Seismic Hazard Assessment and Numerical Modeling for Seismic Microzonation purpose of Dushanbe, Tajikistan

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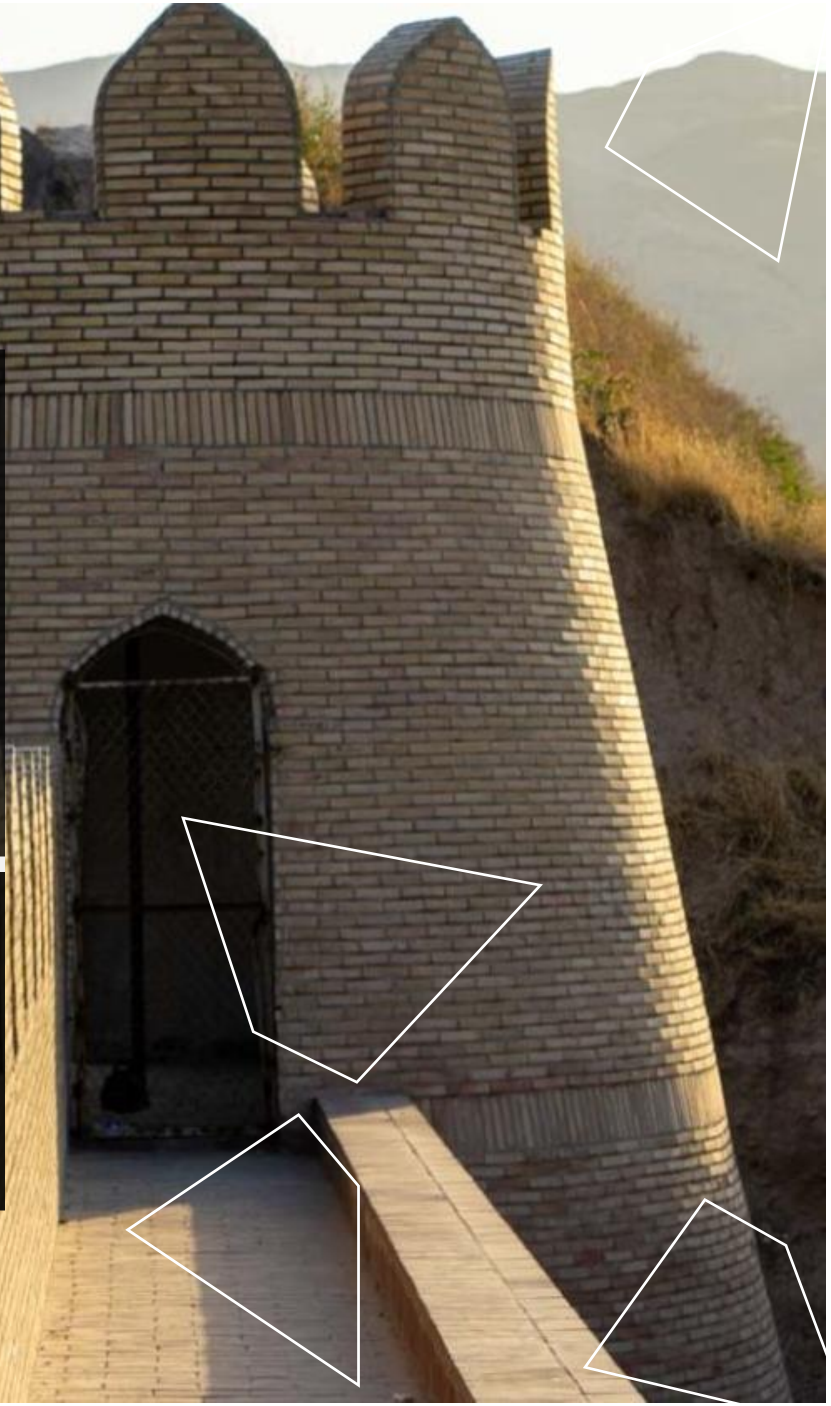
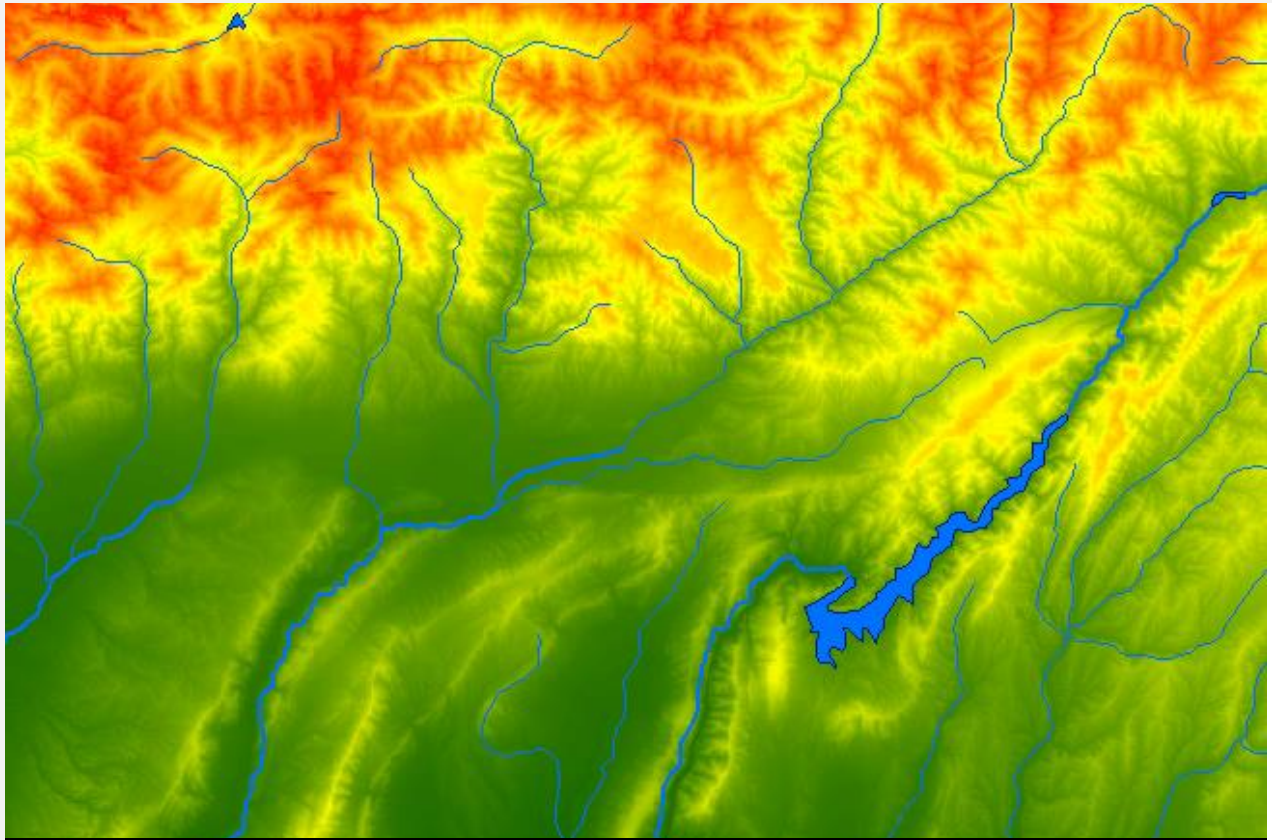
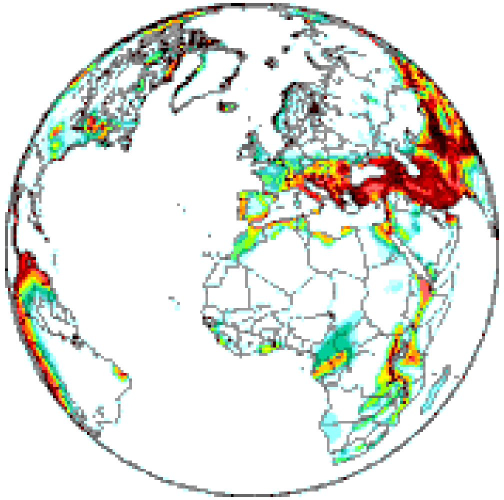




