region generated strong earthquakes [10]. In terms of seismogenic zones, they represent set of overlapped caused by spread of Pleistos areas happened and expected strong earthquakes in the future. Contours of seismogenic zones are defined by taking into account dimensional position of active faults. It considered geometrical and morphological features of tectonic infringements, and their ages. Analysis of the space distribution of earthquakes that occurred in Uzbekistan for the historical and instrumental period of time showed that, earthquakes with $M_L < 5$ can occur both within the seismogenic zones and beyond. Earthquakes with a magnitude $M_L \geq 5$, as a rule, are closer to the zones of active faults and occur within the seismogenic zones. It is picked more than 30 seismogenerating zones on the basis of the seismological and seismotectonic data [10] in Uzbekistan (Fig. 1a), then they were ranked by seismic potential M_{Lmax} value. For the areas located outside of seismogenic zones, in calculation of seismic hazard in the linearly extended seismic sources, the value was $M_{Lmax} = 4.5$.

Consideration along with seismogenic zones, the area sources of earthquakes pursues two main objectives: the first is to consider potential seismic hazard of those areas which are seismotectonicly scrutinized insufficiently (first of all, it concerns the Western part of Uzbekistan) and the second is to differentiate various fields of a unified seismic active region by seismic activity degree.

Three mega zones have been marked in Eastern part of Uzbekistan: Tashkent (I); Talas-Fergana (II); the Fergana depression and its mountain frame (III). The South Uzbekistan mega zone (IV) is considered in Southern part of Uzbekistan. The Western (V) and the Northwest (VI) mega zones are marked in Western part of Uzbekistan. The area of Gazli (VII) was considered separately, due to the special seismological conditions. The source density of strong earthquakes within a megazone can be significantly different (Fig. 2), therefore mega zones have been also divided into subzones, i.e. different seismic activity fields.

3. Earthquakes catalog and general characteristic of the seismic data

Information used was the earthquakes catalog of Uzbekistan and its surrounding areas, compounded in Institute of seismology of Academy of science of Uzbekistan. The catalog includes historical and instrumental recorded earthquakes. As the basic characteristic for earthquakes classification, the power class of earthquakes K is used in the regional catalog. It is determined by the sum of the amplitudes of the bulk P- and S-waves, registered by short-period equipment. The energy class of earthquakes K was introduced into seismological practice by T.G. Rautian in 1964 [11]. It is associated with the seismic energy E released by earthquakes in the formula $K = \lg E$ (J). Transition from energy class K to a local (Richter) magnitude M_L (hereinafter simply M), that determines by measurements of displacement amplitudes of bulk waves by short-period equipment, has been carried out on the basis of T.G. Rautian's nomogram for the area of Central Asia [11,12]:

$$K = 1.8\, M_L + 4.0 \tag{1}$$

The error in the transition from one value to another in this relation is about σ, ranging from 0.4 to 0.5 [12]. Data about strong earthquakes occurred in the Central Asia since historical times has been taken from the catalog of N.V. Kondorskaya and N.V. Shebalin [13]. For the earthquakes classification by magnitude, the magnitude of M_{LH} is used [13] in this catalog. In the regional catalog, transition from M_{LH} magnitude to the energy class K was on the basis of A.S. Mukambaev and N.N. Mikhailov's relations [14]: $M_{LH} = -0.82 + 0.45K$; $\sigma = 0.36$.

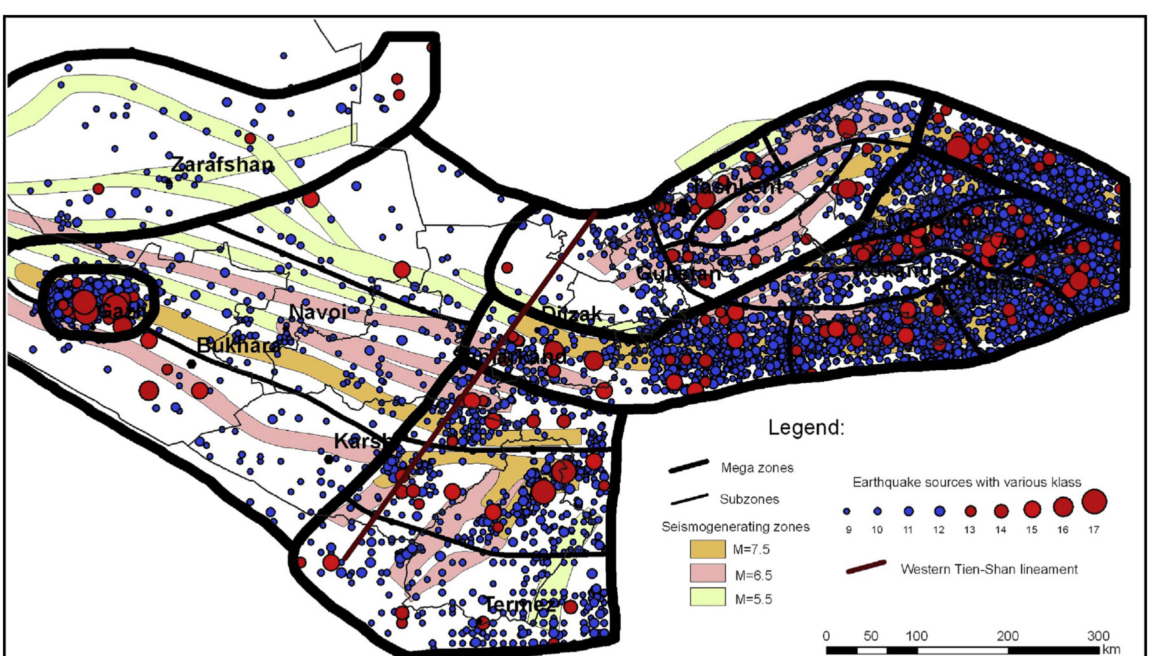

Fig. 2. The map of historical and instrumental recorded earthquake sources with K ranging from 9 to 17 (M ranging from 2.5 to 7.5) in Uzbekistan (East of 63° E) since historical times.

In N.V. Shebalin's dependence, the attenuation of macroseismic magnitude with distance is based on the results of macroseismic surveys of strong earthquakes of different seismic active regions of the globe [15], and it is compared with dependencies obtained in this research, the magnitude M_S is used. Finally, to derive the ground motion prediction equation (GMPE) in the values of maximum velocities and accelerations of ground motions, the magnitude of the moment magnitude M_W is used to classify earthquakes by the magnitude. The relationship between the energy class K and magnitude M_S is based on T.G. Rautian's ratios for Central Asia [16]: $M_S = 5.36 + 0.594\ (K\text{-}14)$ and subsequent recalculation of the M_S magnitude into M_W by A.S. Mukambaev and N.N. Mikhailov's dependencies [14]: $M_W = e^{(-0.222+0.223Ms)} + 2.863$. The value of the standard deviation in the transition from one type of magnitude to another varies from $\sigma = 0.27$ to $\sigma = 0.51$ [14].

Thus, the basic characteristic of the regional catalog for classifying earthquakes by size is the energy class of earthquake K. Magnitudes M_L, M_{LH} and M_S have been calculated through the energy class of earthquake K using above relations and magnitude M_W for each earthquake was calculated through magnitude M_S. Comparison results of magnitudes M_{LH}, M_S, M_W when magnitude M_L changes in the range of 4–7.5 are presented in Table 1.

Distribution of strong earthquake sources by area (Fig. 2) is rather odd. In the east of the Western Tien Shan lineament [17] that is the border between underground structure of Tien Shan and flat area of the Turkistan plate, seismic activity is very high and in the west of the lineament is low. In the Western part of Uzbekistan, Gazli and Bukhara areas are characterized by the high density of strong earthquake sources. Some strong earthquakes are noted around Central Kyzylkum.

Table 1
Conversion results of various magnitudes through magnitude M_L.

M_L	M_{LH}	M_S	M_W
4	4.22	3.70	4.69
4.5	4.63	4.23	4.92
5	5.03	4.77	5.18
5.5	5.44	5.30	5.47
6	5.84	5.84	5.81
6.5	6.25	6.37	6.18
7	6.65	6.90	6.60
7.5	7.06	7.44	7.07

Assessment of representativeness of earthquakes with different energy levels based on studies [18]. From them, one can see how number and location of seismic stations in Uzbekistan have changed over the years. In addition, by taking into account the level of interference at each seismic station, its registration radius of various energy level earthquakes was determined in Ref. [18]. This information was used to construct a set of maps showing contours of the lower threshold of magnitudes of representative earthquakes in each section in different time periods.

These maps are constructed by data of the seismometric network operated in 1930, 1940, 1950, 1955, 1965, 1975 and 1985. After 1985, for a long time, the lower threshold of representativeness of earthquakes ($K = 8.6$, $M = 2.5$) allover of Uzbekistan practically did not change. In second half of 2000s, it was a transferring to digital recording of earthquakes and starting reorganization of the network. Some seismic stations have been closed and some stations have been moved to new positions. During this period (introduction of digital seismometry), seismic records deteriorated temporarily, and the lower threshold of representativeness of earthquakes has been raised. Therefore, for correct assessments of long-term characteristics of a seismic mode, the discussed period of earthquakes with power class $K = 9$ has been constrained by 2005 and earthquakes with $K = 10$ by 2010. Now, earthquakes with $K = 8.6$ ($M = 2.5$) are representative for all area of Uzbekistan.

Earthquakes with a power class $K = 15$ were considered, since 1901 (the beginning of instrumental recording seismology in the Central Asia). Earthquakes with K ranging from 16 to 17 are considered since 1850 because such level seismic events have been noted in literature (documentary records), and hence fully included in the strong earthquakes catalog by N.V. Kondorskaya and N.V. Shebalina's edition [13], in particularly, if they happened near to such cultural centers of Uzbekistan, as Tashkent (earthquakes 1868, 1886), or Samarkand (Uratjubinsky earthquakes of 1897). Fig. 3

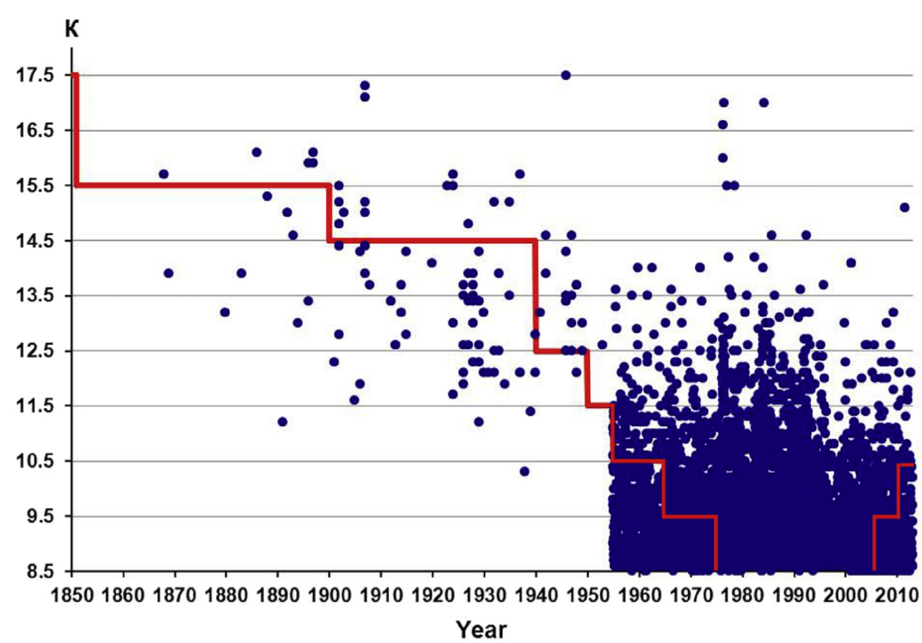

Fig. 3. Time interval for different power level earthquakes for constuction the OSR-2017 maps of Uzbekistan.

shows the time intervals of seismic records with different energy levels. The earthquakes catalog of Uzbekistan which was used for the further constructions contains 9248 events.

Removal of strong earthquake aftershocks was made by using of different spatial and time windows for earthquakes with different energy levels. The dimensions of these windows are from Ref. [19]. The catalog is divided into the main pushes and earthquakes, shown in Fig. 4. Red color demonstrates strong earthquakes, and their aftershocks have been removed; dark blue color demonstrates aftershocks, and green color is for weak and moderate earthquakes which remained after a filtering of aftershocks.

Table 2 shows the average recurrence interval of earthquakes with different energy level in Uzbekistan. The average recurrence interval of earthquakes is obtained by standardizing the representative recording interval of each power level event and the number of earthquakes reaching the energy level interval.

Earthquake reoccurrence figures have been constructed to obtain quantitative characteristics of seismic hazard from the catalog filtered off from aftershocks. At the magnitude classification of earthquakes, Gutenberg–Richter relation binding number of earthquakes of different energy levels with magnitude dependence is [20]:

$$\lg N_M = a - bM \quad (2)$$

In power classification of earthquakes used by authors, the equation of this straight line usually refer to power class $K_0 = 10$, and this dependence is [21]:

$$\begin{aligned} &\lg N_k = \lg N_{10} - \gamma(K - 10) \\ &K = \lg E, K \le K_{\max} \end{aligned} \quad (3)$$

The value of $A_{10} = N_{10}\frac{1000}{ST}$ that representing an average number of earthquakes, occurring in one year on the area of 1000 km^2, is called seismic activity, and value of slope of this straight line γ is seismic divisibility (γ-factor) of environment [22]. Here S is the area (in km^2) of a seismic source, and T is period of the used seismological data (in years).

Earthquake reoccurrence figures for all area of Uzbekistan were constructed by total set of earthquakes with K in the interval of 9–17, taking into account terms of their representative registration, separately weak and moderate earthquakes with K in the interval of 9–13, and the moderate and strong earthquakes with K in the interval of 12–17 (Fig. 5). In the same figure, there are values of seismic activity A_{10} and seismic divisibility γ, calculated by using seismic events of different power classes. It should be noted that the values A_{10} and γ, calculated from strong earthquakes, were below the values of the value corresponding to weak and moderate earthquakes.