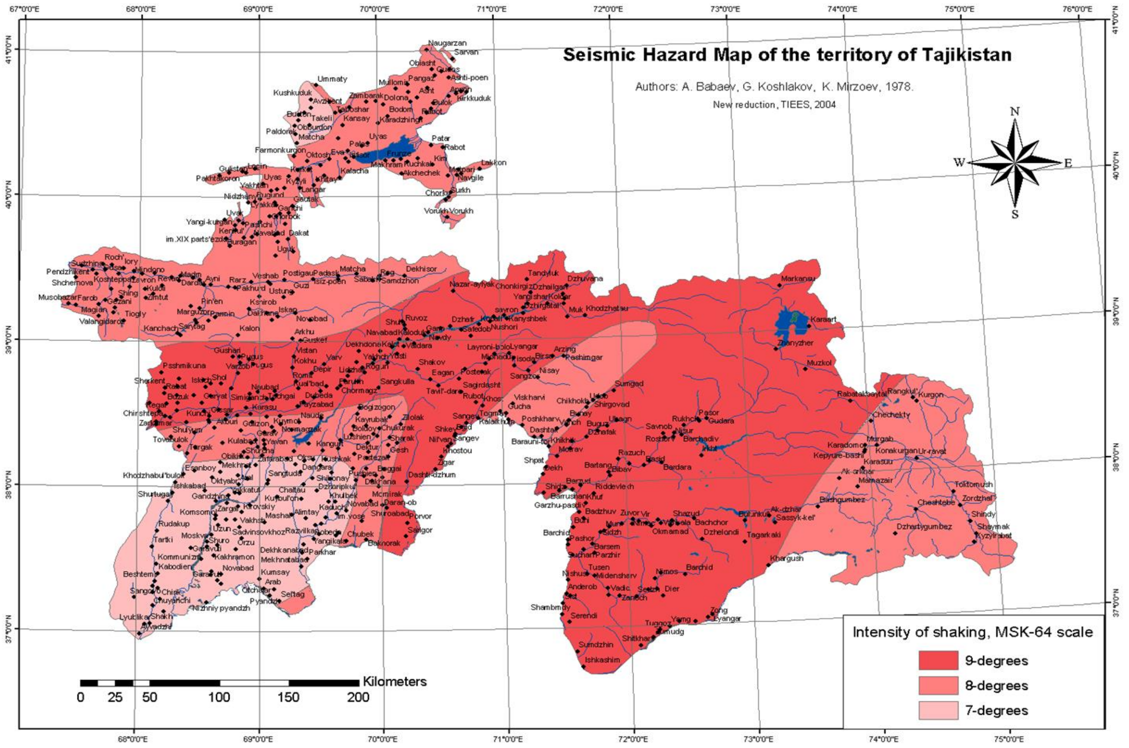
INTRODACTION

Regional Seismic Hazard

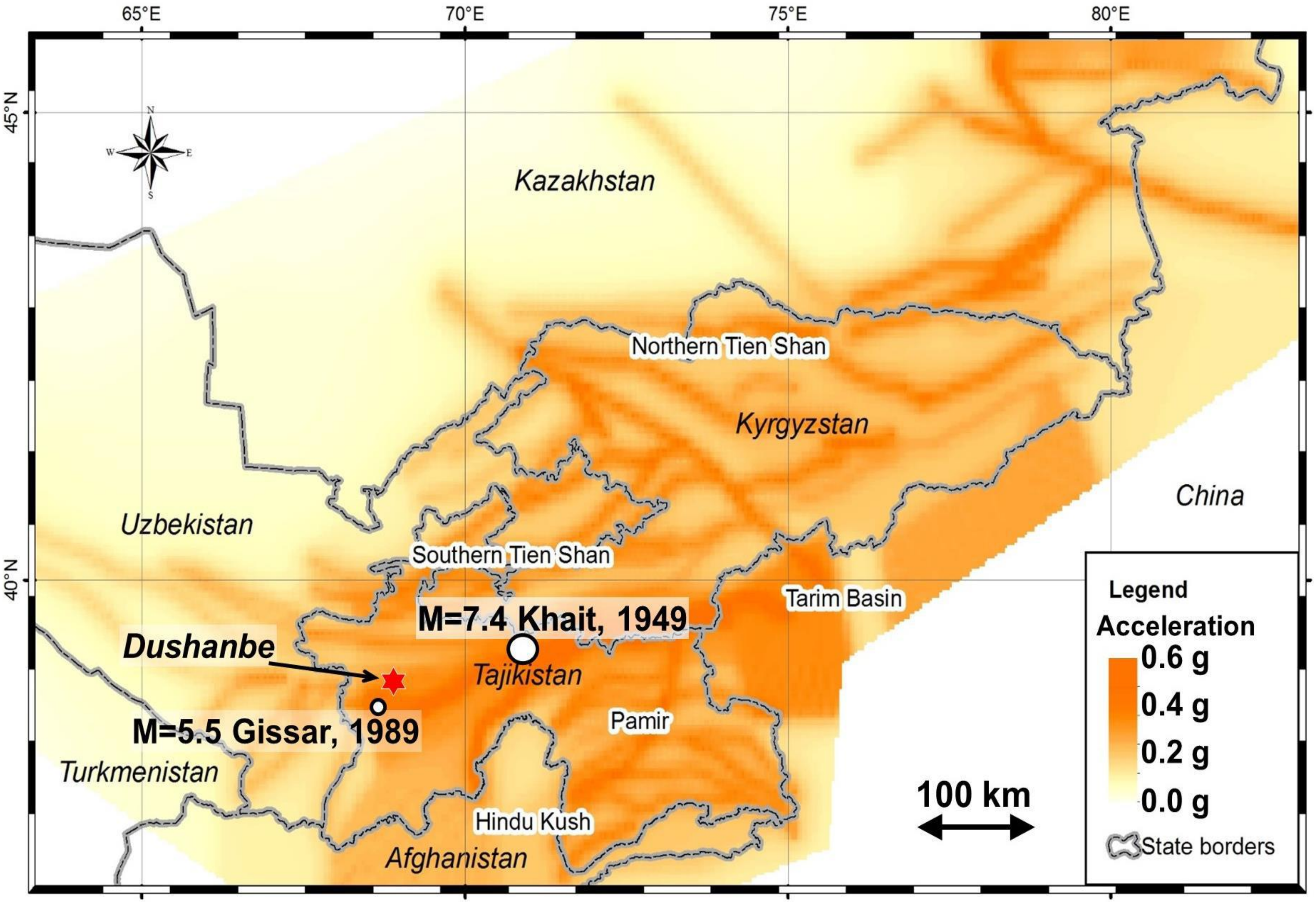


Seismic hazard assessment of urban areas is an important and extremely challenging task. It is so important because without the knowledge of the influence of local soil conditions and properties, of the changing layer thickness in urban areas, and without considering multiple possible scenario earthquakes for this territory, engineers do not have enough information on how to design and construct seismically safe buildings. The particular challenge of this task is due to the great uncertainty affecting the prediction of the spatially (and sometimes even temporally) changing seismic properties of soils with respect to urban development.

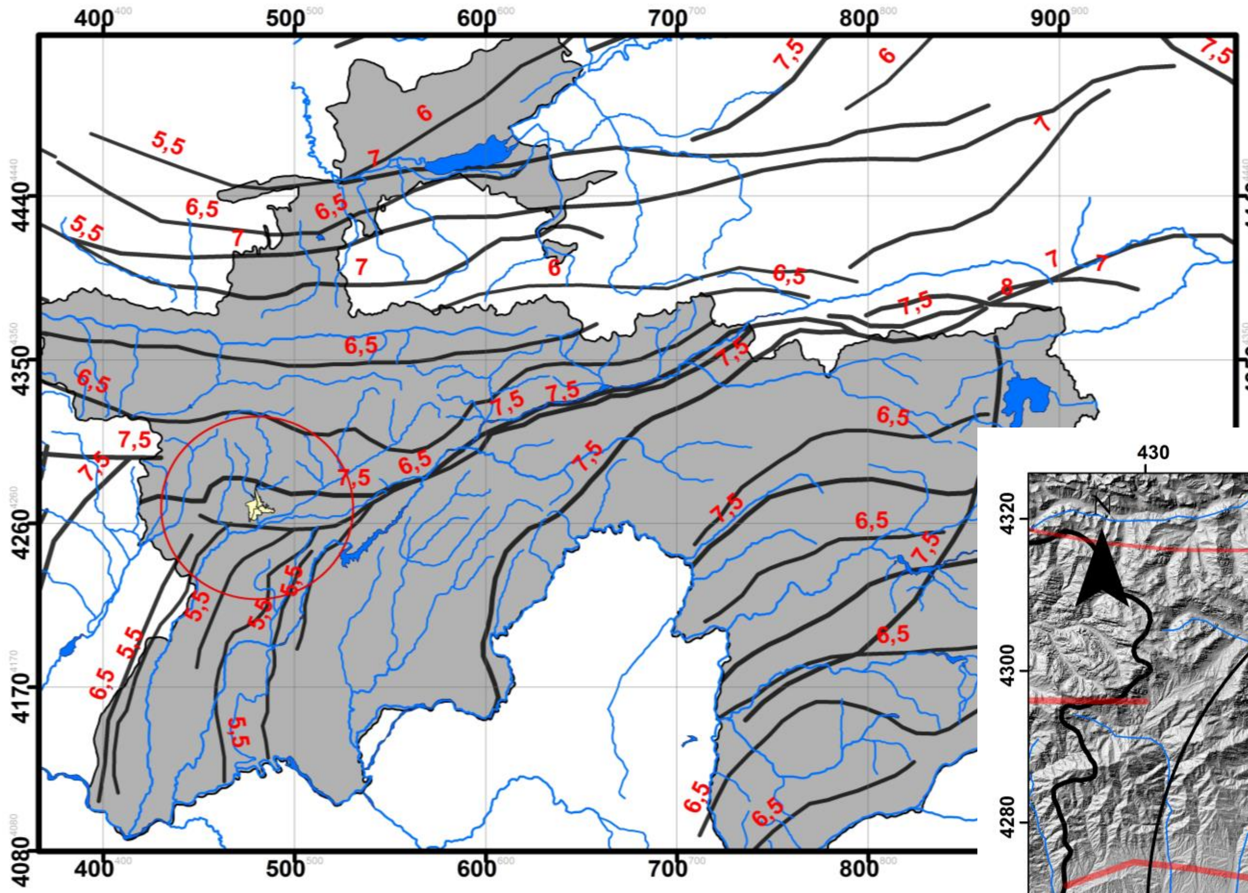
Existing seismic action estimations are based on the old approaches when the main factors of the local soil conditions only consider general engineering-geological features of the territory as well as macro-seismic observations data. An additional problem is the building code in Tajikistan; it uses the estimation of the ground motions in terms of the MSK-64 scale, but does not enough take into account the variety of the soil conditions in the Dushanbe city area. Existing seismic hazard estimation of the area of Tajikistan is based on the so-called “The map of general seismic zoning of the territory of Tajikistan”, that was produced in 1978 in terms of MSK-64 scale. The seismic microzonation map of the Dushanbe city area was made in 1975 in terms of MSK-64 scale as well and was based on the engineering-geological approach mostly. This map does not represent the highly variable soil conditions of the Dushanbe city area which are partly due to the anthropogenic influence of the large city. Therefore, earlier seismic zonation maps assigned an intensity of IX to most districts of the city.



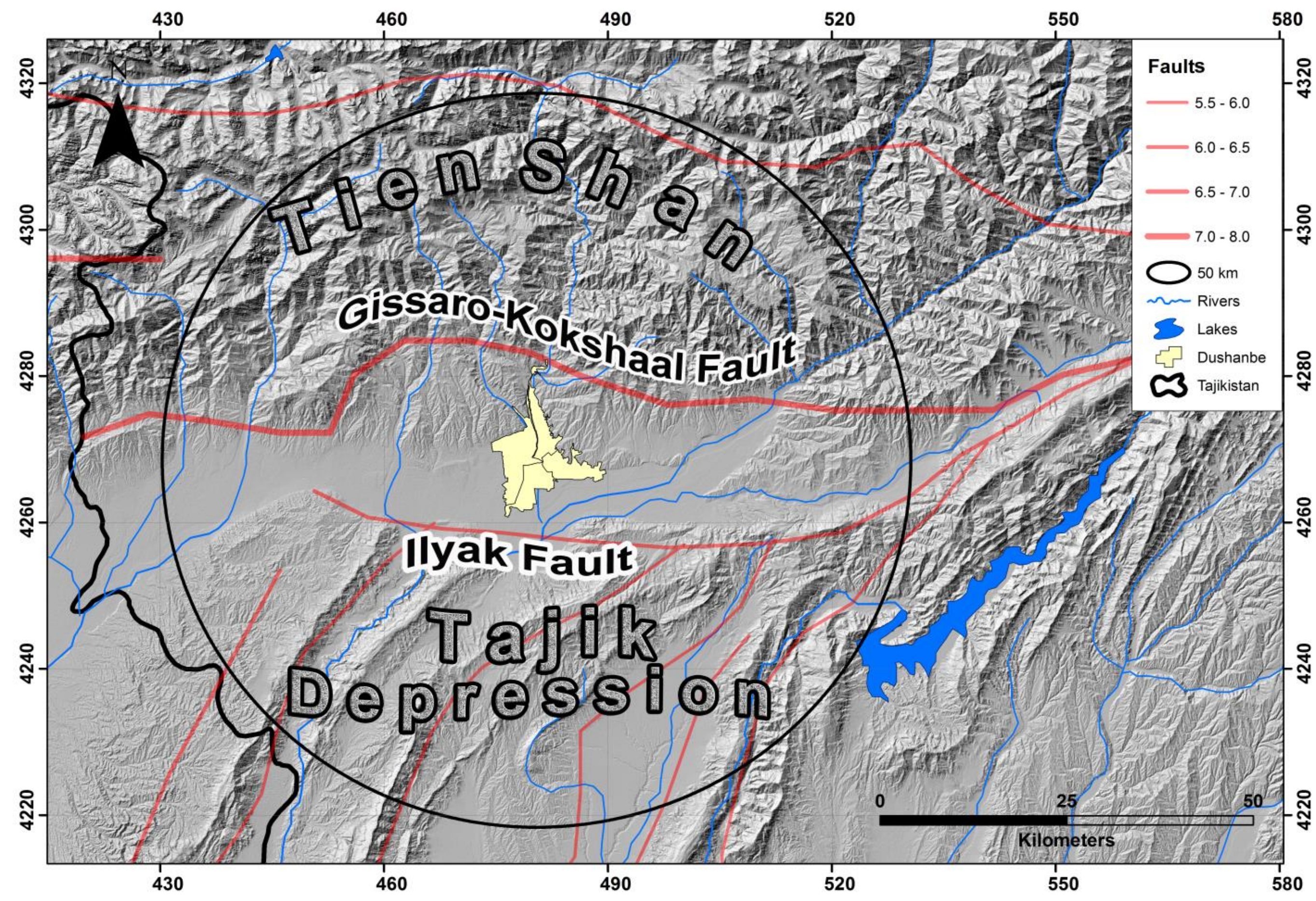
Based on the geological and seismological data the general seismic zoning map in terms of intensity by MSK-64 scale of the territory of Tajikistan was created in 1978 (Babaev et. al, 1978), and it uses as the seismic building code till now.



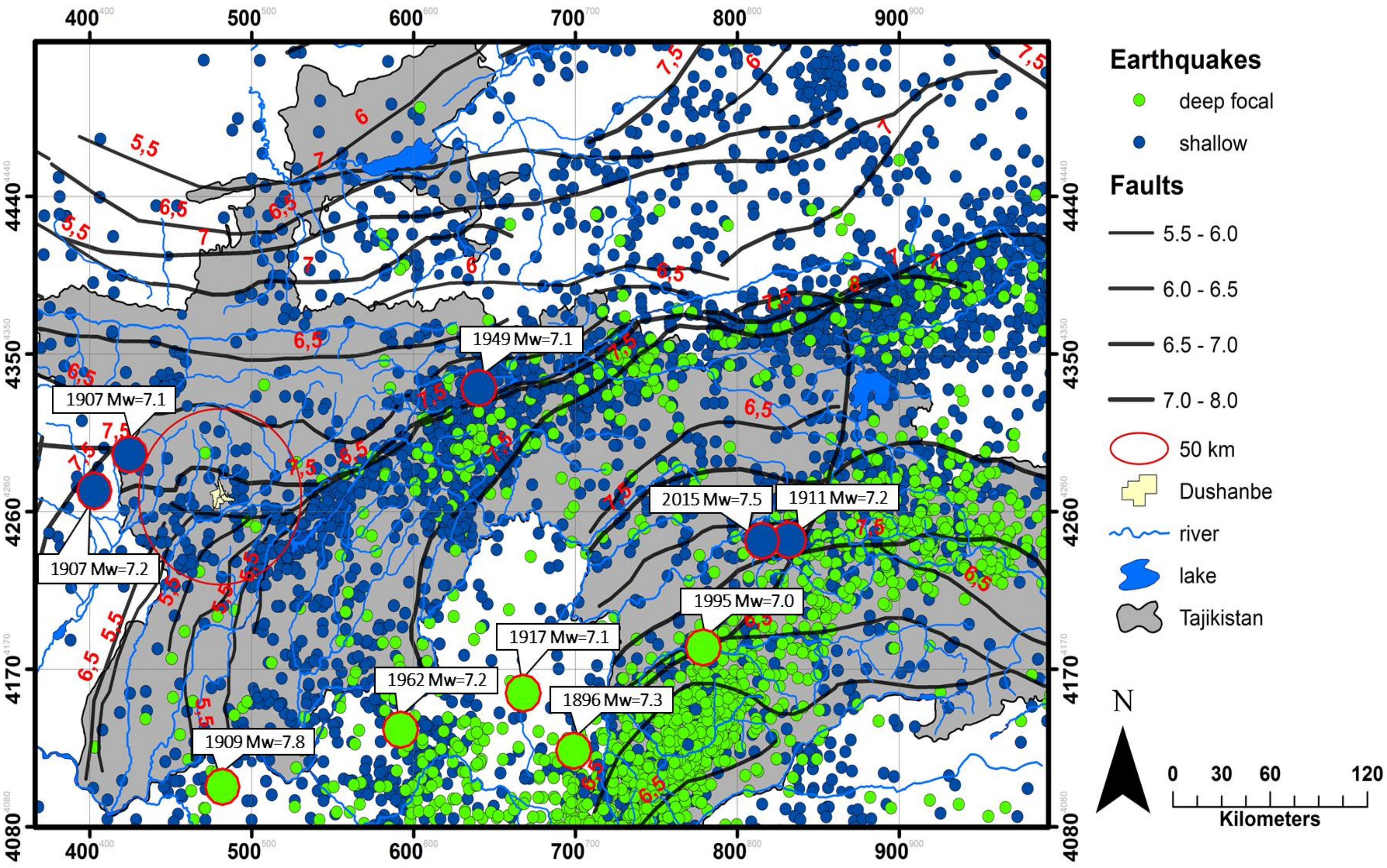
Seismic hazard map of the SE part of Central Asia, entirely including the countries of Kyrgyzstan and Tajikistan (mod. from Ischuk et al., 2018). Indicated are the locations of the Khait and Gissar earthquake events and of Dushanbe (see also city map on the right).

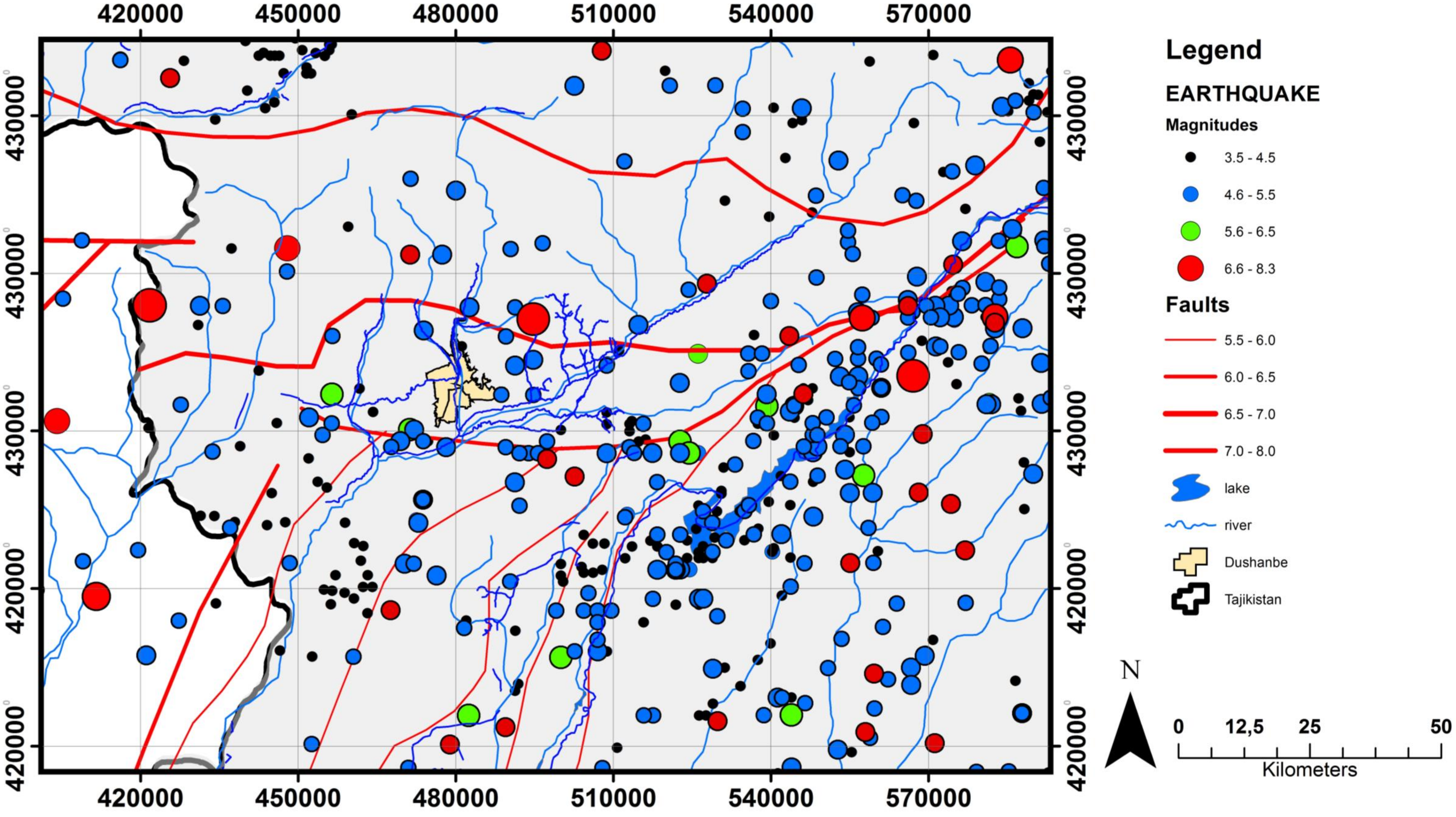


Dushanbe city is located between the southern border of the Tien Shan and the northern part of the Tajik Depression, between two major fault zones: Gissaro-Kokshaal in the north and Ilyak in the south.



Present a map of earthquake epicenters with M> 3.0 from the CASRI catalog (compiled during the ISTC KR project #1176), which has data from ancient times until 2009 (Abdrakhmatov, 2009) and additional earthquakes were added from 2010 to 2020 from the USGS catalog. The strong earthquakes on the territory of Tajikistan are distributed unevenly. Epicenters are located in South Tien Shan, South Ferghana, and Pamir-Hindu Kush seismic active zones.