There is a debatable issue that, what part of the reoccurrence figure is necessary to be used in the assessment of seismic hazard: statistically provided with seismic events, with power classes K within interval of 9–13, or statistically considerable worse events with power classes K within interval of 12–17, but representing information about the most important earthquakes, intensity of shakes exceeded by 6–7 points. The researches made by authors [23,24] showed that parameters definition errors of earthquake reoccurrence, related to incompleteness of the initial data, may lead to essential errors in assessments of seismic hazards. Discrepancies in identification of earthquake reoccurrence figure slope (parameter γ) lead to considerably large contribution to hazard assessments errors than a variation of seismic activity A_{10}.

Distribution of seismic events by depths is presented in Fig. 6. In the figure, there is a equation set using least squares method to find the most likely depth of earthquake occurrence with different energy levels, which was used subsequently in calculation of seismic

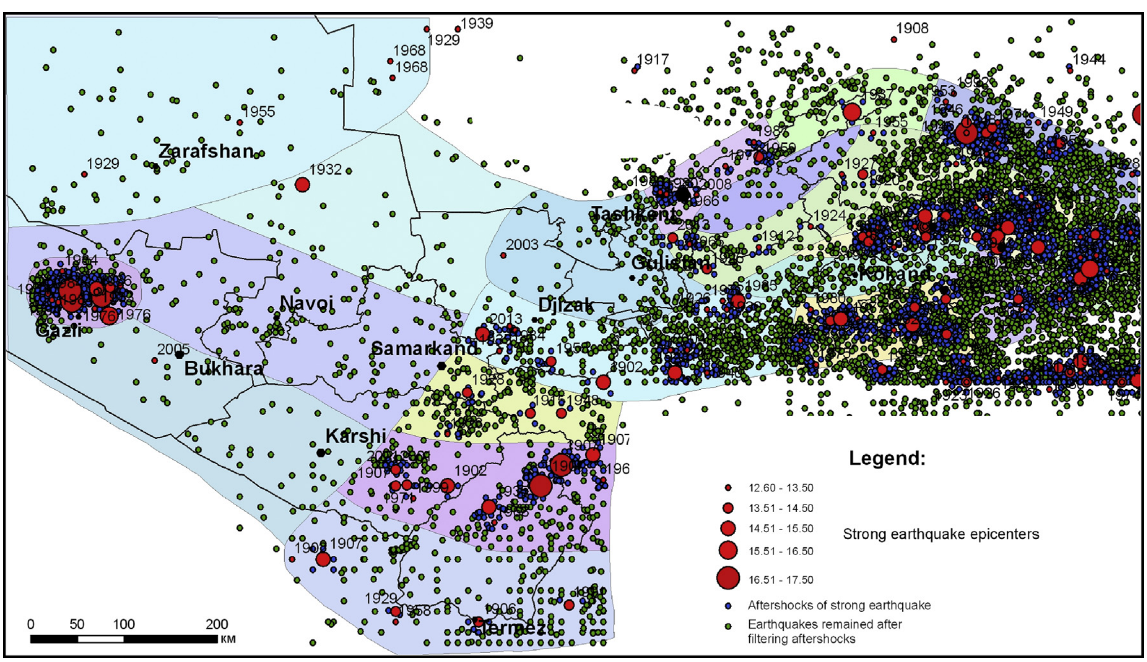

Fig. 4. Division of the catalog into main shocks and aftershocks.

Table 2
Average periods of reoccurrence of earthquakes of different energy levels in Uzbekistan.

K	$K = 9$	$K = 10$	$K = 11$	$K = 12$	$K = 13$	$K = 14$	$K = 15$	$K = 16$	$K = 17$
T	2.5 days	11 days	1.5 months	6 months	1.5 years	4.5 years	7.5 years	23.5 years	55 years

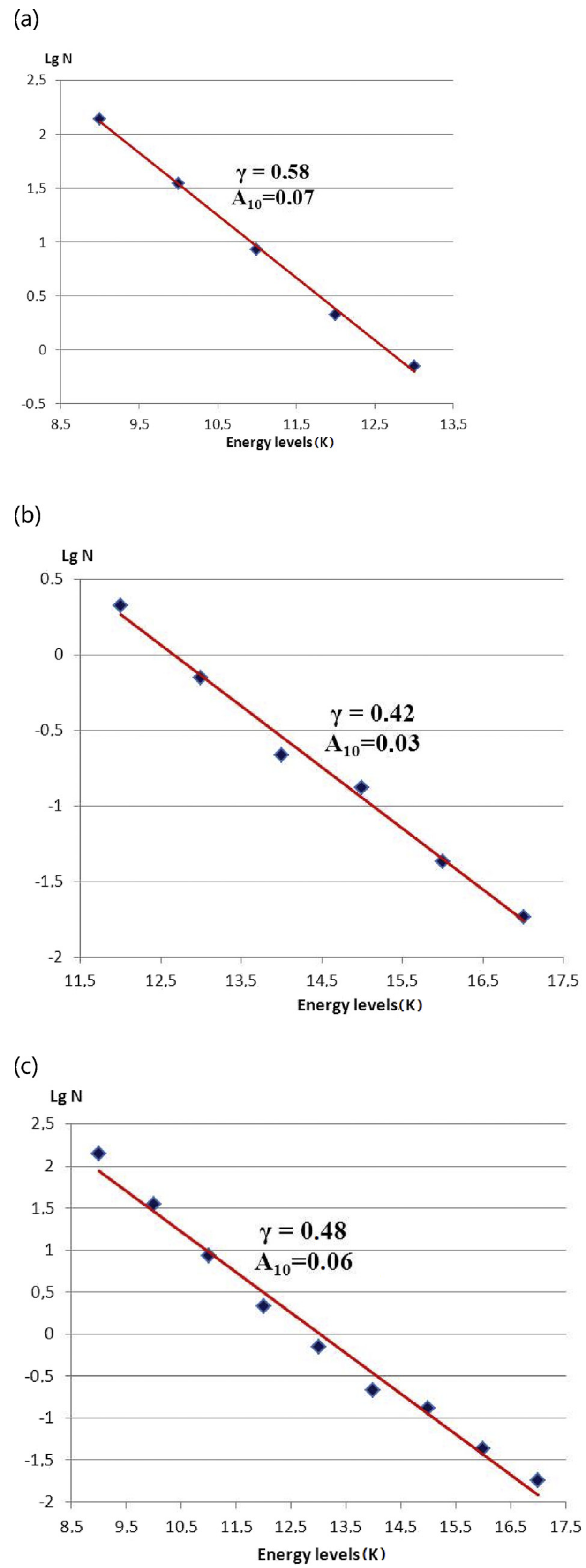

Fig. 5. Earthquake repeatability graphs had been constructed by earthquakes of different energy levels considering the periods of their representative registration: a) K ranges from 9 to 13; b) K ranges from 12 to 17; c) K ranges from 9 to 17 for all territory of Uzbekistan.

hazard. Fig. 6 also shows the value of the standard deviation for each energy class in green. It is obvious that by increasing power class of earthquake, the most likelihood of occurrence depth increases non-linearly. Use of uniform, so-called "average" depth of the source (usually assumed $H = 15$ km) for earthquakes of all energy levels, can lead to essential errors in an assessment of seismic hazard [23,24].

4. Seismological parameterization of seismic sources

Seismological parameterization of seismic sources includes defining the parameters of earthquake reoccurrence with different energy levels, discovering the seismic potential and motion type for each considered sources. When there is significant statistics of seismic events, seismic activity A_{10} and seismic divisibility γ is usually obtained directly from earthquake reoccurrence figure. If the number of seismic events is not large enough to determine reoccurrence parameters of seismic sources, A_{10} and γ can be determined independently from each other. In this case, seismic divisibility γ finds the area essentially exceeding the dimension of a seismic source by least squares method or a method of Kulldorf [25,26]. Seismic activity A_{10}, with known parameter γ, can be calculated from sample of the earthquakes getting immediately in the area of averaging. For definition of A_{10}, allocation and summation methods [3,21,27,28] were used.

4.1. Parameters of reoccurrence and seismic potential of seismogenerating zones

If there are at least 20 representative earthquakes with power classes K within interval 9 to 14, the reoccurrence parameters for a particular seismogenerating zone can be possible. Distribution of reoccurrence parameters in seismogenic regions of Uzbekistan is in Figs. 7–8. For two seismic active zones, Sultanuizdag and Kyzyldarinsko-Lyangar, by reason of statistical restrictions, definition of seismic activity A_{10} and seismic divisibility γ are unreliable.

The seismic potential of seismogenic zones is estimated by complex of seismological and seismotectonic methods [3,10].

The major factor in defining the M_{max} is the large scale level of rock deformation and failure process, which are described by following parameters, like length of fault, depth, the dimensions and degree of consolidation of the blocks which are exposed to shift together as a unit [10]. The fault movement depends on amplitude and speed of tectonic movements, composition and strength properties of rocks. The more strength of rocks and higher speed of tectonic movements, the more energy released at motions on a seismogenic fault. The size of the maximum possible earthquake was defined as the upper limit of magnitudes recorded in each seismogenerating zones with similar seismotectonic parameters. As the basic characteristics in structure comparison, in Ref. [10] It was considered: history of geological development, intensity and orientation of the newest and modern movements, scale comparability of tectonic frames and their integrity from passing positions of seismotectonic processes. For Uzbekistan and its surrounding regions, three categories of seismogenic zones are set [10], where by set seismotectonic laws, it is possible earthquakes with the maximum magnitude ($M_{max} \le 5.5$, $M_{max} \le 6.5$ and $M_{max} \le 7.5$) may occur (Fig. 9).

Seismological methods of maximum possible earthquake assessment are based on physical and statistical regularities of rocks destruction process in the tectonic deformation, specified by the analysis of seismic catalogs. The applied methods are based on correlation of seismic zones activity with the maximum size of possible earthquake, arising within their borders [3,21]; a method is based on an assessment of a thickness and linear extent of seismic active bed [29]; a method of an assessment of M_{max}, is

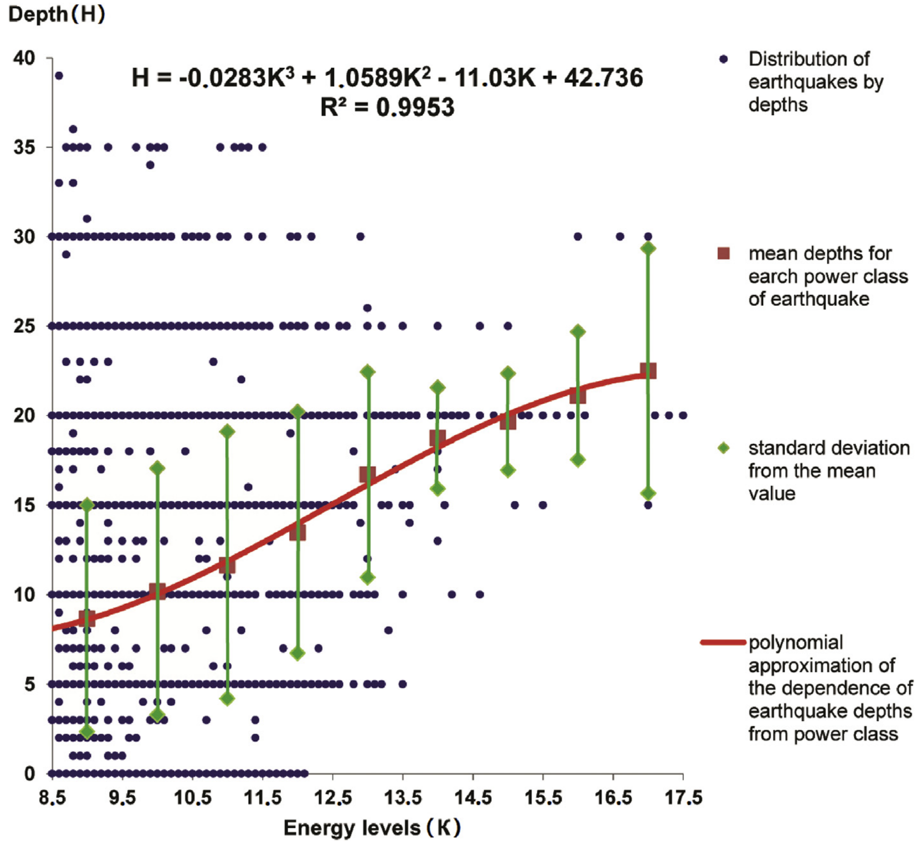

Fig. 6. Distribution of earthquakes with different energy levels by depths.