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EARTHQUAKE
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4.6 - 5.5
5.6 - 6.5
6.6 - 8.3
Faults
5.5 - 6.0
6.0 - 6.5
6.5 - 7.0
7.0 - 8.0
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river
Dushanbe
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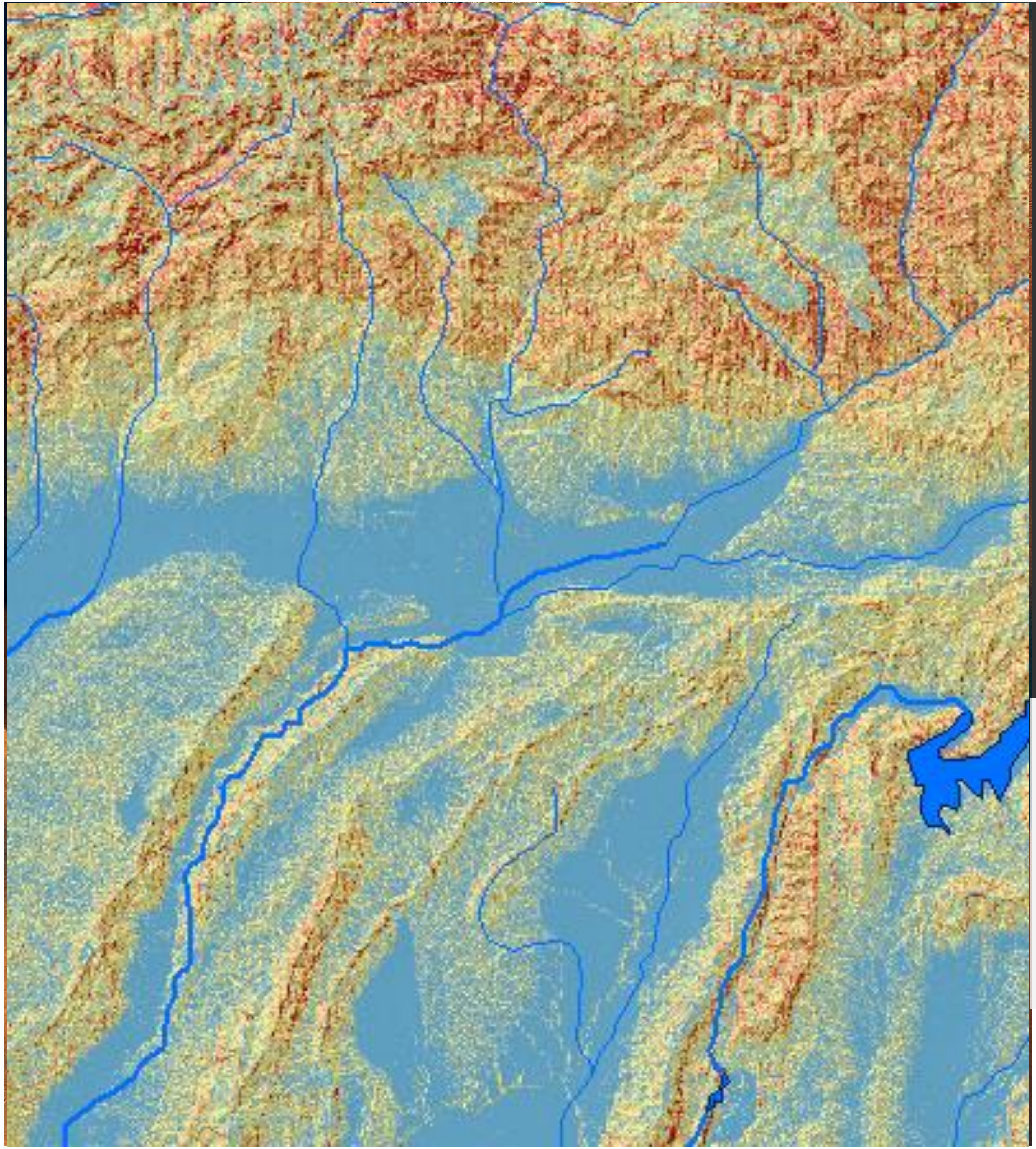
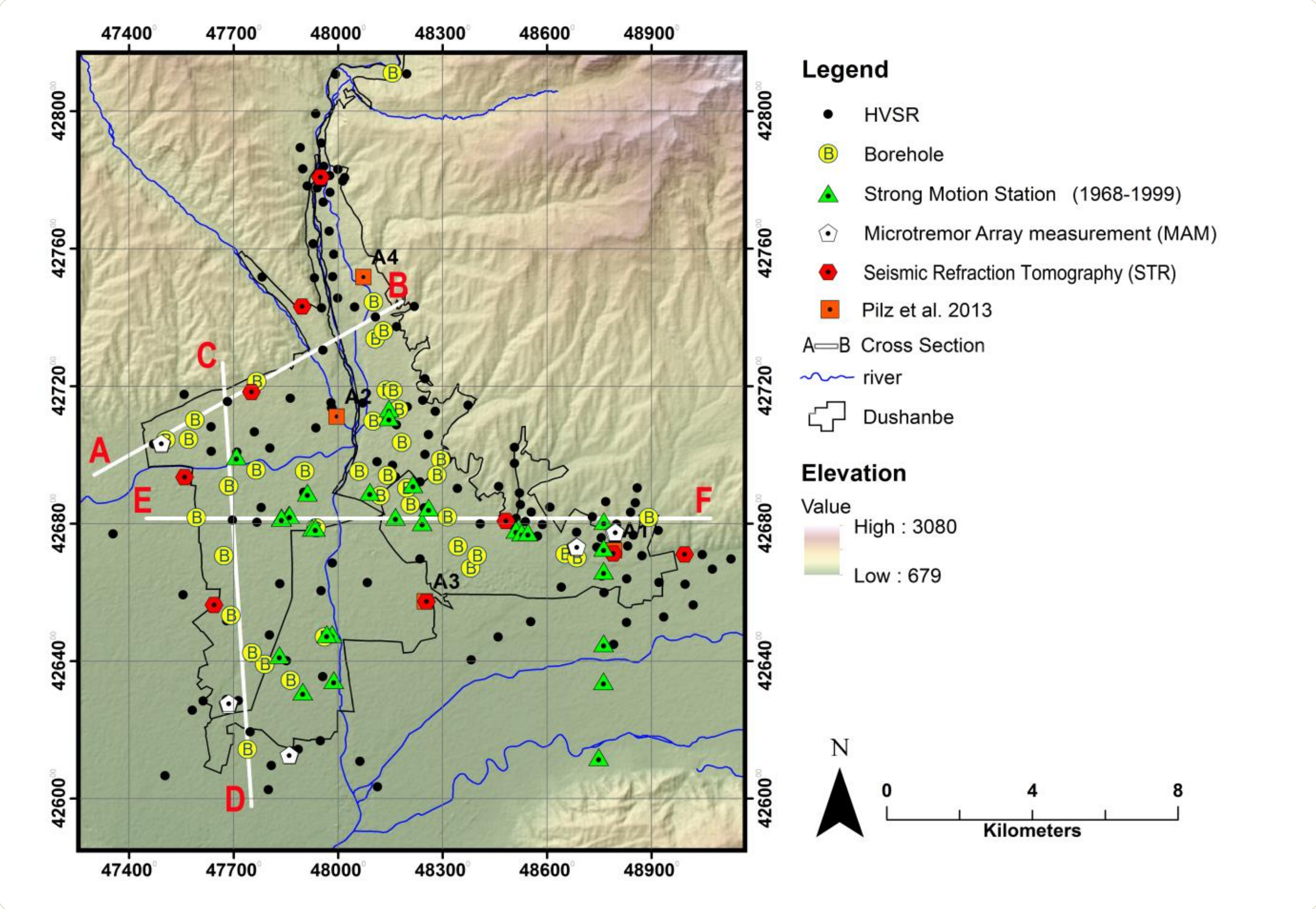


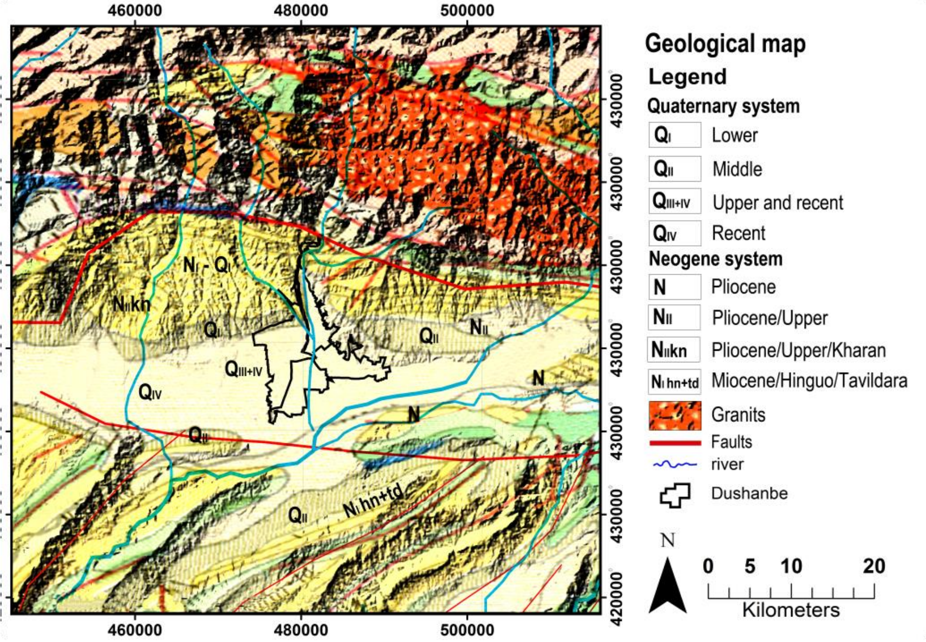
Seismic Micorzonation Data Collection

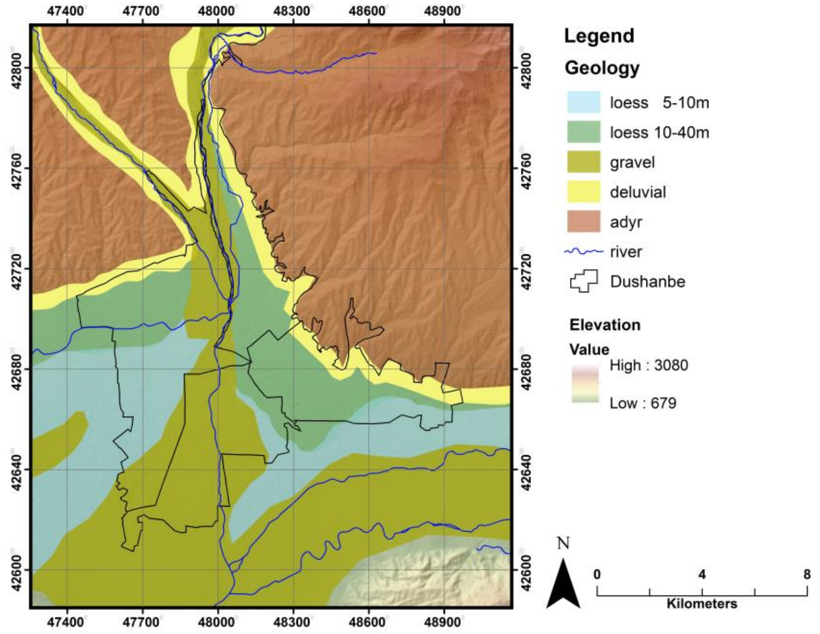
Data collection, analysis, and evaluation of data

Up to now, extensive research was focused on the qualitative approach of seismic microzoning. Even though such methods proved to provide valuable outputs for urban planning, those ones can mostly not be directly used for engineering purposes (construction) as they do not represent any 'measurable' value. The quantitative approach consists of data collection from strong ground motion recordings, micro-tremor studies, shear wave velocity data, and other information relevant for assessing the seismic response of the ground – combined with numerical models. The analysis and data results that we get from numerical models can be assessed and validated by comparison through field data.



I. Topographic and existing regional seismotectonic and geological data

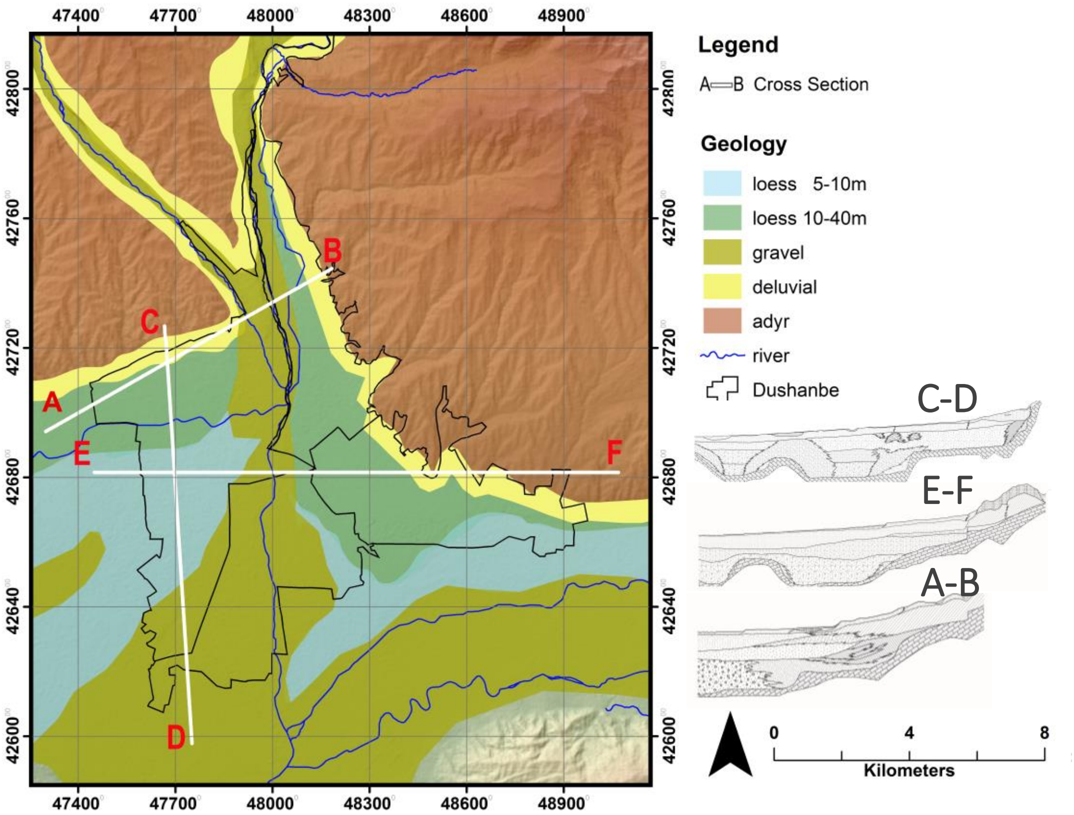


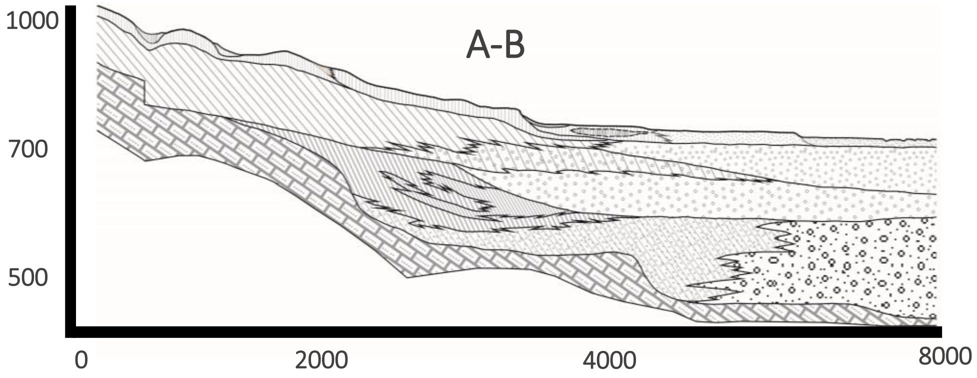


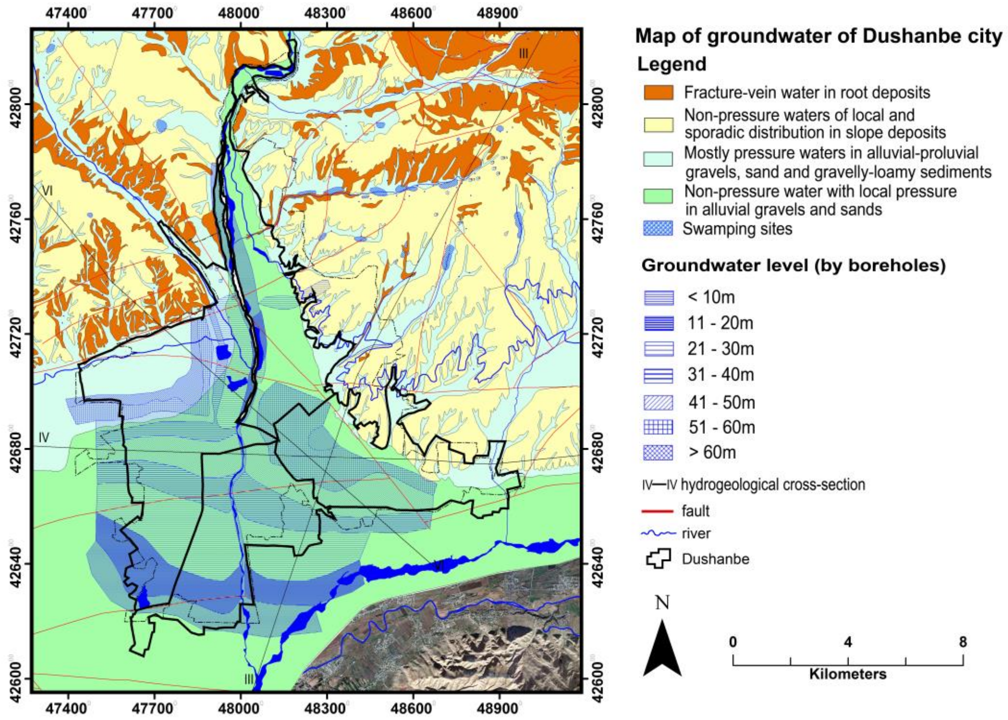
- The general geological map of the region of the Dushanbe city (from Geological map of the Tajik SSR. Scale 1:500000. Chief Editors: A.P. Markovsky and V.I. Verkhov. Published by VSEGEI, Moscow, 1974).

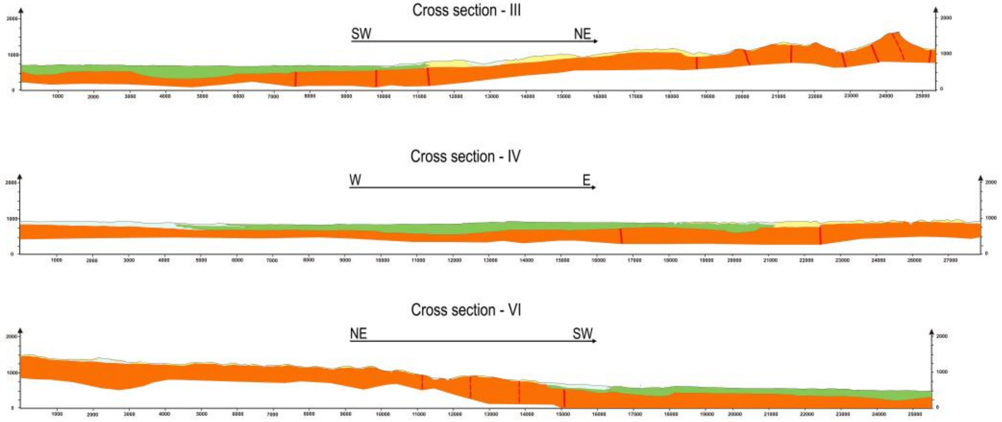
- The map of engineering geology conditions of the Dushanbe city area. Colors indicate surface soil materials (Zolotarow et al. 1968). The thick black line represents today´s administrative border of the city.