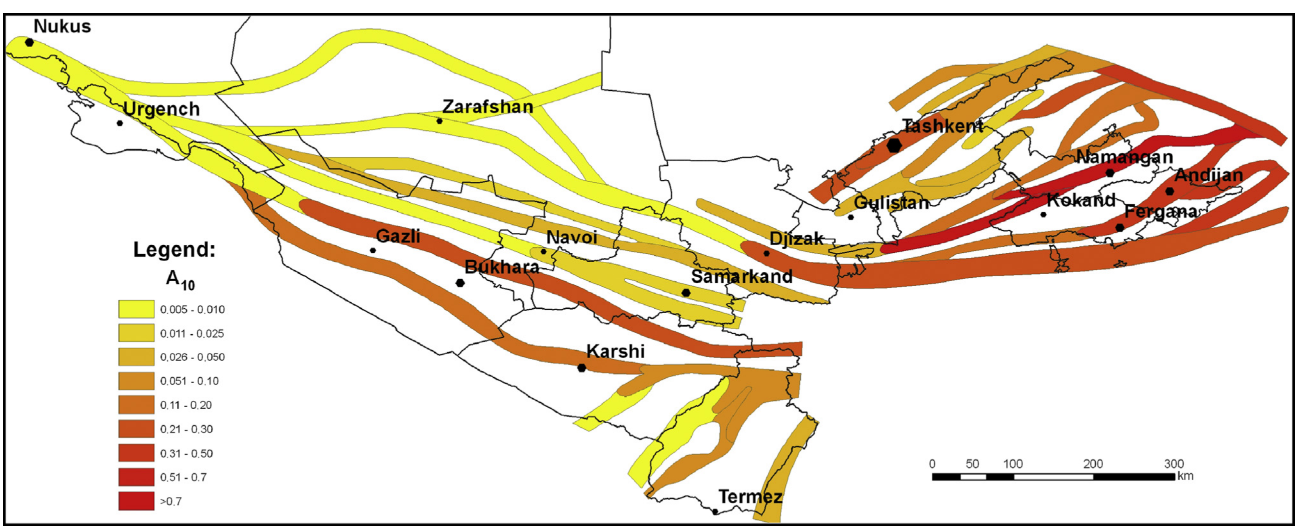

Fig. 7. Seismic activity of seismogenic zones in Uzbekistan.

based on the statistics of the maximum likelihood from the right parts of earthquake reoccurrence figures [30]. The Gumbel method is based on the statistics of extreme values [31] and other methods [3,4] were applied too. Fig. 10 shows the complex variant of M_{max} constructed on the basis of seismological design techniques.

In majority of cases, values of M_{max} calculated by seismological and seismotectonic methods, fits each other (deviations were in range 0.2–0.4 magnitude units), which confirms reliability of made constructions. When deviation in assessments of seismic potential of seismic active zones by various methods was significant, these zones (Sandalash, Chatkal, North-Kuldzhuktau-Turkestan) were a subject for further study and discussion by experts.

4.2. Parameters of reoccurrence and seismic potential of the areal sources

Table 3 shows seismic activity A_{10} and seismic divisibility γ for each research megazones taken directly from earthquake reoccurrence figures. There are definition errors of seismic divisibility (parameter γ) of each megazone. Within each megazone, value of

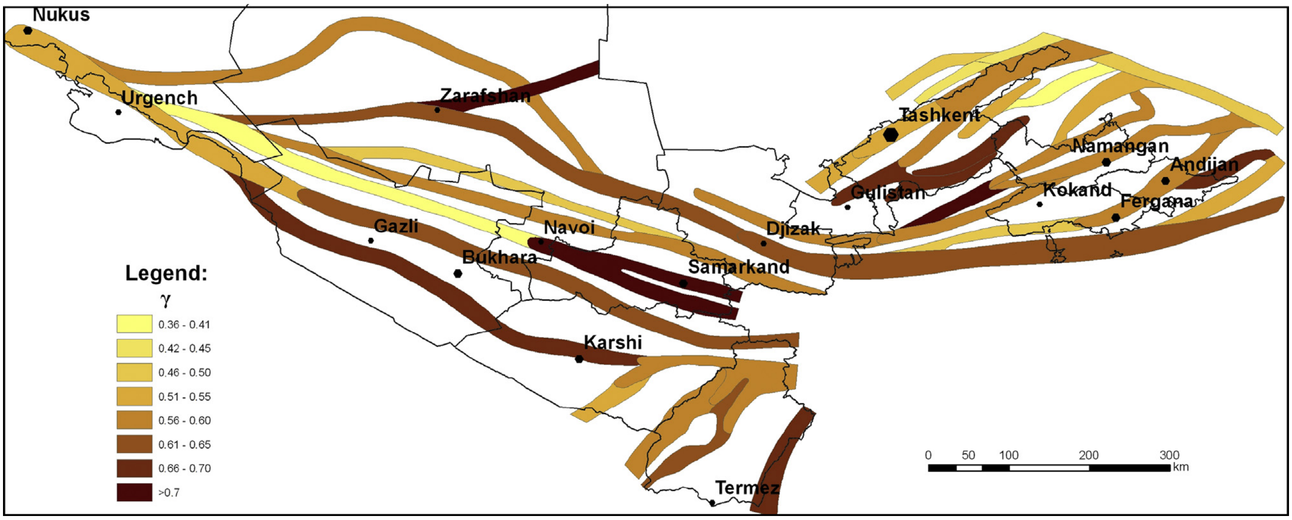

Fig. 8. Seismic divisibility of seismogenic zones in Uzbekistan.

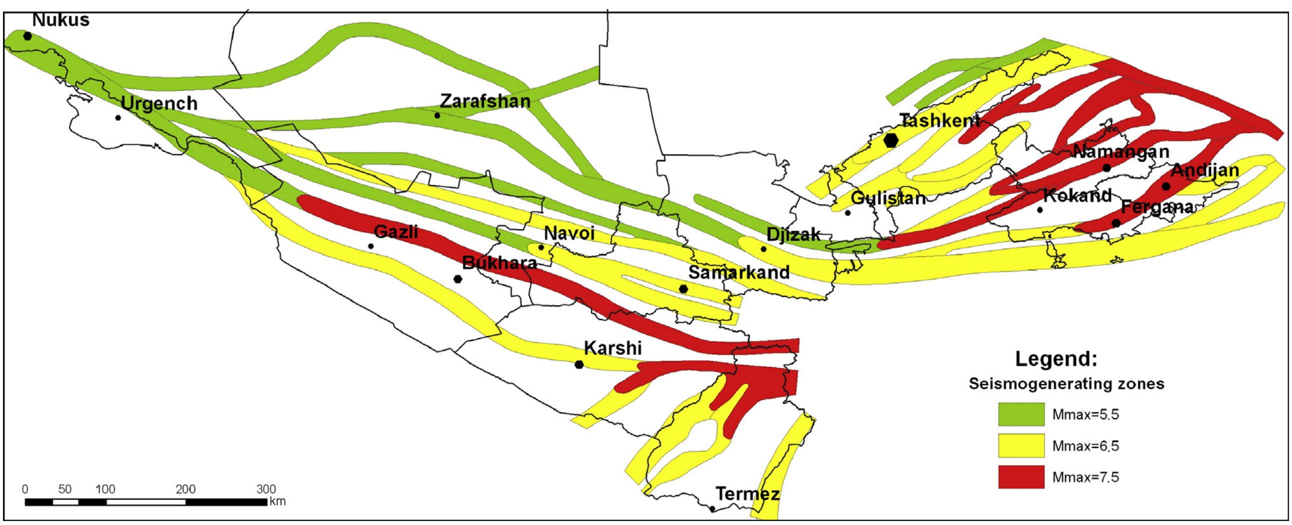

Fig. 9. Uzbekistan seismic potential of seismogenic zones on the basis of seismotectonic methods of M_{max} assessment (according to R.N. Ibragimov, etc. [10]).

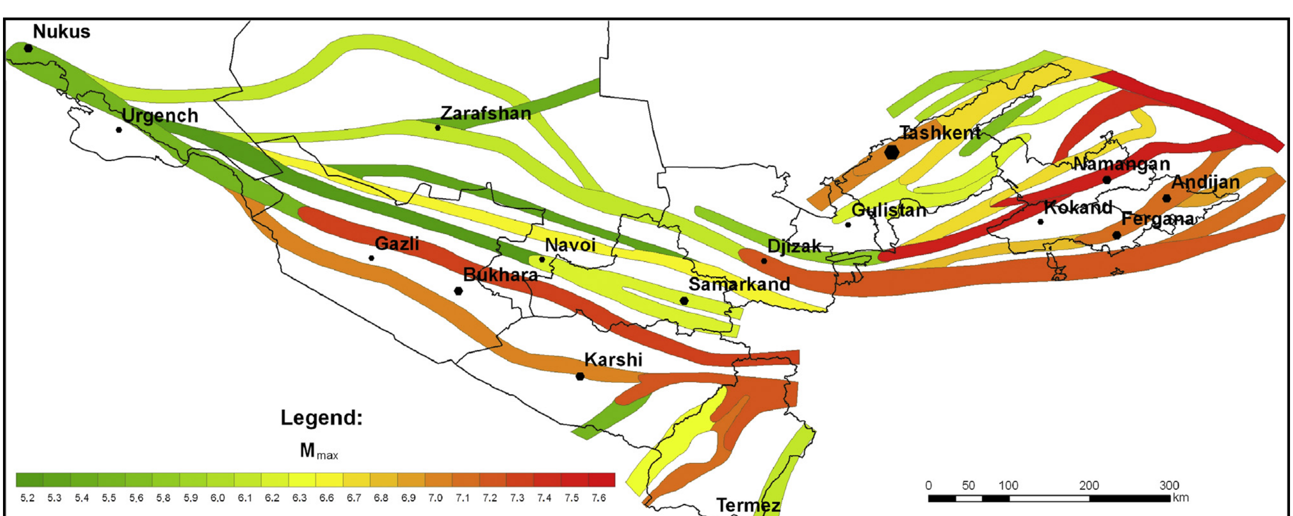

Fig. 10. Seismic potential of seismogenic zones in Uzbekistan by using a complex of the seismological data.

Table 3
Allocation of reoccurrence parameters of earthquakes (A_{10} and γ) by the area megazones used for power classes calculation.

No.	K = 9-13	K = 12- K_{max}	K = 9- K_{max}
I megazone	$\gamma = 0.45 \pm 0.02$ $A_{10} = 0.043$	$\gamma = 0.26 \pm 0.042$ $A_{10} = 0.012$	$\gamma = 0.37 \pm 0.016$ $A_{10} = 0.037$
II megazone	$\gamma = 0.49 \pm 0.019$ $A_{10} = 0.197$	$\gamma = 0.3 \pm 0.056$ $A_{10} = 0.046$	$\gamma = 0.39 \pm 0.015$ $A_{10} = 0.163$
III megazone	$\gamma = 0.55 \pm 0.008$ $A_{10} = 0.25$	$\gamma = 0.46 \pm 0.035$ $A_{10} = 0.119$	$\gamma = 0.49 \pm 0.007$ $A_{10} = 0.228$
IV megazone	$\gamma = 0.57 \pm 0.02$ $A_{10} = 0.048$	$\gamma = 0.29 \pm 0.038$ $A_{10} = 0.011$	$\gamma = 0.37 \pm 0.013$ $A_{10} = 0.036$
V megazone	$\gamma = 0.63 \pm 0.041$ $A_{10} = 0.008$	$\gamma = 0.35 \pm 0.106$ $A_{10} = 0.0005$	$\gamma = 0.46 \pm 0.03$ $A_{10} = 0.007$
VI megazone	$\gamma = 0.41 \pm 0.051$ $A_{10} = 0.005$	Definition is impossible about statistical regulations	$\gamma = 0.41 \pm 0.049$ $A_{10} = 0.005$
VII megazone	$\gamma = 0.53 \pm 0.015$ $A_{10} = 1.035$	$\gamma = 0.39 \pm 0.044$ $A_{10} = 0.255$	$\gamma = 0.46 \pm 0.013$ $A_{10} = 0.74$

reoccurrence A_{10} and γ parameters strongly varies depending on a range of the power classes. For some megazones, the difference in definition of parameter γ by strong and weak earthquakes exceeds $\Delta\gamma = 0.1$. In turn, this may mean that errors in definition of seismic hazard because of discrepancies in definition of parameter γ, obtained by allocation of only strong earthquakes, can reach one macroseismic point. Reasonable solution to this situation is the combination of reoccurrence assessments of the seismic events based on regional value γ, obtained from all range of power classes K within interval 9 to 17 (that raises accuracy of hazard assessments, but worsens details of definitions at the area mapping) and the reoccurrence assessments obtained by individual values γ of each megazones, according to weak and moderate earthquakes with K in the interval 9 to 13 (that raises details, but reduces some accuracy of definitions).

The combination of such assessments was made by making a logic tree.

Assessments of reoccurrence parameters A_{10} and γ for the subzones of a megazone, taken directly from figures, by statistical reasons, as a rule, are not steady. Therefore, seismic activity A_{10} in each subzone is determined by known value of seismic divisibility using summation and allocation methods.

In various variants of seismic activity calculation, summation and allocation methods are used as regional value of parameter γ, obtained from all set of earthquakes with K in interval of 9–17, and value γ, calculated by weak and moderate earthquakes with K in range of 9–13, occurred direct in the megazone where research subzone is located. Thus, four variants has been obtained for the area sources (Fig. 11), and each of them can be used for calculation of seismic hazard according to the weight.