I. Topographic and existing regional seismotectonic and geological data



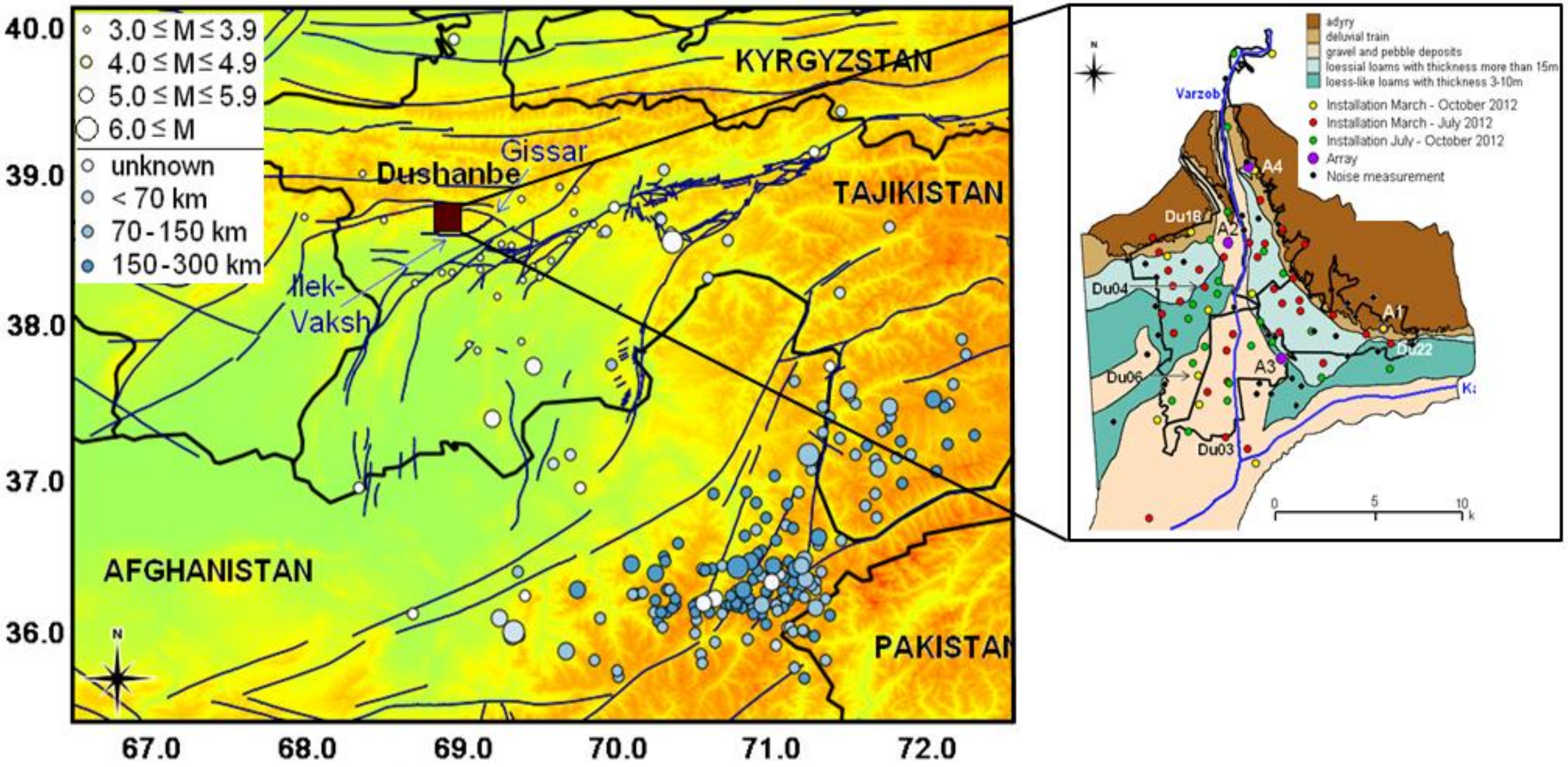






II. Seismological and vulnerability data collection

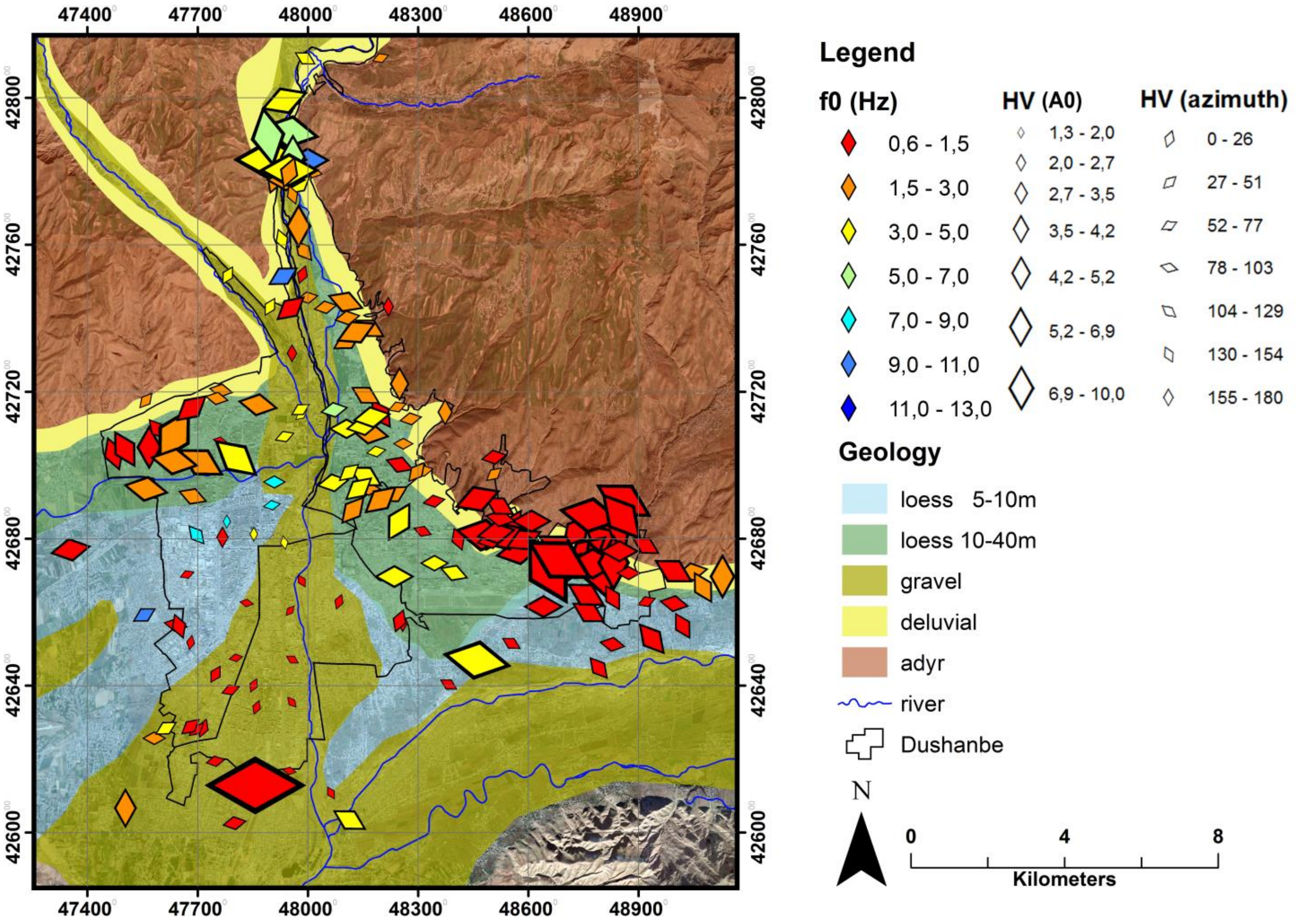
In the framework of the international project GEM-EMCA (Earthquake Modeling for Central Asia), an instrumental study of seismic properties of soils in the territory of Dushanbe was carried out in 2012 (Pilz et al., 2013). For these purposes, a temporary seismic network (March – October 2012) was installed to collect seismic records in 72 points inside the Dushanbe city area, using portable EDL seismic stations. In addition, ambient seismic noise was measured using 37 single stations, and 4 seismic arrays were constructed. All measurements were made within the actual boundaries of the built-up area (see overview map by Pilz et al. 2013).



The seismic network recorded 292 earthquakes (Pilz et al., 2013). The distribution of epicenters is shown in right part. The data set consists of 27 close and 257 distant earthquakes. Another eight tele-seismic earthquakes were added to this set. Thanks to the various epicentral distances, a wide spectral range was covered by the recordings.

III. Focus on HVSR, Array and Seismic profile, data collection and processing

Passive – source recording of ambient noise: HVSR
H/V ambient noise measurements were completed with a MARK L-4C-3D seismometer connected to an EDL (PR6-24) microseismic station. Ambient noise was recorded during 30 minutes after setting up the sensor in a flat and quiet zone. Between September 2019 – October 2019, a total of 175 single microseismic recordings were completed in the study area. All measurements were processed with the Geopsy software (Wathelet, 2005). A large part of the responses resulted in double frequency peaks f0 (fundamental frequency) and f1 (secondary frequency), this means that more than one layer interface was detected. The HVSR results are presented through a combined form of lozenge shape: the frequency value is marked by the color of the lozenge, the associated amplitude by its size and the preferred azimuth of the shaking by the orientation of the long diagonal of the lozenge. In the case of double peaks, two lozenges (generally with different size, i.e marking a different amplitude) are superposed. In order to structure the results, the study area was subdivided in 4 zones.



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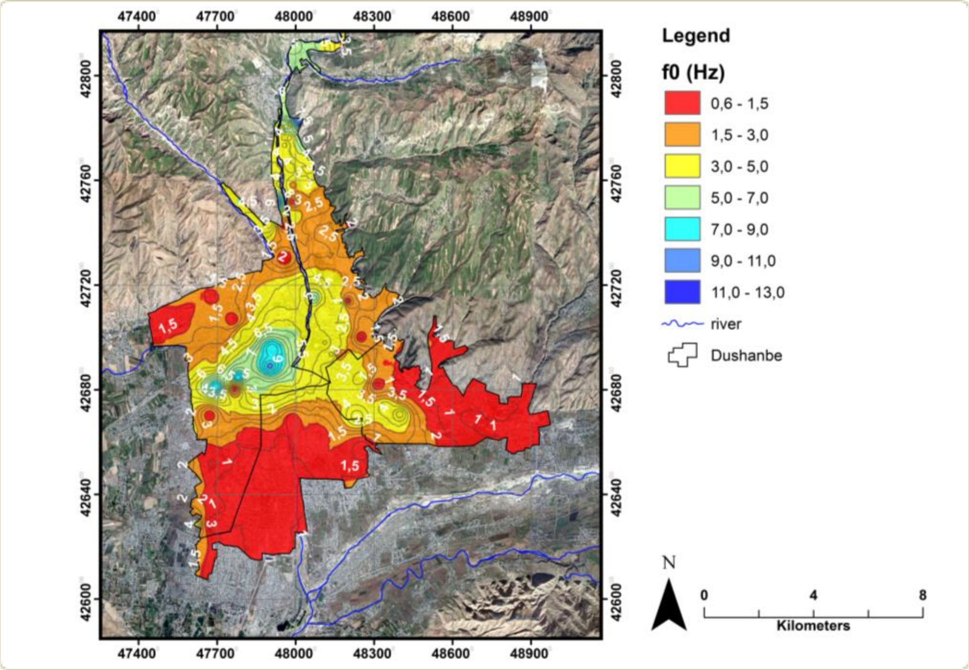
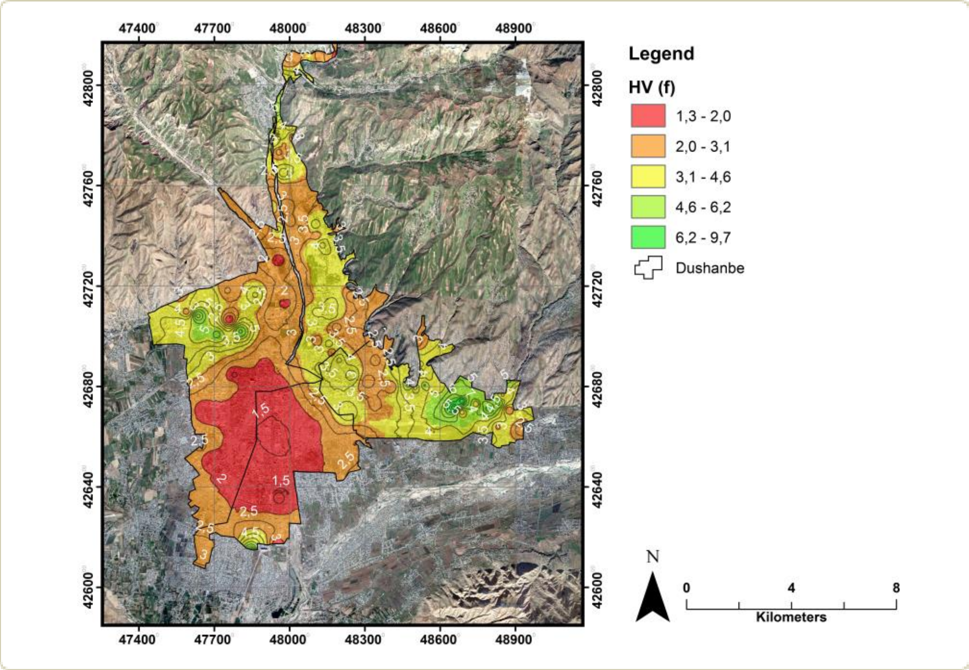
Passive – source recording of ambient noise: HVSR



- Map of the fundamental frequencies of the Dushanbe city area.

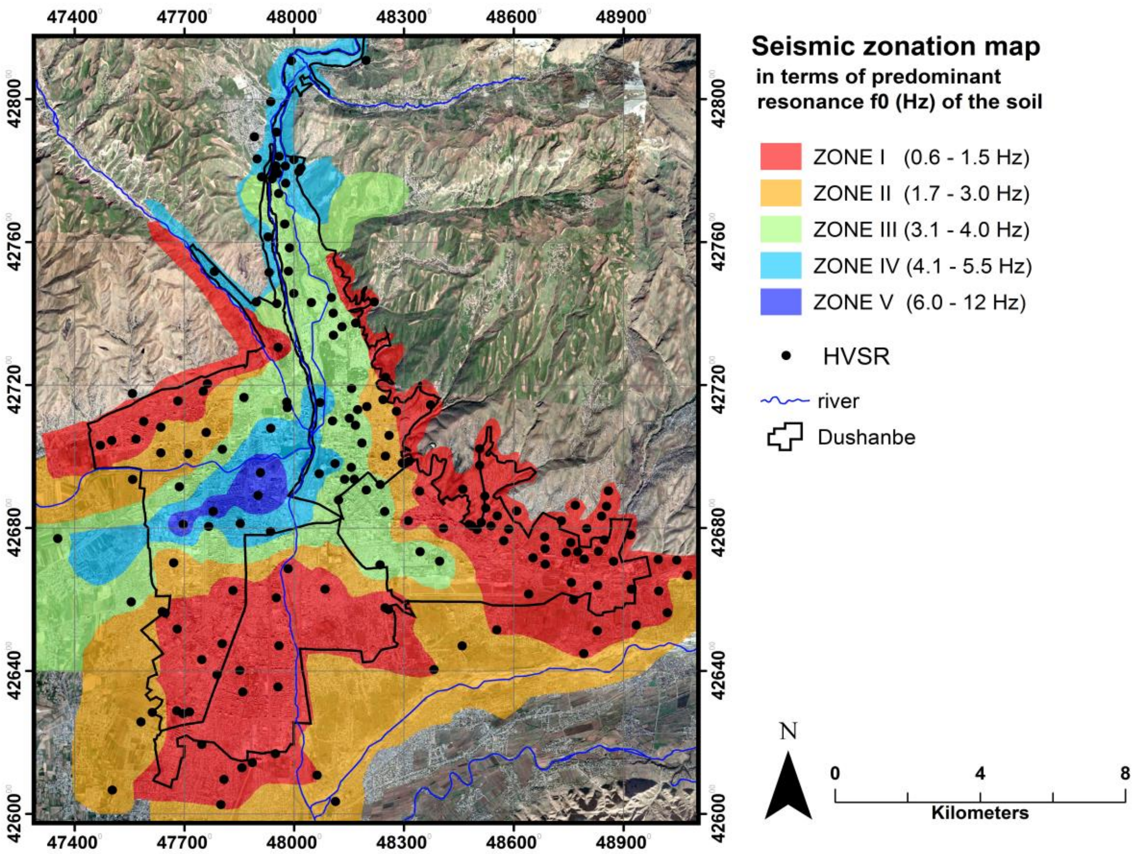


- Map of the HV amplitude of the Dushanbe city area.