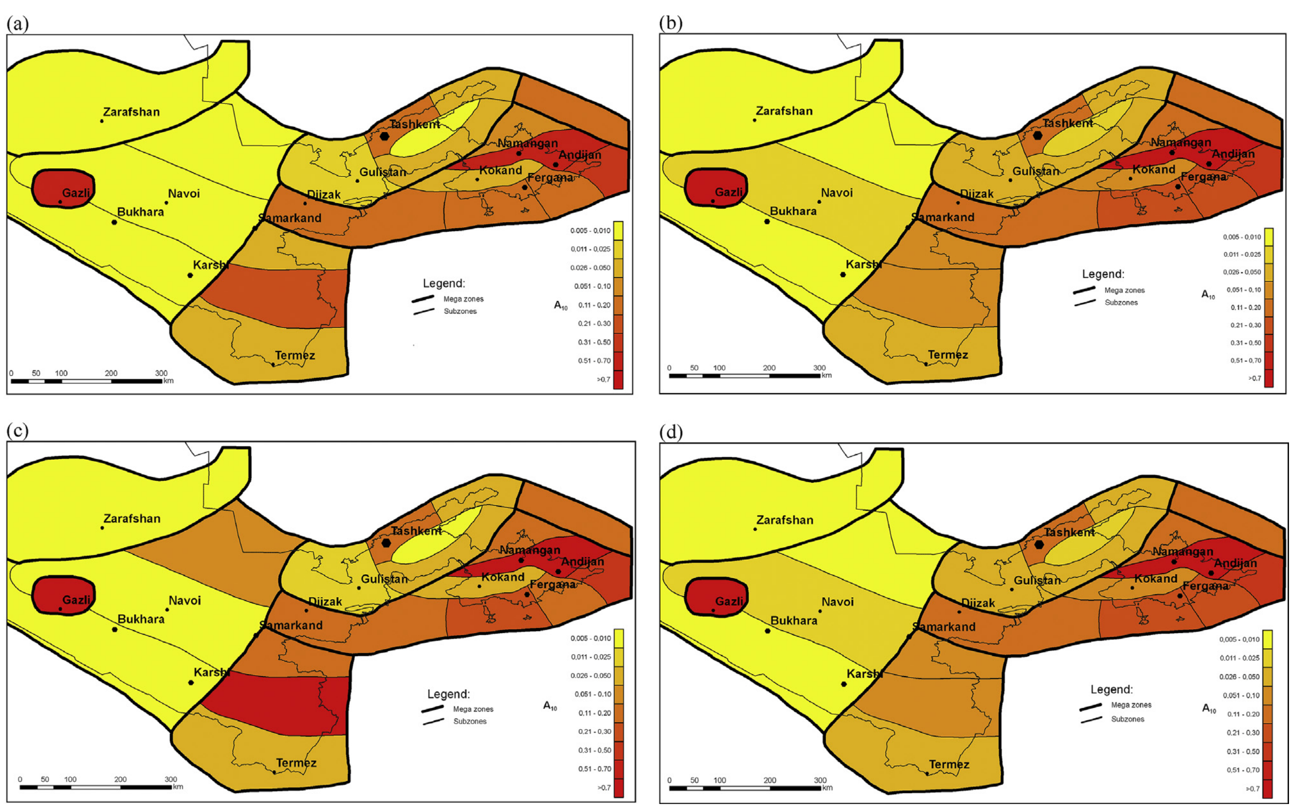

Fig. 11. a,b)-Maps of seismic activity of regional area sources,c,d)- local value for megazones of seismic fractionality, a,c)-calculated by a distribution method; b,d)- summation method.

Seismic potential of this megazone was determined, considering the observed maximum magnitude of one megazone, as well seismotectonic and seismological M_{max} of those seismogenic zones that are in the research megazone. Each megazone has taken value of M_{max}, the greatest of these three values. So, for example, in Tashkent megazone, there is a series of seismogenerating zones with different seismic potential, the greatest value of them $M_{max} = 6.5$ according to the seismotectonic data and $M_{max} = 6.8$ by a complex of seismological parameters.

The observed maximum magnitude earthquake in this megazone is $M_{max}^{obs} = 6$. Therefore, in calculation of seismic hazard for this zone, $M_{max} = 6.8$ was taken. M_{max} for other megazones are shown in Table 4. Within subzones of each megazone, the seismic potential M_{max} was not varied.

During determination of general type of motion in the source of the selected megazones, authors used researches of E.M. Bezrodniy [32], L.M. Matasova [33] (the data till 1985), as well the Harward's the earthquake mechanisms catalog HGT (Harvard Global Centroid Moment Tensor Catalog) (the data from 1976 to 2015) [34]. Fig. 12 shows the fragment of sources mechanisms of strong earthquakes in HGT catalog for Uzbekistan. Dark blue color shows earthquakes with reverse fault type in the source, red color is normal fault, green color is strike-slip.

Prevailing type of a motion in the source for all megazones is reverse fault. Individual earthquakes occurring with a motion of normal type fault, practically it is not marked strike-slip earthquakes. Absolutely similar pattern is noted in data about earlier earthquakes in E.M. Bezrodniy and L.M. Matasova's works [32,33].

5. Seismic intensity attenuation

For earthquakes with different energy levels, the relationship between macroseismic intensity and distance considered by following equation:

Table 4
Observed maximum magnitude of earthquakes M_{max} for different megazones.

Megazones No.	I	II	III	IV	V	VI	VII
Seismic potential of megazones (M_{max})	6.8	7.5	7.5	7.5	7.5	6.0	7.5

$$\frac{I - I_0}{\lg R - \lg H} = -(dM - e\lg H + f) \quad (4)$$

where $I_0 = aM - b\lg H + c$, $R = (\Delta^2 + H^2)^{1/2}$

in which, the attenuation factor of seismic intensity with distance is assumed to depend on magnitude M and depth H. Choosing this dependence allows to consider the known empirical fact that at equal magnitude of seismic event, earthquake with smaller depth have greater macroseismic effect in near source areas, than deeper earthquakes, but in the surface layer earthquake, the reduction points moving outward from the source is faster than that in the earthquakes located on the deeper layers.

Obtain I by:

$$I = aM - b\lg H + c - dM\lg\frac{R}{H} + e\lg H\lg\frac{R}{H} - f\lg\frac{R}{H} \quad (5)$$

Dependence coefficients is based on the macroseismic data of Central Asia (over 160 schemas isoseists of earthquakes have been analyzed). Fig. 13 shows the distribution of strong earthquake sources in Central Asia. Dependence coefficients have been mapped and calculated according to available macro seismic data.

The following relationship between seismic load intensity attenuation and distance for earthquakes with different energy levels was obtained by the least square method:

$$I = 1.475M - 2.646\lg H + 1.905 - 0.498M\lg(R/H) + 1.159\lg H\lg(R/H) - 1.401\lg(R/H) \quad (6)$$

The value of standard deviation in the dependence is $\sigma = 0.565$.

Earlier in Refs. [3,4], when assessing the seismic hazard of Uzbekistan, the Black – Shebalin type dependence was used to calculate seismic load: $I = aM - b\lg R + c$. In Ref. [15], Shebalin N.V. determined the coefficients for Central Asia as: $a = 1.5$; $b = 3.5$; $c = 3.0$. Taking into account additional macroseismic data of last 50 years, we renewed these coefficients: $a = 1.32$; $b = 3.01$; $c = 3.55$. The standard deviation of the dependence is $\sigma = 0.728$.

Fig. 14 shows the attenuation curves of macroseismic points with distance, calculated for author's dependence, for earthquakes with magnitudes $M = 7.5$, $M = 6.5$ and $M = 5.5$, occurring at different depths and the similar curves of the N.V. Shebalin's Central Asian dependence [15].

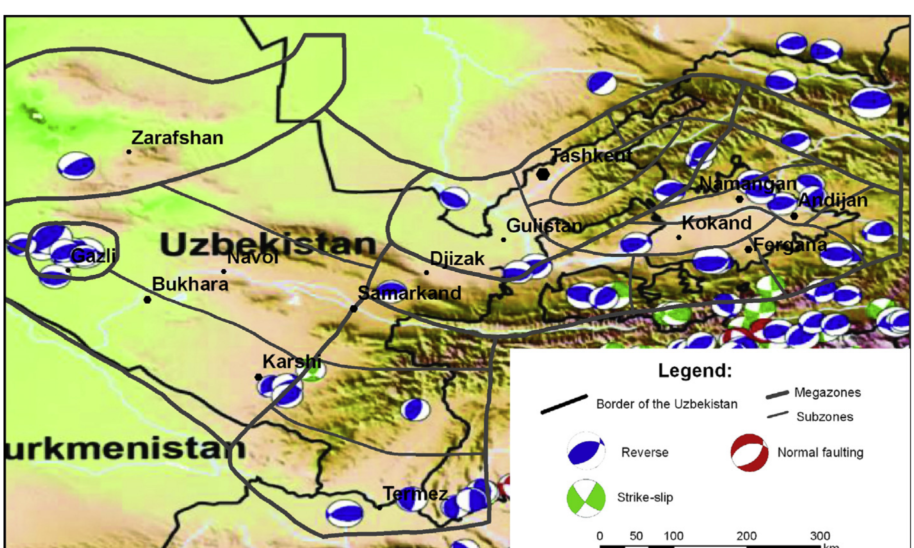

Fig. 12. Strong earthquakes focal mechanism in the HGT catalog from 1976 to 2013 [6].

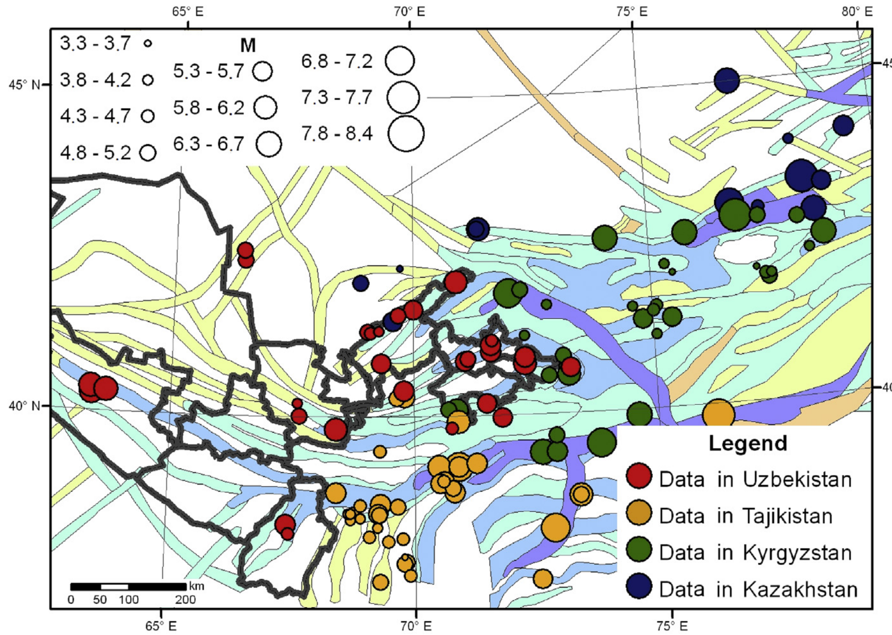

Fig. 13. Distribution of strong earthquake sources in Central Asia based on available macro seismic data.

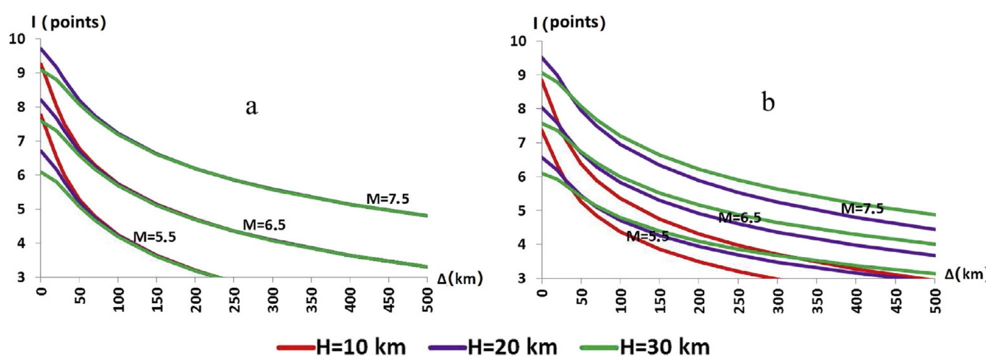

Fig. 14. Macroseismic point attenuation with distance for the earthquakes occurring at different depths. a)-N.V. Shebalin's Central Asian dependence, b) author's dependence.

One can see in figures that the author derived dependence $I = I(M,R,H)$, when a source depth increases, a macroseismic effect in the epicentral area decreases. By moving away from source areas, attenuation of points is faster for earthquakes at small depths than those with deeper depths, which coincide with the empirical facts. N.V. Shebalin's dependence $I=I(M,R)$, more macroseismic effect is in near zones for earthquakes with small depths, but attenuation in far zones is similar to earthquakes with various depths. Within a near zone, both dependences have confirming results.

Determining attenuation of ground motion velocity and regional relationship between spectral amplitude and distance [35], a component of seismogram with the greatest amplitude of transverse wave has been analyzed. We studied more than 1000 velocigrams and 300 record spectra of ground motion velocity produced by earthquakes in the range of M_L3.8 to M_L6.2, with epicentral distances from 12 to 500 km [35]. All set of analyzed earthquakes have been divided into several magnitude group, with discretization step of 0.5*M*. For example, in Fig. 15, there is experimental data (v,R) for earthquakes magnitude groups *M*4.0- *M*6.0, occurred within the Fergana intermountain depression (Megazone III). In Fig. 16, it is shown the experimental log of the spectral

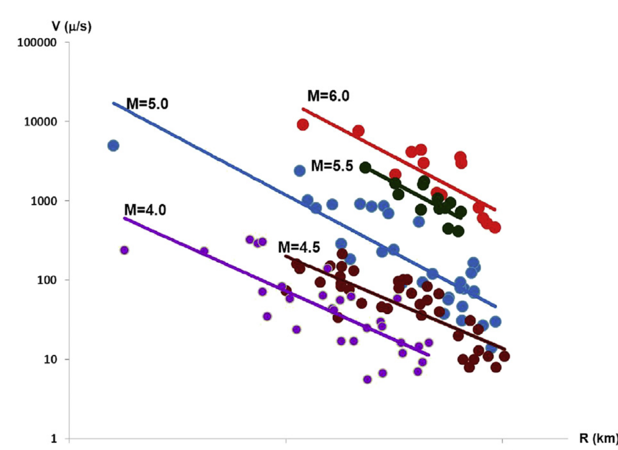

Fig. 15. Experimental data of ground fluctuation velocity amplitude attenuation for earthquakes with magnitude *M*4-*M*6 in the Fergana intermountain depression.

amplitudes of the ground oscillation velocities $\lg S_V$ (μ/s) of earthquakes, which occurred in the East of Uzbekistan (megazones I–III).

For each magnitude group that has been constructed by least square method, dependence of $\lg v = a\text{-}b\lg R$, where v is the maximum value of amplitude of a S-wave (in microns per second), R is source to site distance (in kilometer). By combining these equations, the ground fluctuation velocity attenuation with distance is obtained. For East Uzbekistan, the equation is:

$$\lg v = M - 1.7\ \lg R - 3.09\ (\sigma = 0.11)\ 10 < R \leq 100\ \text{km} \quad (7)$$

$$\lg v = M - 2.35\ \lg R - 1.74\ (\sigma = 0.08)\ 100 \leq R \leq 500\ \text{km}$$

where the velocity v is in centimeters per second (cm/s).

Under different periods of vibration T, the attenuation of the spectral amplitudes of ground motion velocities, and the vibration S_T with distance from the source are as follows:

$$\lg S_{0.05} = 1.021M\text{-}3.000\lg R\text{-}2.206 \pm 0.18$$

$$\lg S_{0.1} = 1.072M\text{-}3.162\lg R\text{-}1.641 \pm 0.16$$

$$\lg S_{0.2} = 1.073M\text{-}2.575\lg R\text{-}2.154 \pm 0.14$$

$$\lg S_{0.3} = 1.184M\text{-}2.318\lg R\text{-}2.983 \pm 0.15$$

$$\lg S_{0.5} = 1.260M\text{-}2.009\lg R\text{-}3.902 \pm 0.11$$

$$\lg S_{0.75} = 1.316M\text{-}1.767\lg R\text{-}4.650 \pm 0.13$$

$$\lg S_{1.0} = 1.328M\text{-}1.556\lg R\text{-}5.061 \pm 0.08$$

$$\lg S_{1.5} = 1.402M\text{-}1.399\lg R\text{-}5.828 \pm 0.12$$

$$\lg S_{2.0} = 1.443M\text{-}1.434\lg R\text{-}6.131 \pm 0.08$$

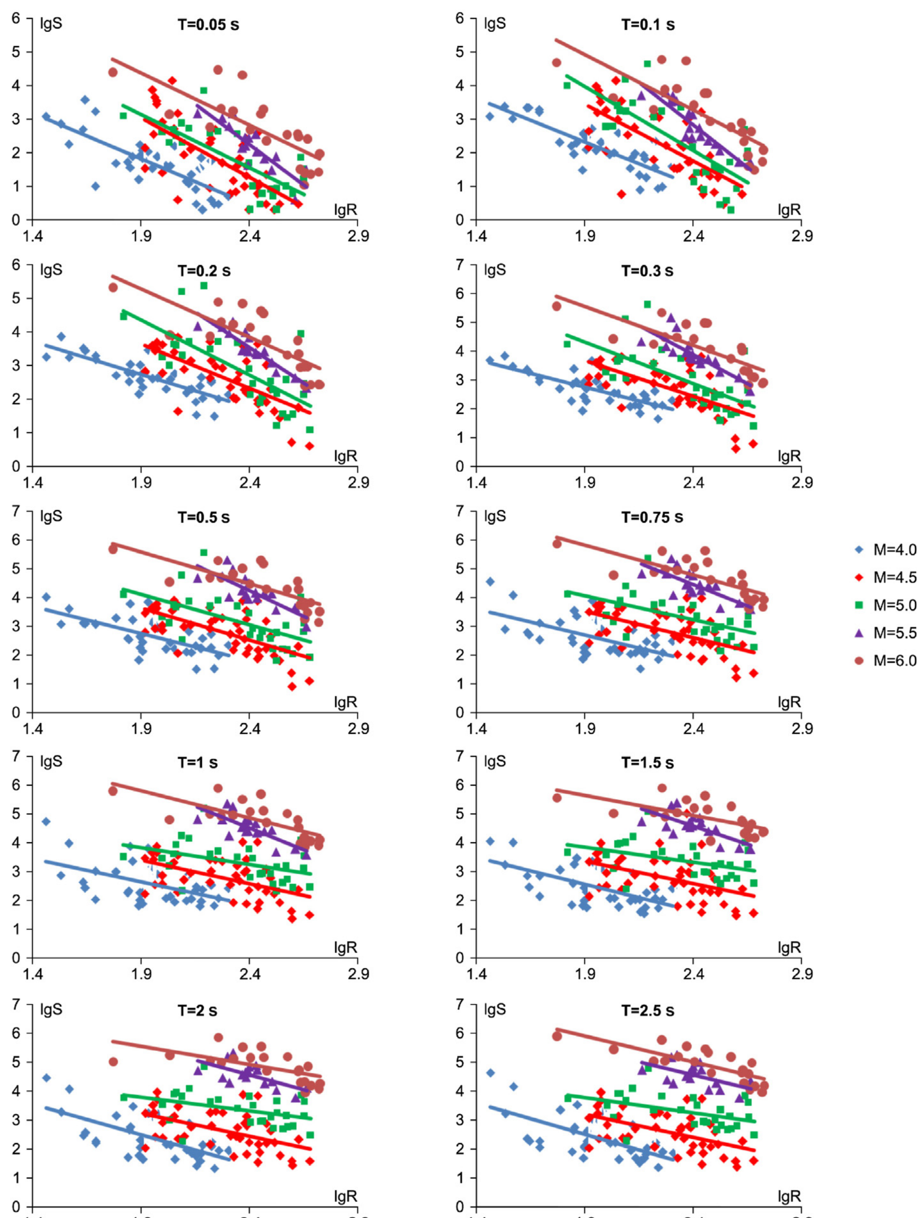

Fig. 16. The experimental values and linear approximations of the logarithms of spectral amplitudes (lg$S$, μ/s) recorded at different distances from the epicenters R (km) of each magnitude group.

$lgS_{2.5} = 1.464M\text{-}1.557lgR\text{-}6.129 \pm 0.09$

where the source to site distance R is expressed in kilometers, and the amplitude of the velocity spectrum of the ground oscillations S_T is in centimeters per second.

Fig. 17 shows system smoothed source spectrums of velocities for earthquakes of East Uzbekistan with $M5$ - $M7$, and transformation features of source spectrums when moving away from a seismic source [3].

In order to construct the relation between the maximum accelerations of ground motions and magnitude M, and the hypocentral distance R. Experimental data including analog recordings of the basic pushes accelerations and numerous aftershocks of Pap and Gazli earthquakes (over 200 records in the range of $M3.8$ to $M7.3$ with epicentral distances up to 150 km) [2,36] and digital records of accelerograms, recently obtained by seismic stations in the Central Asian. The available regional accelerograms did not cover all necessary magnitudes range and epicentral distances. Taking into account the additional data of the European strong motions database and some digital records of earthquakes in China under similar geologic-tectonic conditions, an assessment of the maximum accelerations dependence [4] is obtained:

$$lga_{max} = 0.452M - 0.993\ lgR + 0.796 \pm 0.18 \quad (8)$$

Fig. 18 shows the comparison of amplitude attenuation characteristics of peak accelerations for earthquakes with the magnitude 4–7 with distance, and calculation different seismic active regions of the globe, and according to their correlation. It can be seen from the accelerograms of researching region that differences are significant.

The above-mentioned regional relationship of intensity attenuation with distance have been used for calculation and mapping of seismic hazard of Uzbekistan, expressed in points of a macroseismic scale, velocities and accelerations of ground fluctuations, and spectral amplitude of seismic fluctuations.

In this paper, seismic hazard assessment was carried out in the framework of the probabilistic-deterministic approach described in Refs. [3,5,21]. Calculations have been done by using *SEISMHAZARD_UZ* software package, developed by the Laboratory of Regional Seismicity and Seismic Zoning of the Institute of Seismology of Academy of Sciences of Uzbekistan [37]. As input parameters for calculation, a long-term characteristics of seismic process in each source was used (seismic activity A_{10}, seismic divisibility γ, seismic potential M_{max}, distribution of earthquakes with different energy levels by depths $H = f(M)$, prevailing type of a motion in the sources).

Unit grade square of a geographical grid was broken into 16 parts by latitude and longitude, i.e. 256 cells which were attributed by input parameters values.

In the first stage for each fixed level of seismic load intensity, I ranges from 5 to 10 points ($a_{max} = 1$–900 cm/s^2, $v_{max} = 1$–300 cm/s) with discrete ($\Delta I = 0.01$ point, $\Delta a_{max} = 0.1$ cm/s^2, $\Delta v_{max} = 0.1$ cm/s) in each knot of a grid calculated the periods of shakes repetition T_I. The following integral is the core of frequency calculation of shaking B_I ($B_I = 1/T_I$), with set intensity $I \geq I_0$ ($a_{max} \geq a_0$, $v_{max} \geq v_0$):

$$B_I = \int_V N_{\sum} dV \quad (9)$$

where N_Σ is a time unit; the volume of the expected number of earthquakes, with the source in elementary volumes dV, can cause shakes with intensity not less than I points ($a_{max} \geq a_0$, $v_{max} \geq v_0$) [3,21,37] in observation point.

Considering frequency of earthquake occurrence in each unit cell (Gutenberg–Richter dependence), the recurrence frequency of B_I tremors with an intensity of $I \geq I_0$ ($a_{max} \geq a_0$, $v_{max} \geq v_0$) is determined by the formula [21]:

$$B_I = \frac{1}{10^{0.5\gamma} - 10^{-0.5\gamma}} \int_V A_{10}\left[10^{-\gamma(K^1 - K_0)} - 10^{-\gamma(K_{max} - K_0)}\right] dV \quad (10)$$

where K_0 is a class to which seismic activity is converted (in this case, $K_0 = 10$);

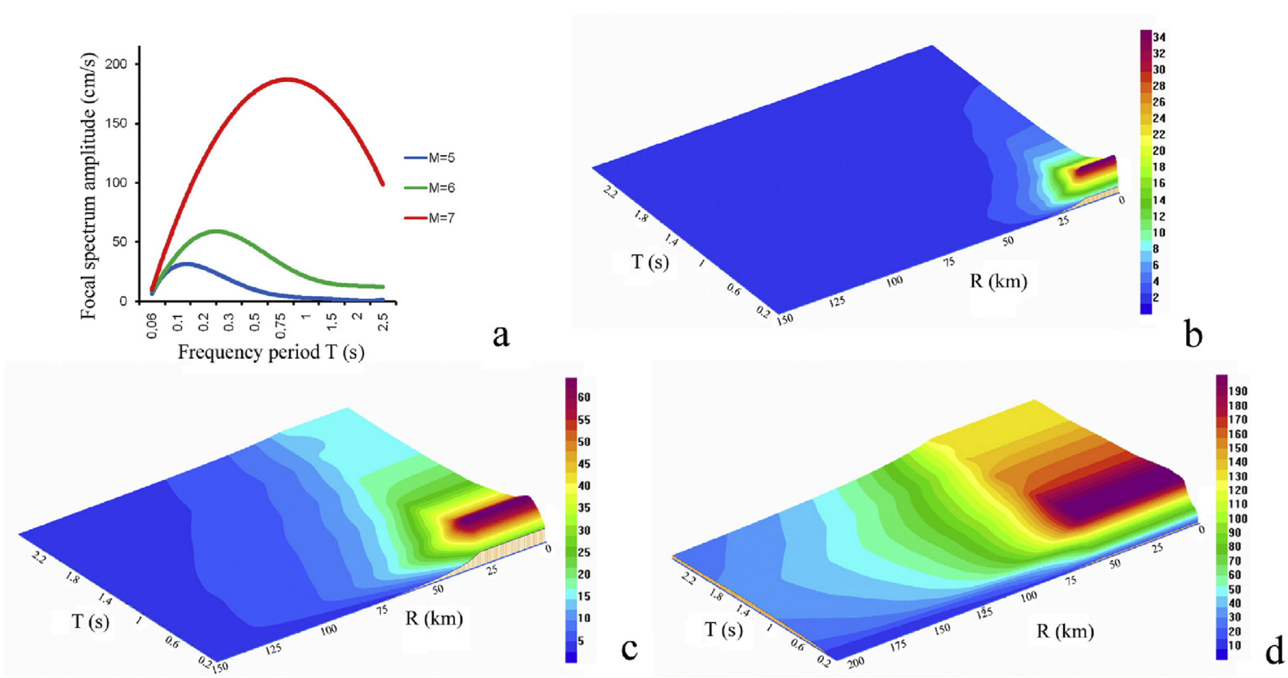

Fig. 17. a)-Source spectra of ground motion velocity for earthquakes with magnitude $M5$ -$M7$; b),c),d)- their transformation when moving away from a source.