III. Focus on HVSR, Array and Seismic profile, data collection and processing

Passive – source recording of ambient noise: HVSR

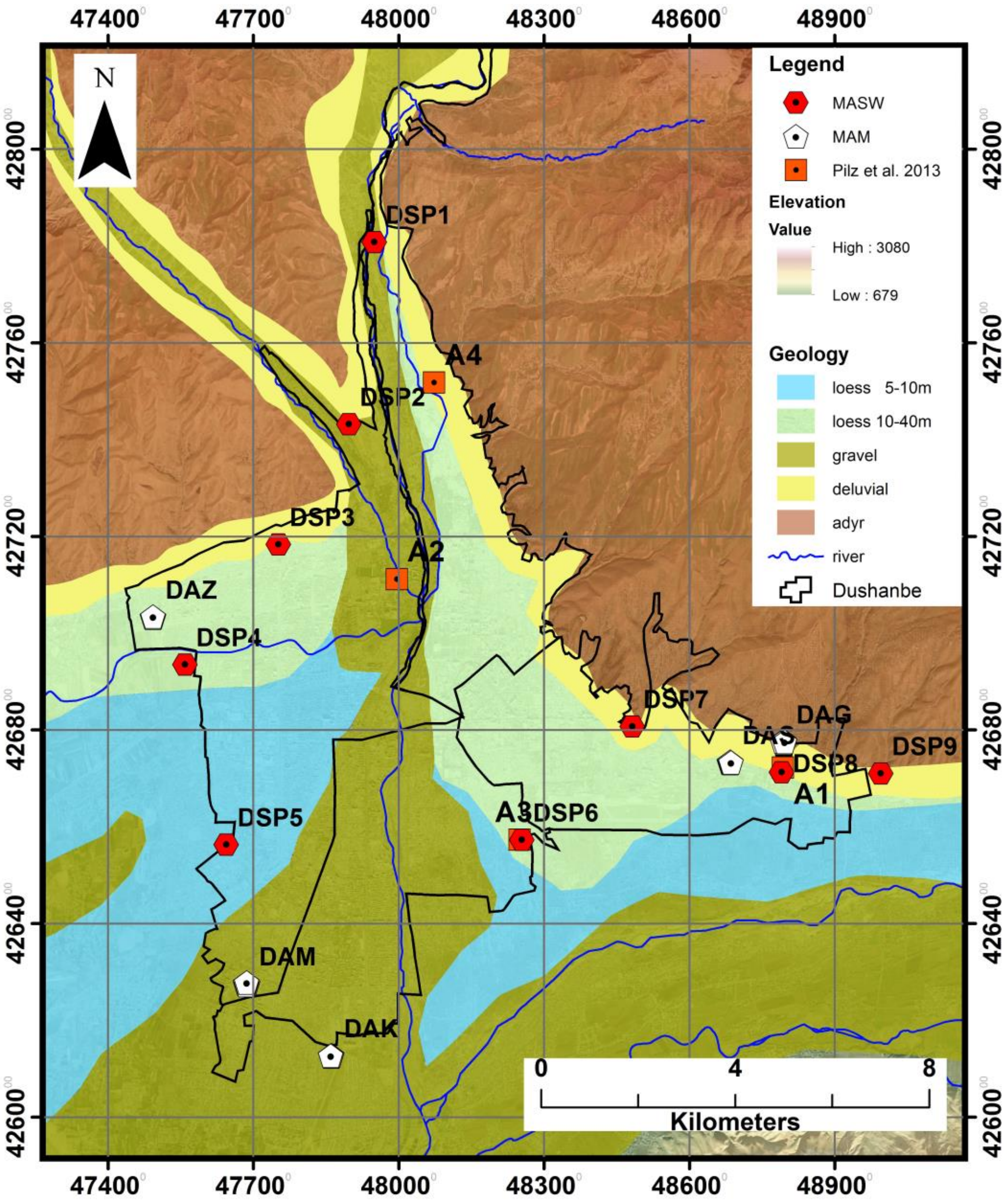
Seismic zoning of the city of Dushanbe in terms of predominant resonance frequency f0 of the soil.
The area number and the dominant resonance frequency range (in Hz) are indicated. Dots are the locations registered for the ambient noise. The boundaries of the zones are approximate and further analysis should be confirmed.



III. Focus on HVSR, Array and Seismic profile, data collection and processing

Passive – source recording of ambient noise: Microtermor Array measurement (MAM)

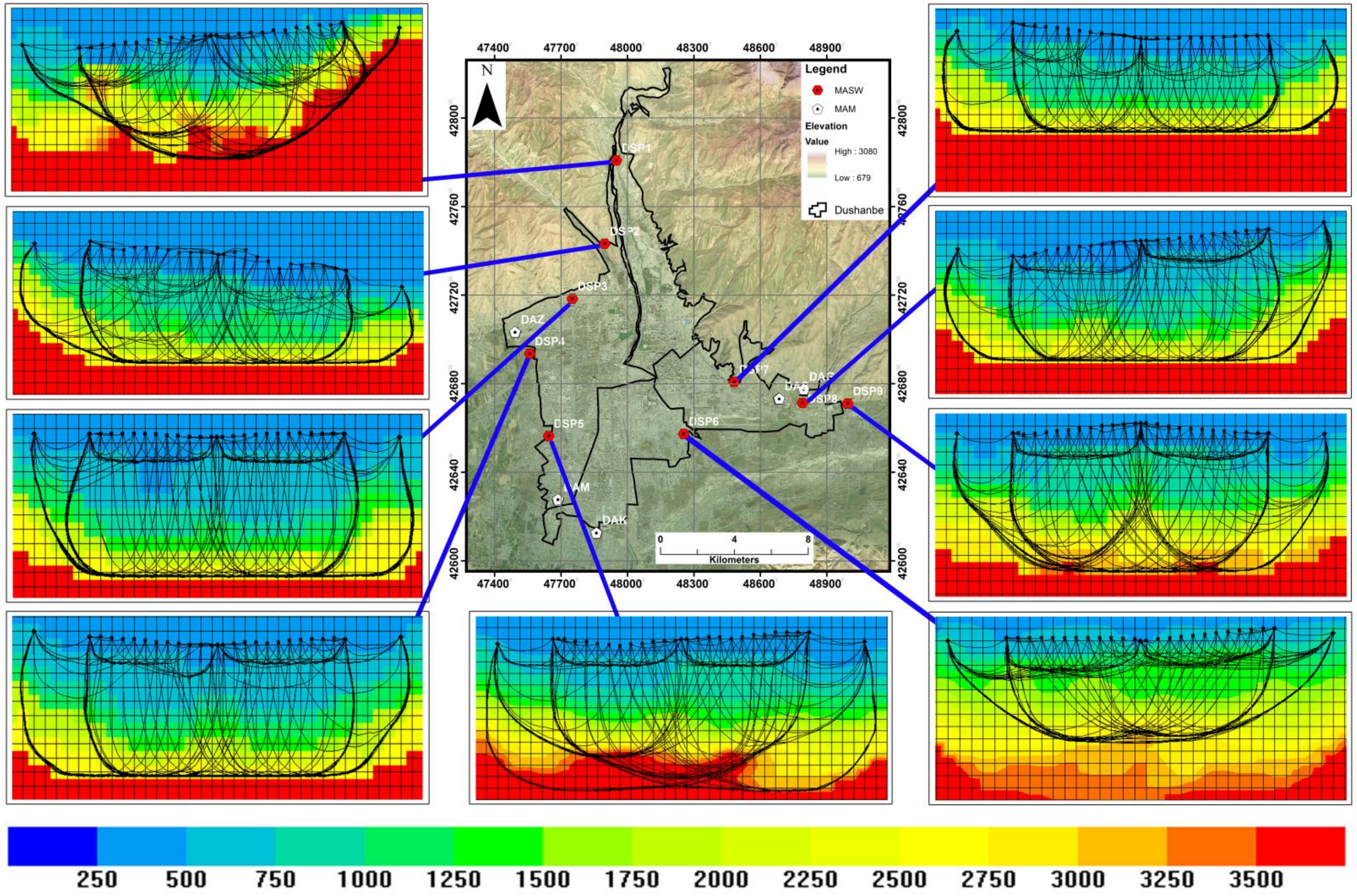
In September 2019, 5 arrays of 5 seismic stations were installed in different parts of Dushanbe city. For this purpose, we used a seismometer Trillium Compact 20s connected to a 24-bit recorder DATA-CUBE3. Trillium Compact 20s from Nanometrics (Ontario, Canada) is a seismometer with extended low-frequency sensitivity in the frequency range of 0.1-100 Hz and a resonance frequency of 20 s. Seismic equipment has been rented from the Institute of Geology, Earthquake Engineering and Seismology.