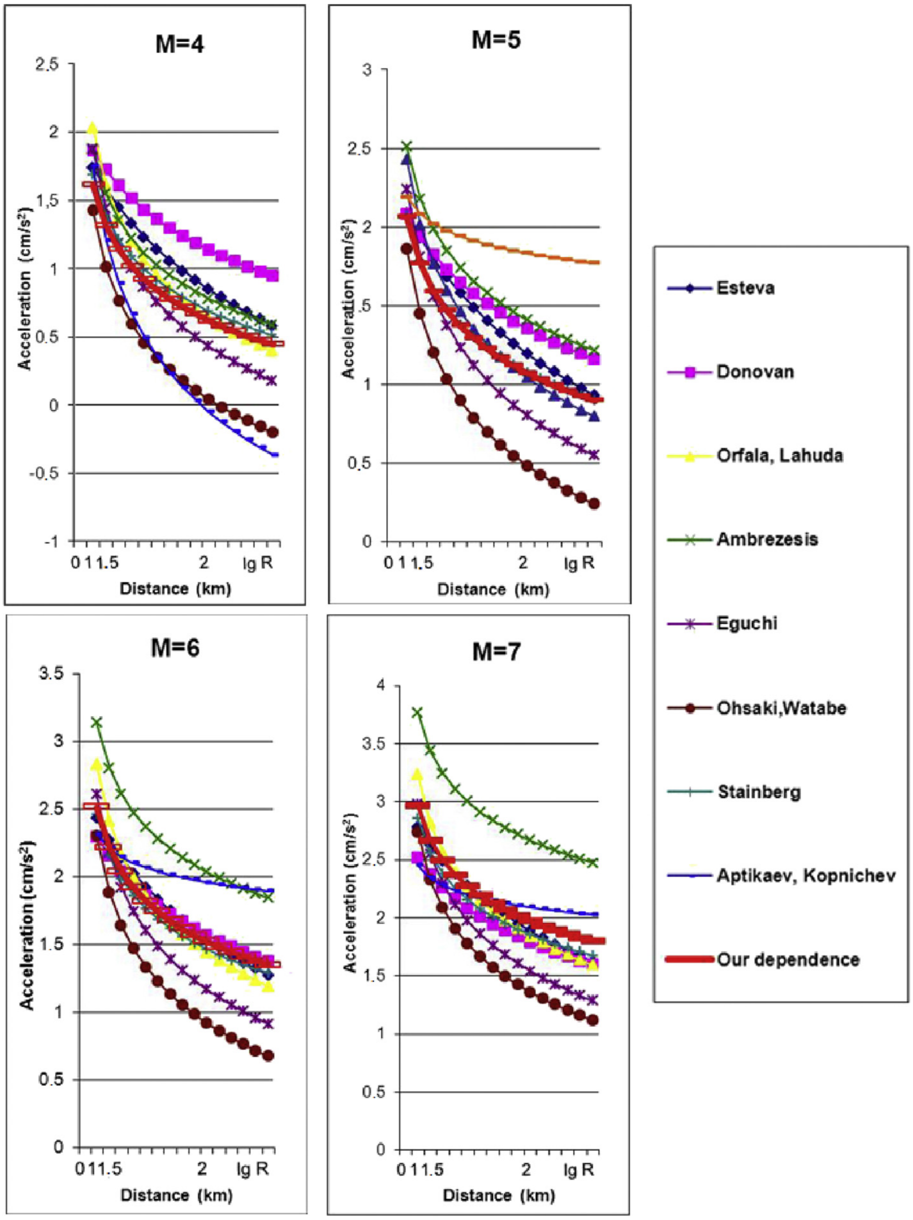

Fig. 18. Comparison of the maximum acceleration of different epicentral distances of different magnitudes according to global and regional data.

K^1 is a class that can cause shaking at a given point with $I \geq I_0$ ($a_{max} \geq a_0$, $v_{max} \geq v_0$);

K_{max} is the maximum magnitude of the possible earthquake;

A_{10} is seismic activity;

γ is slope of the recurrence graph in the distribution of earthquakes by energy classes.

The value of K^1 is a calculated characteristic that obtained on the basis of the laws of seismic load attenuation in distance.

The authors of this study recognize that within the framework of the used approach, the aleatory uncertainties associated with the stochastic nature of seismic load are not fully taken into account, which may lead to some underestimation of seismic hazard. Therefore, in the calculations of ground motion prediction equation (GMPE), one standard deviation σ was added to the median value of the velocities and maximum accelerations of ground motions.

At the second stage, zones of the maximum intensity with the mean return periods of $T = 500$, $T = 1000$, $T = 2500$ and $T = 5000$ years have been marked out. These zones are areas in which probability not exceeding of seismic load during a term $\tau = 50$ years, accordingly $P = 0.9$, $P = 0.95$, $P = 0.98$ and $P = 0.99$.

6. Seismic hazard in the area of Uzbekistan

Seismic hazard calculation of Uzbekistan was made separately for different types of seismic sources. On the basis of intensity attenuation laws, the assessments of earthquakes reoccurrence parameters and seismic potential, with with reverse faults and strike-slip type in the focal area is carried out. For an example, Fig. 19 is map of seismic hazard in points of a macroseismic scale for probability $P = 0.98$, not exceeding level of seismic intensity within

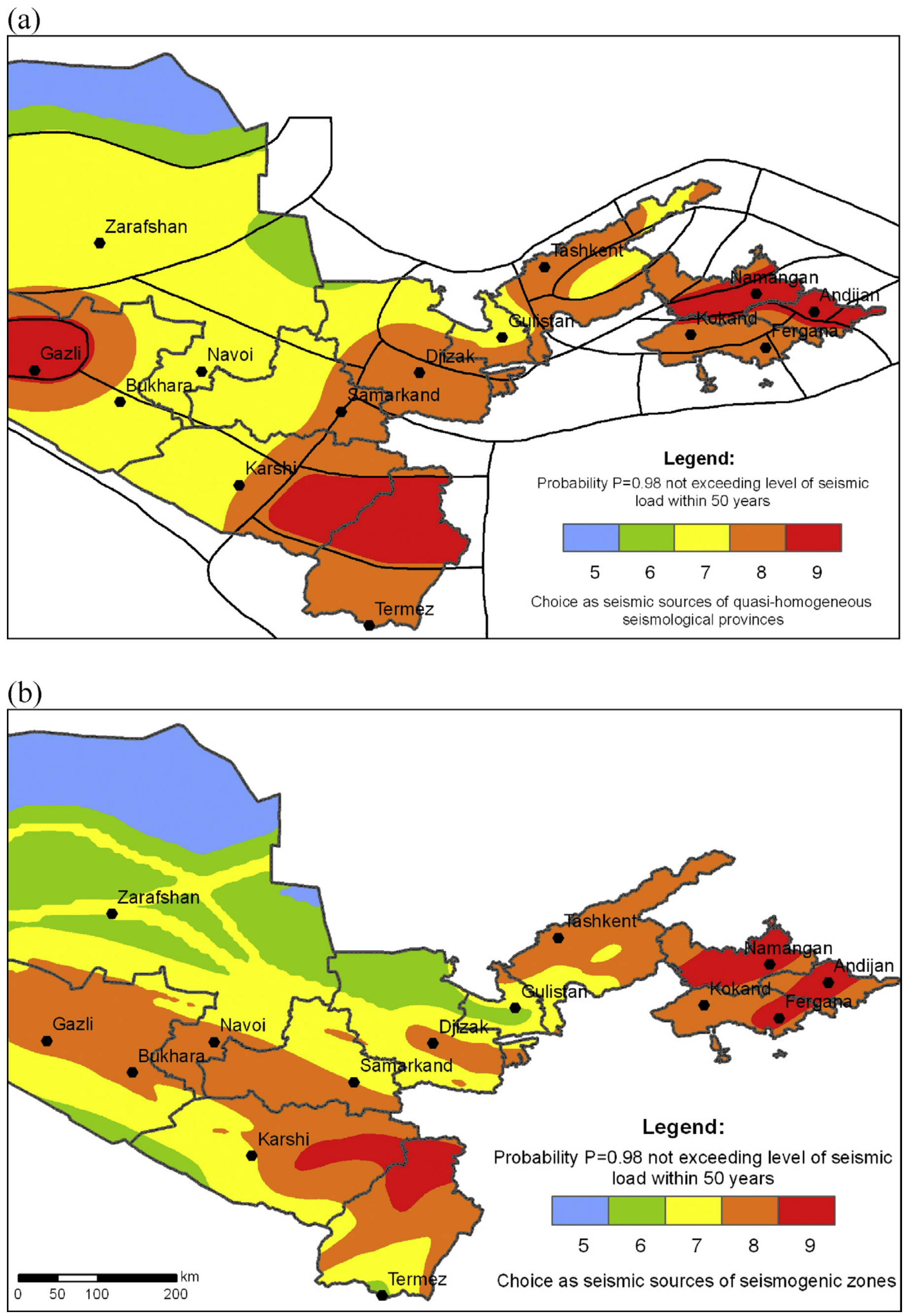

Fig. 19. Maps of seismic zoning of Uzbekistan (East of 63° E) for $P = 0.98$ for the selected seismic sources of a)-quasihomogeneous seismological provinces b)-seismogenic zones.

50 years as seismic sources of quasi-homogeneous seismological provinces (a) and seismogenic zones (b).

The influence factors of input parameters uncertainty on the results of seismic hazard assessment is made in Refs. [23,24]. It is discovered that the maximum deviation can arise if there is significant difference between actual and calculated depths of the earthquake sources ($\Delta I = 1.5$ points), statistical errors in defining slope of reoccurrence curve γ ($\Delta I = 0.96$ points), and definition discrepancies of possible maximum size earthquake $M_{\max}$ ($\Delta I = 0.84$ points). The contribution of factors uncertainty is smaller, such as the inexact set of seismic activity A_{10}; choice of an incorrect prevailing type; using not local, but regional laws of intensity attenuation of seismic loads in distance, and the values are $\Delta I = 0.24$; $\Delta I = 0.34$ and $\Delta I = 0.22$ points respectively.

Uncertainty factors of the input parameters is necessary for seismic hazards assessment (the epistemic uncertainties), and OSR-2017 is obtained by building a logic tree during construction maps of seismic zoning (Fig. 20).

Weights to tree branching were obtained from the parameters distribution function (depth, the source mechanism etc.), and heuristic reasons (source type choice, repeatability parameters definition methods etc.).

Figs. 20–22 show the average seismic effects in the logical tree branches in terms of the macroseismic scale, the velocities and accelerations of ground motions; different probabilities ($P = 0.90$; $P = 0.95$; $P = 0.98$ and $P = 0.99$) will exceeding the seismic load within 50 years. The constructed maps are seismic zoning maps of Uzbekistan (Fig. 23).

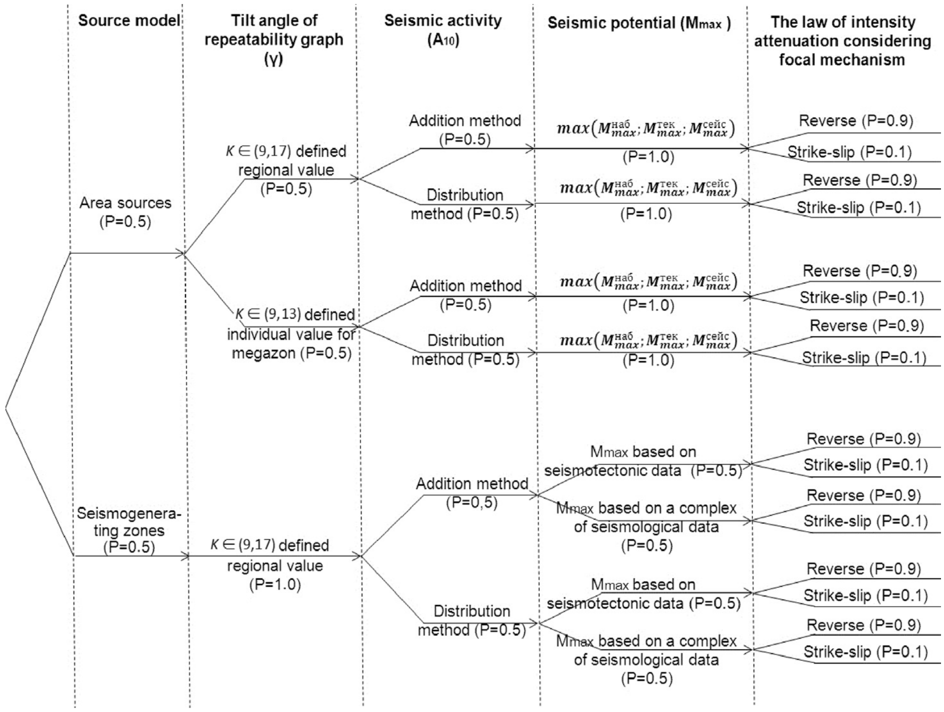

Fig. 20. Logical tree for accounting uncertainty factors of input parameters in seismic hazard calculation.

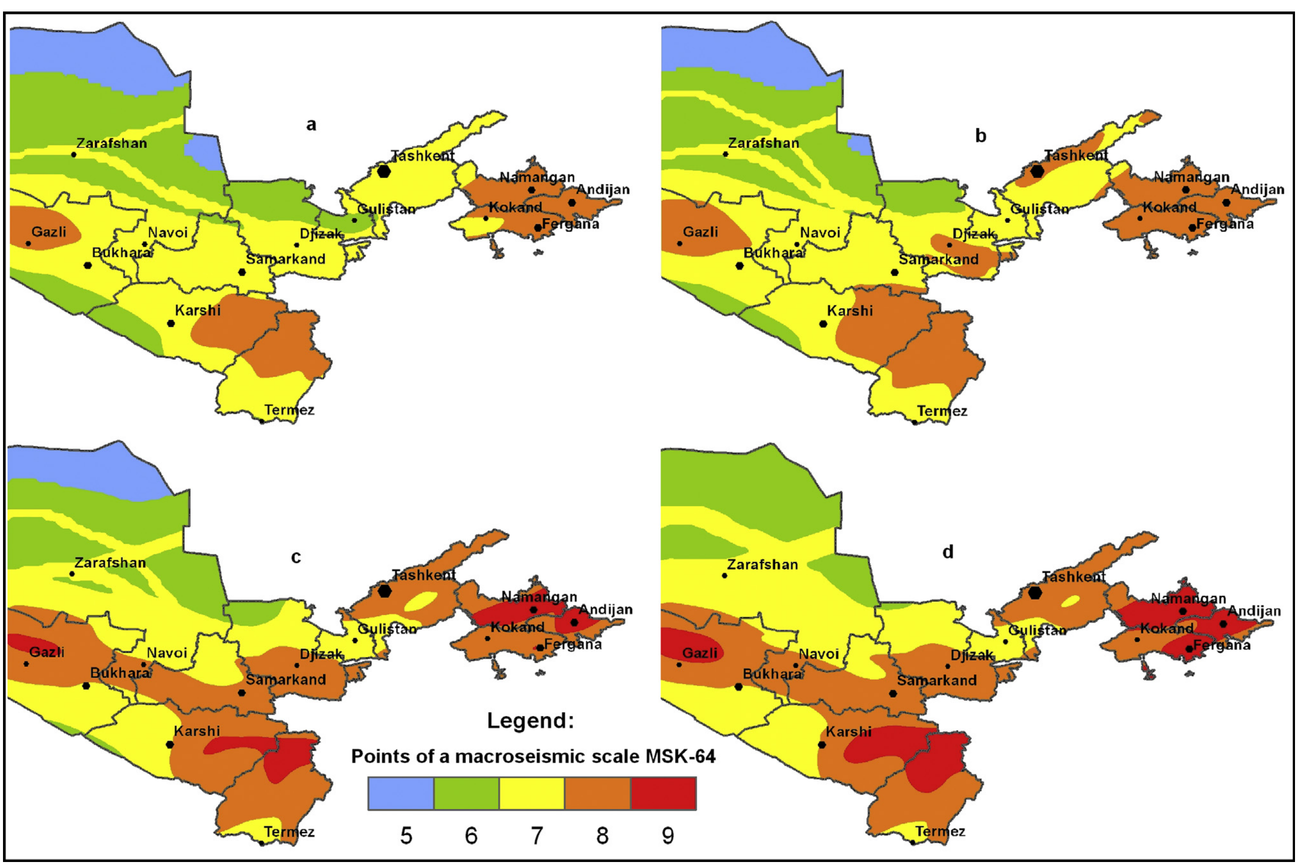

Fig. 21. General seismic zoning of Uzbekistan (East of 63° E) in macroseismic scale MSK-64, with different probabilities not exceeding the seismic load within 50 years: a) $P = 90\%$; b) $P = 95\%$; c) $P = 98\%$; d) $P = 99\%$.

Seismic hazard curves for some large cities of Uzbekistan are presented in Fig. 24.

7. Seismic hazard assessment of western Uzbekistan from 63 °E

Fig. 25 shows the fragment of strong earthquake sources in the Central Asia since historical times. The area in western Uzbekistan (from 63° E) is framed. The instrumental data about earthquakes with 8.6 (the minimum energy level of the regional catalog) in Aral area is few. Meanwhile, presence of historical earthquakes (for example, around Urgench, 1207–1208, $M = 6.1$), there is no doubts that strong and moderate earthquakes will occur here in the further. Obtaining statistically reliable parameters assessments of the seismic mode is necessary for seismic hazard

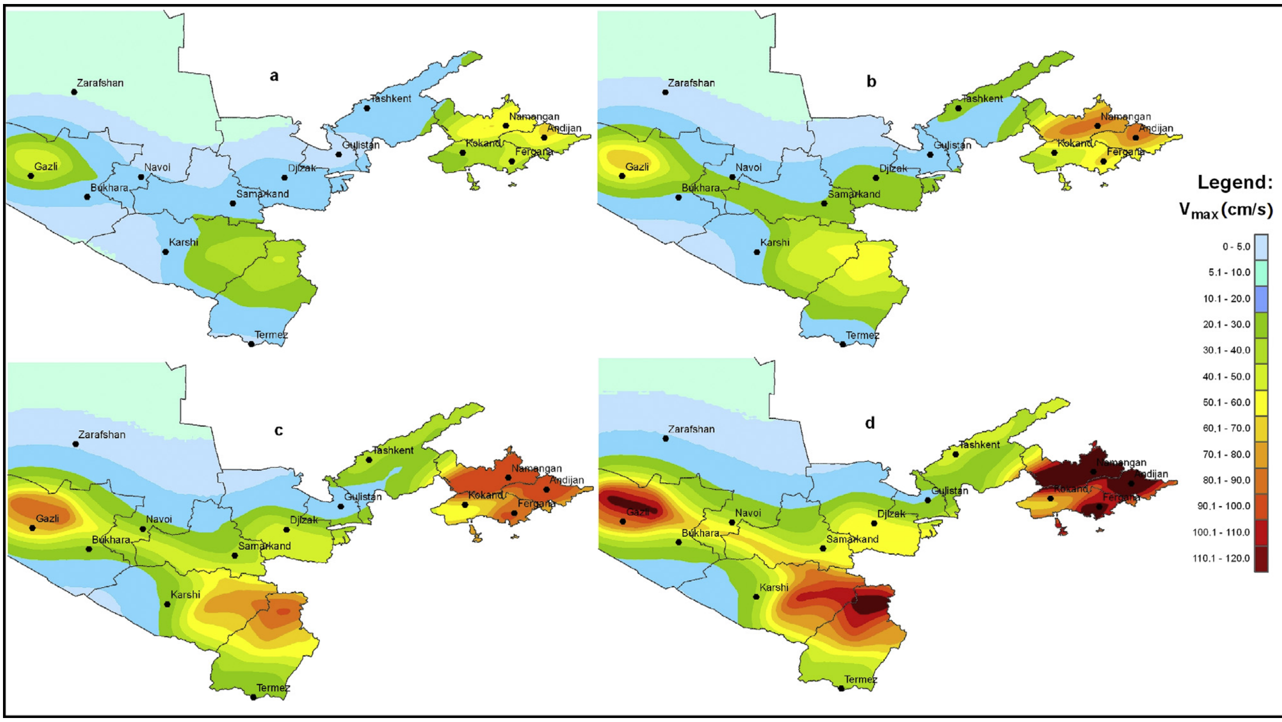

Fig. 22. General seismic zoning of Uzbekistan (East of 63° E) in ground fluctuation velocities (cm/s) for different probabilities not exceeding the seismic load within 50 years: a) $P = 90\%$; b) $P = 95\%$; c) $P = 98\%$; d) $P = 99\%$.

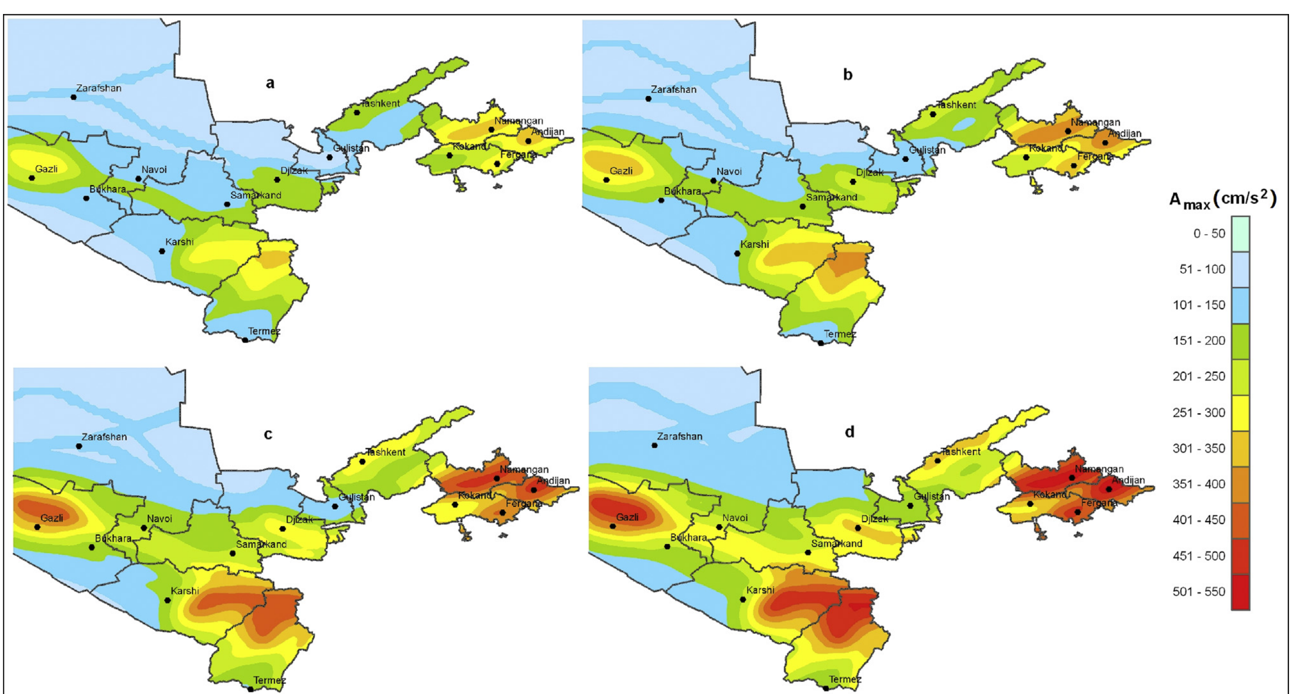

Fig. 23. General seismic zoning of Uzbekistan (East of 63° E) in amplitudes of the maximum accelerations (cm/s^2) for different probabilities not exceeding the seismic load within 50 years: a) $P = 90\%$; b) $P = 95\%$; c) $P = 98\%$; d) $P = 99\%$.

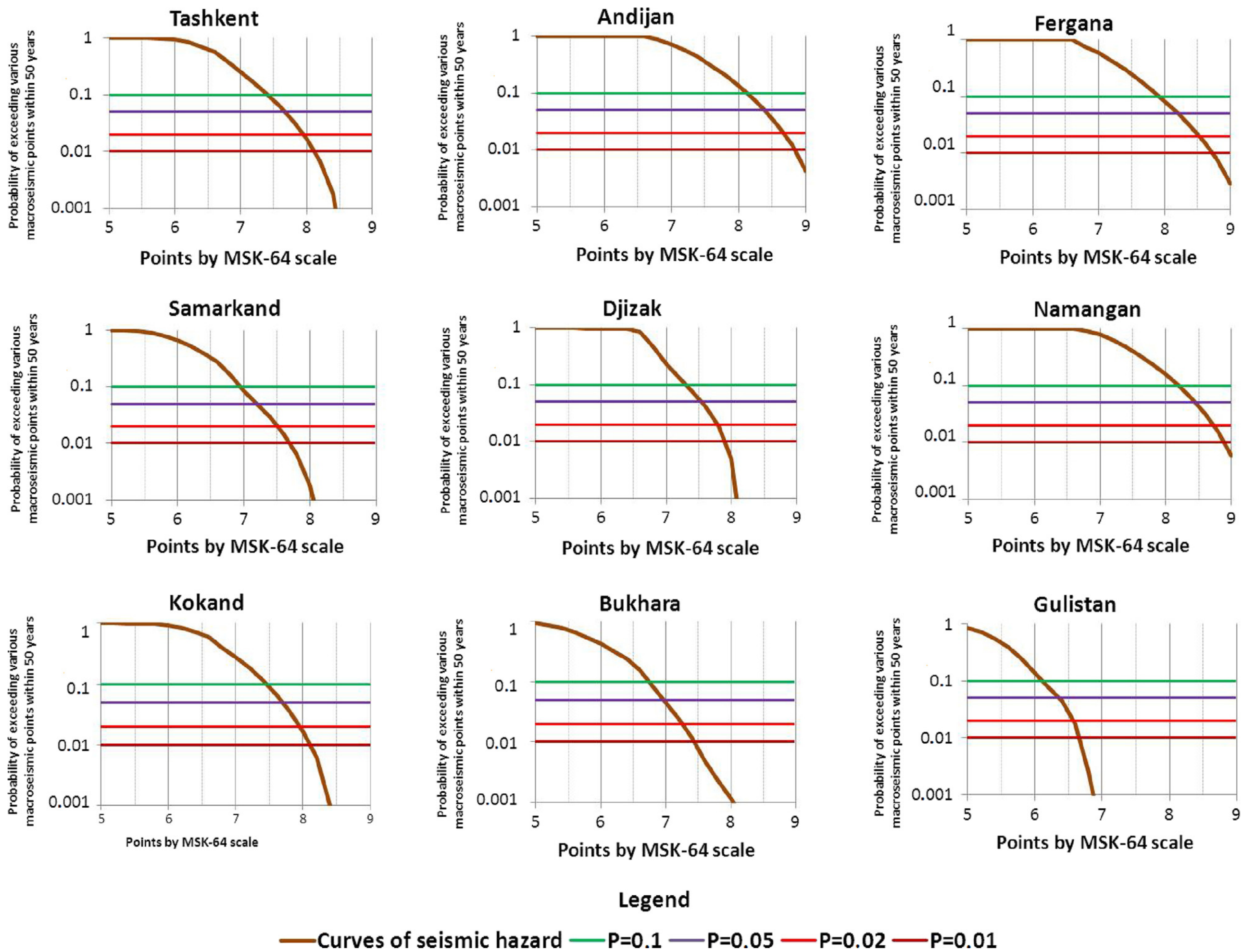

Fig. 24. Seismic hazard curves for some large cities of Uzbekistan.

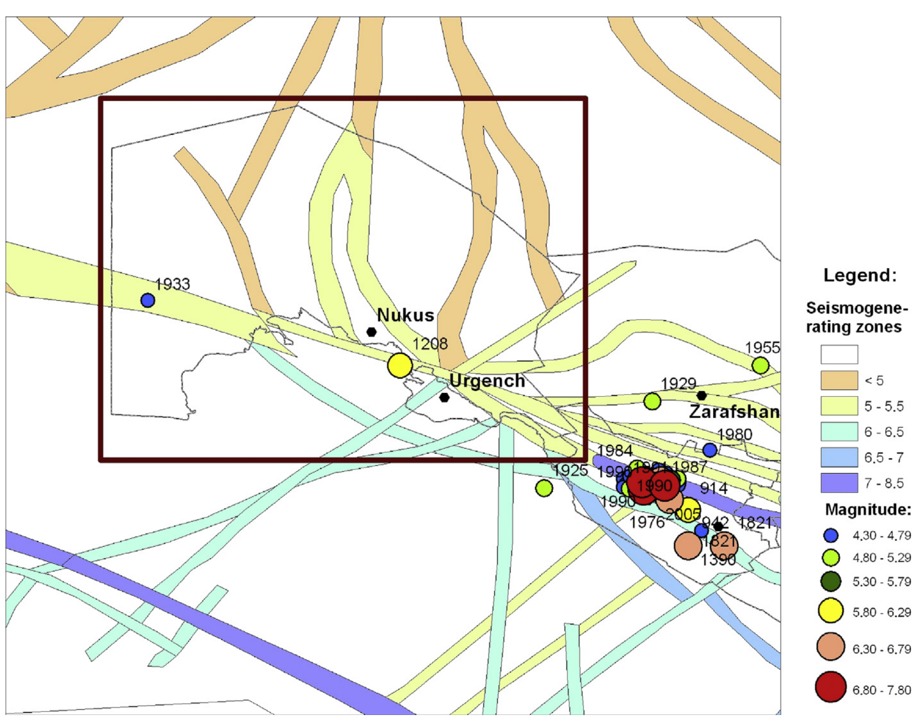

Fig. 25. Strong earthquakes epicenters' distribution of the Central Asia since historical times. The frame noted the west of Uzbekistan from 63° E.

assessment of these areas, which is impossible currently. Therefore, according to the relation between the seismic potential of seismic active zones and the repeatability parameters of strong earthquakes, the seismic activity and seismic divisibility of the zone are defined.

Within the research area, by the seismotectonic and geologic-geophysical data [10], the seismogenerating zones with seismic potential estimated value $M_{max} = 5.5$ and fragmentary $M_{max} = 6.5$ are marked.

Seismological parameterization of marked seismic active zones was carried out as follows. On the basis of comparison of parameters of repeatability of earthquakes to size of seismic potential M_{max} in the seismogenerating zones of eastern Uzbekistan located to 63 °E, it has been revealed [3,4] that seismic activity A_{10} increases with growth of seismic potential of a seismic active zone, and seismic divisibility γ, oppositely decreases. The constraint equations between considered parameters are:

$$\begin{aligned} \lg A_{10} &= 0.825M_{max} - 6.387 \\ Y &= -0.075M_{max} + 1.063 \end{aligned} \tag{11}$$

Values A_{10} and γ, describing seismic activity and seismic divisibility of the seismogenic zones located to the west from 63 °E, fitting to seismic potential M_{max} marked for the seismic active regions by the above relation have been taken. As laws of macroseismic intensity attenuation in distance, dependence of Blejk-Shebalin for the area of the Western Uzbekistan [3] was used. Fig. 26 shows results of seismic hazard calculation in points of a macroseismic scale for Uzbekistan located to the West from 63 °E, where zones with equal probability ($P = 0.9$, $P = 0.95$, $P = 0.98$ and $P = 0.99$) not exceeding seismic intensity within 50 years. Thus, quantitative characteristics of seismic hazard have been obtained for all areas of Uzbekistan.

8. Conclusion

Assessment of seismic hazard and construction of the seismic zoning maps of Uzbekistan have been done on the basis of the revealed regional laws of seismic process and seismic ground motions. In the developed seismic zoning maps, seismic hazard is expressed in points of a macroseismic scale, velocities and accelerations of ground motions. It is also characterized by calculated intensity of seismic load which in average soil with the set probability ($P = 0.9$, $P = 0.95$, $P = 0.98$ and $P = 0.99$) will not be exceeded within 50 years.

All kinds of seismic sources are used in the seismic zoning map, considering the uncertainty of input parameters due to the incompleteness of original seismic structure information, the likelihood of seismic process and seismic load. Based on the experience of international seismic risk assessment and mapping, a new seismic zoning map is developed, which fully describes the actual seismic risk of the study area. They reflect structure of crust and differentiation of seismic active zones by degree of seismic activity. In new general seismic zoning map, an intensity of macroseismic loads in points of MSK-64 are related to average soil conditions. The developed seismic zoning maps are designed for carrying out antiseismic measures.

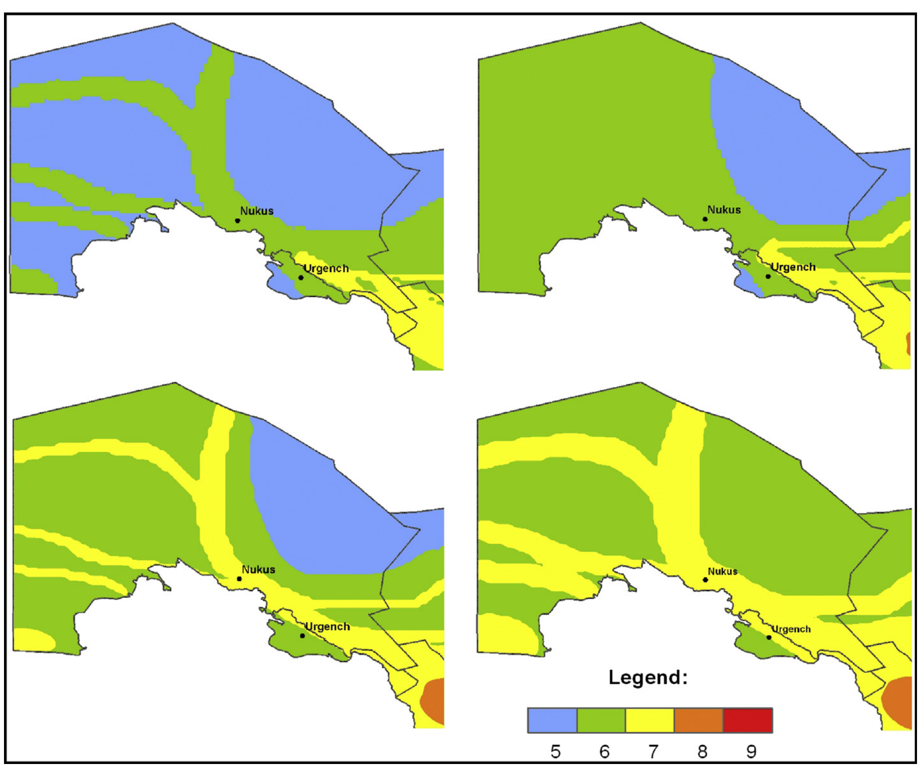

Fig. 26. Maps of seismic zoning of the Western Uzbekistan (west of 63° E) with different probabilities not exceeding the seismic load within 50 years: a) $P = 90\%$; b) $P = 95\%$; c) $P = 98\%$; d) $P = 99\%$.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgments

Research Funders: Institute of Seismology, Academy of Science of the Republic of Uzbekistan Grant number is FA-F8-007.

References

[1] K.N. Abdullabekov, T.U. Artikov, R.S. Ibragimov, Seismic hazard and seismic zoning technology of Uzbekistan, Miner. Resour. Geol. 6 (2002) 32–37.

[2] T.U. Artikov, R.S. Ibragimov, F.F. Ziyaudinov, A Complex of Maps of General Seismic Zoning of the Territory of the Republic of Uzbekistan OSR-2011. Explanatory Note and List of Cities and Towns Located in Seismic Areas, GP "Institute GIDROINGEO", Tashkent, 2012.

[3] T.U. Artikov, R.S. Ibragimov, F.F. Ziyaudinov, Seismic Danger of the Territory of Uzbekistan, Fan, Tashkent, 2012.

[4] K.N. Abdullabekov, T.U. Artikov, R.S. Ibragimov, F.F. Ziyaudinov, Seismic hazard of Uzbekistan territory, in: H.A. Akbarov (Ed.), Geosciences in Uzbekistan, GP "NIIMR,", Tashkent, 2012, pp. 195–202.

[5] Seismicity and Seismic Zoning of Northern Eurasia, in: V.I. Ulomov (Ed.) Issue vols. 2–3, United IFZ RAS, M, 1995.

[6] Earthquake Hazard and Risk Assessment in Kyrgyzstan and Tajikistan with Cooperation to Afghanistan and Uzbekistan 2011-2014, Norwegian Ministry of Foreign Affairs, 2015.

[7] D. Giardini, The global seismic hazard assessment program (GSHAP)-1992/1999, Ann. Geofisc. 42 (6) (1999) 957–974.

[8] Sh. Ullah, D. Bindi, M. Pilz, L. Danciu, G. Weatherill, E. Zuccolo, A. Ischuk, N. Mikhailova, K. Abdrakhmatov, S. Parolai, Probabilistic seismic hazard assessment for Central Asia, Ann. Geophys. 58 (1) (2015) S0103, https://doi.org/10.4401/ag-6687.

[9] V.I. Ulomov, V. Starkhov, D. Giardini, Seismic hazard assessment in northern Eurasia, Ann. Geophys. XXXVI (3–4) (1993) 83–92.

[10] R.N. Ibragimov, U.O. Nurmatov, O.R. Ibragimov, Seismotectonic method of seismic hazard assessment and seismic zoning issues, in: K.N. Abdullabekov (Ed.), Seismic Zoning and Earthquake Forecast in Uzbekistan, Publishing house of the State Enterprise "Institute of Hydrogeology and Engineering Geology (HYDROINGEO)", Tashkent, 2002, pp. 59–74 (in Russian).

[11] T.G. Rautian, The determination of the earthquakes energy at distances up to 3000 km, Inst. Phys. Earth USSR Acad. Sci. Proc. 32 (199) (1964) 72–98.

[12] T.G. Rautian, The problem of determining the energy of earthquakes, in: Magnitude and Energy Classification of Earthquakes, Institute of Physics of the Earth of the USSR Academy of Sciences, Moscow, 1974, pp. 107–112.

[13] N.V. Kondorskaya, N.V. Shebalin (Eds.), New Catalog of Strong Earthquakes of the USSR from Ancient Times to 1975, Science, M, 1977.

[14] A.S. Mukambaev, N.N. Mikhailova, Solving the problem of heterogeneity of magnitudes in works on seismic zoning of the territory of the Republic of Kazakhstan, Bulletin Natl. Nucl. Cent. Republ. Kazakhstan 4 (2014) 86–92.

[15] N.V. Shebalin, Methods of Using Engineering-Seismological Data for Seismic zoning//Seismic Zoning of the USSR, Science, M., 1968, pp. 95–111.

[16] T.G. Rautian, V.I. Khalturin, K. Fujita, K.G. Mackey, A.D. Kendall, Origins and methodology of the Russian energy K-class system and its relationship to magnitude scales, Seismol Res. Lett. 78 (2007) 579–590.

[17] A.R. Yarmuhamedov, The Morphostructure of the Middle Tien Shan and its Relation with Seismicity, Fan, Tashkent, 1988.

[18] M.S. Yakubov, M.V. Sokolov, Analysis of the effectiveness of the network of seismic stations in Uzbekistan at the main stages of its development, in: K.N. Abdullabekov (Ed.), Seismicity of the Territory of Uzbekistan, Fan, Tashkent, 1990, pp. 19–28.

[19] L. Knopoff, J. Gardner, Is the sequence of earthquakes in Southern California with aftershocks removed Poissonian, Bull. Seismol. Soc. Am. 64 (5) (1974) 1363–1367.

[20] B. Gutenberg, C. Richter, Frequency of earthquakes in California, B. Seismol. Am. 34 (4) (1944) 185–188.

[21] Ju.V. Riznichenko, Selected Works. Problems of Seismology, Publishing House of the USSR Academy of Sciences, Moscow, 1985 (in Russian).

[22] N.V. Shebalin, S.S. Arefyev, V.Yu. Vasilyev, R.E. Tatevosyan, From the seismicity of areas to the structure of seismicity, Physics of the Earth 9 (1991) 20–28.

[23] T.U. Artikov, R.S. Ibragimov, T.L. Ibragimova, M.A. Mirzaev, A Study of the Errors of Modern Seismic Zoning Maps (Using the Example of the Territory of East Uzbekistan) №1, Georisk, 2017, pp. 36–44.

[24] T.U. Artikov, R.S. Ibragimov, T.L. Ibragimova, M.A. Mirzaev, Study of modern seismic zoning maps' accuracy (case for Eastern Uzbekistan), J. Geodesy Geodyn. 7 (6) (2016) 416–424, https://doi.org/10.1016/J.GEOG.2016.04.015.

[25] G. Kulldorf, Introduction to the Theory of Estimation, Science, M, 1966.

[26] G.A. Sobolev, Fundamentals of Earthquake Prediction, Science, M, 1993.

[27] I.V. Gorbunova, Composition activity map with constant accuracy, in: Yu.V. Riznichenko (Ed.), Experimental Seismic, Publishing house of the Academy of Sciences of the USSR, M., 1964, pp. 138–147.

[28] S.S. Seyduzova, Maps of seismic activity of central and eastern Uzbekistan, in: K.N. Abdullabekov (Ed.), Seismicity of the Territory of Uzbekistan, Fan, Tashkent, 1990, pp. 107–118.

[29] N.V. Shebalin, About limiting magnitude and limiting intensity of earthquakes, Physics of the Earth 6 (1971) 12–20.

[30] V.F. Pisarenko, Statistical estimation of the highest possible earthquakes, Physics of the Earth 9 (1991) 38–47.

[31] Z. Gumbel, Statistics of Extreme Values, World, M, 1965.

[32] E.M. Bezrodny, Kh.A. Tuychiev, Uzbekistan Strong Earthquakes Focal Mechanism, Fan, Tashkent, 1987.

[33] L.M. Matasova, Earthquakes focal mechanism of the Fergana depression and its mountain framing, in: Yu.V. Riznichenko (Ed.), Regional Studies of the Seismic Regime, Shtiintsa, Kishinev, 1974, pp. 166–173.

[34] G. Eksrom, M. Nettles, Global CMT Web Page, 2013. http://www.globalcmt.org/. (Accessed 17 April 2014).

[35] T.U. Artikov, R.S. Ibragimov, T.L. Ibragimova, K.I. Kuchkarov, M.A. Mirzaev, Quantitative assessment of seismic hazard for the territory of Uzbekistan according to the estimated maximum ground oscillation rates and their spectral amplitudes, Geodynamics & Tectonophysics 9 (4) (2018) 1173–1188, https://doi.org/10.5800/GT-2018-9-4-0389.

[36] S.K. Adylov, V.Yu. Sokolov, B.M. Fremd, Yu.K. Chernov, Strong Earthquakes of Uzbekistan in 1984-1985, IFZ, M, 1988.

[37] R.S. Ibragimov, T.L. Ibragimova, Program for assessing the seismic hazard of the territory of Uzbekistan. State Patent Office of the Republic of Uzbekistan, Certificate №DGU 10 (28) (2016) 4041.

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