III. Focus on HVSR, Array and Seismic profile, data collection and processing

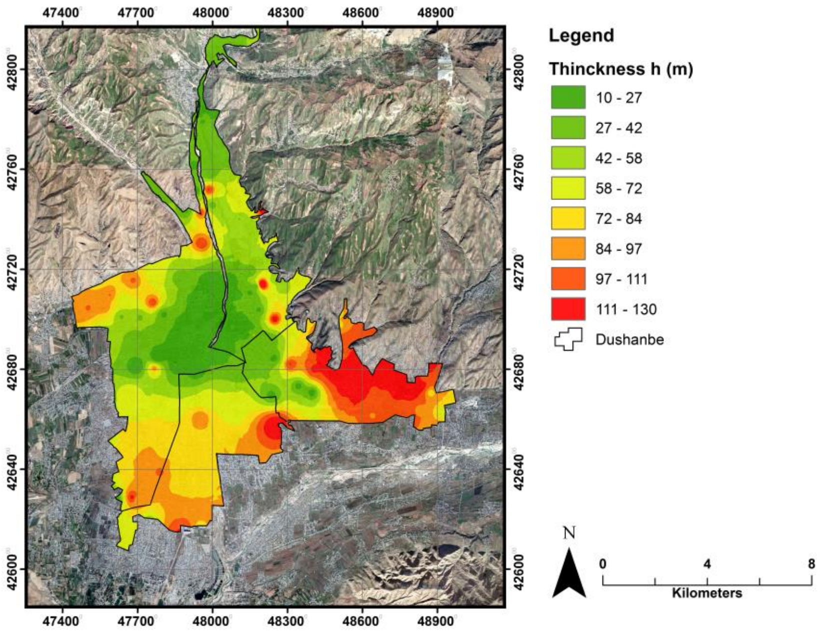
Active – source recording: MASW

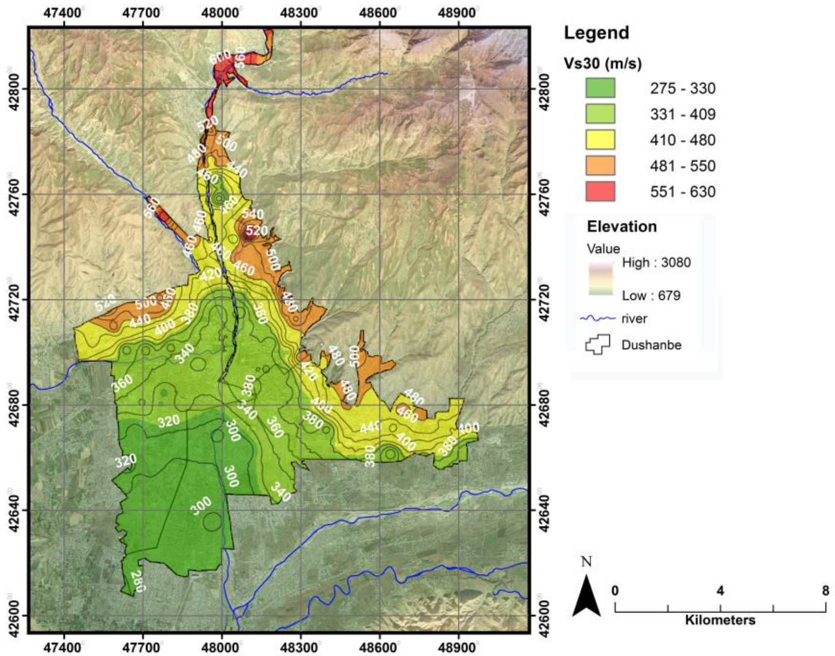
For the purpose of investigating the seismic properties of the subsurface, we performed the seismic refraction tests were conducted along nine profiles of 115 m length in Dushanbe city. Seismic waves were recorded with the use of 24 geophones (with an interval of 5 m) connected to a 16-bit 24-channel seismograph (Geometrics ES-3000). Seismic waves were generated on the ground surface by a 20 kg sledgehammer hitting a metal sheet at various points along the profiles. The moving wave signals were recorded by a set of 24 geophones with a cut-off frequency of 4.5 Hz installed along a straight line at various distances from the source. The profile lengths were selected based on the availability and size of each location.



III. Focus on HVSR, Array and Seismic profile, data collection and processing

Passive – source recording of ambient noise: HVSR



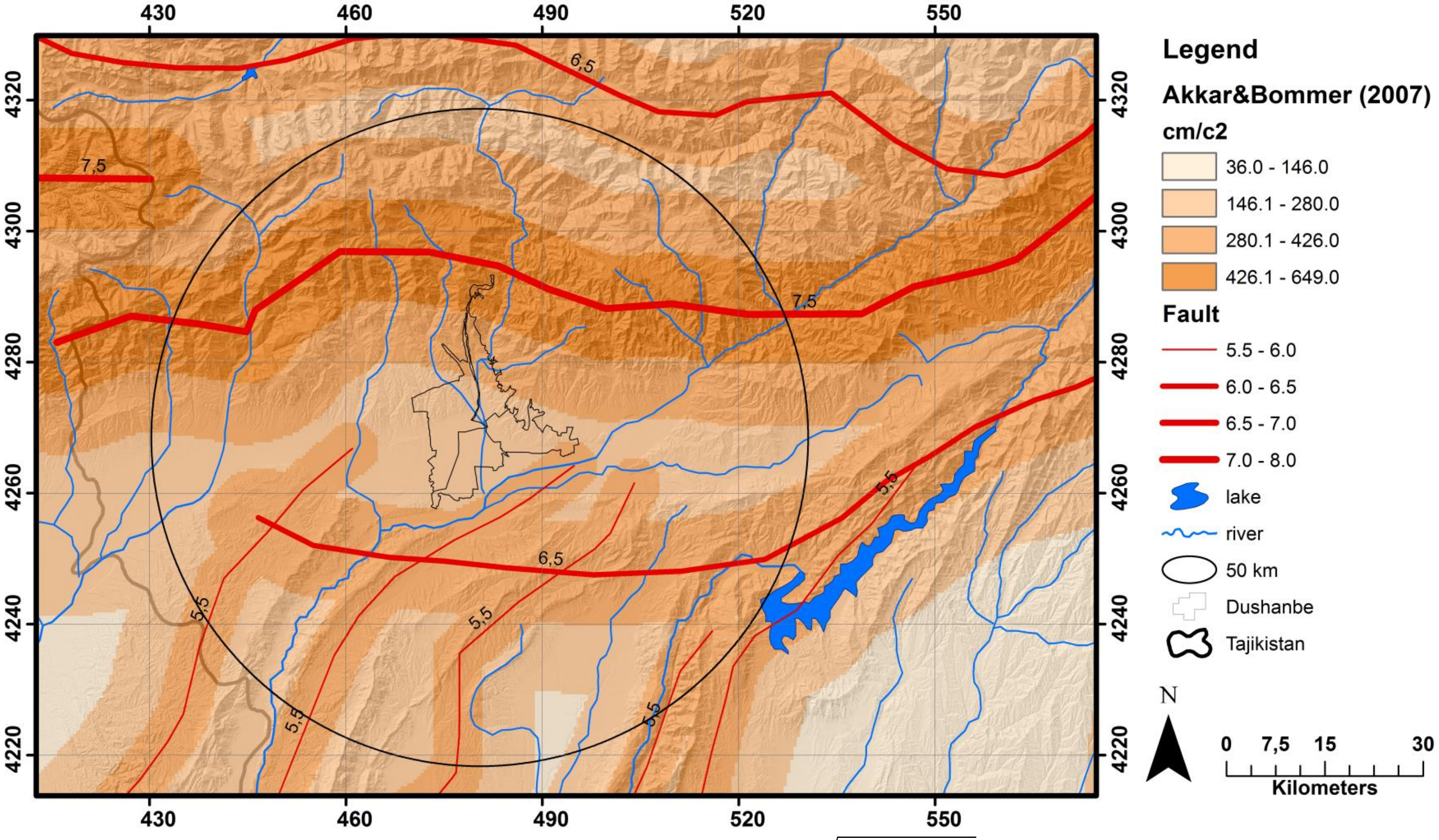


- Map of the sediment cover thicknesses above the bedrock for the Dushanbe city area.
- Map of the Vs,30 distribution of the Dushanbe city area.

IV. Seismic hazard estimation of the Dushanbe city area

The GMPE proposed by Akkar and Bommer in 2007 (Akkar and Bommer, 2007) was used in this study because it is the good fit to the geological conditions of the Tajikistan:

The reason for the high seismic hazard specifically near Dushanbe is also related to its location between two fault systems: Hissaro- Kokshaal fault and Ilyak fault (see PGA map for the rock surface the one shown in, upper part, computed with the attenuation law of Akkar and Bommer (2007). The last seismic zoning map of Dushanbe (now considered as a standard) was established in 1975 (Cogan et al., 1975, with minor updates added in 1980).



$$\log[\mathrm{PGA}] = 4.185 - 0.112\mathbf{M} + (-2.963 + 0.290\mathbf{M}) \log\sqrt{R_{\mathrm{jb}}^2 + 7.593^2} + 0.099 S_S + 0.020 S_A - 0.034 F_{\mathrm{N}} + 0.104 F_{\mathrm{R}}$$

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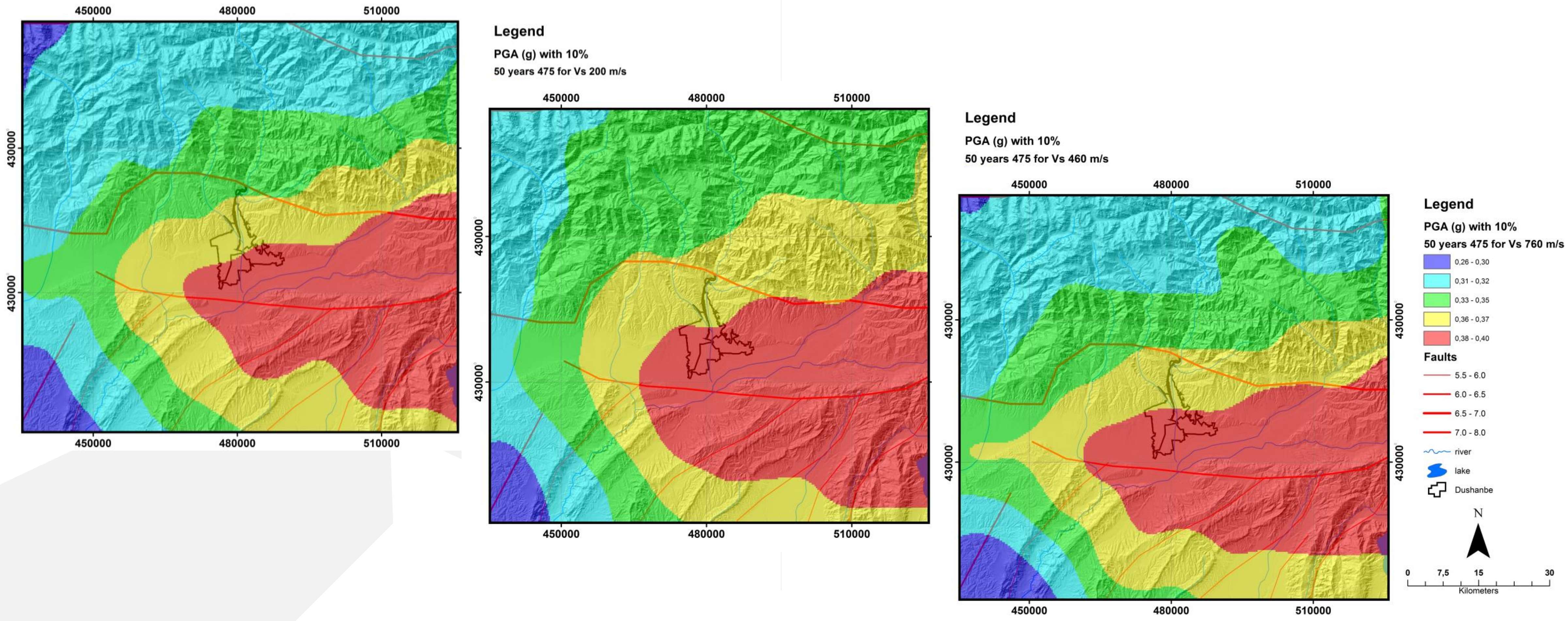

Conclusions

Many cities of Central Asia have been extensively damaged by earthquakes, such as Almaty in 1911, Ashgabat in 1948 and Tashkent in 1966. Dushanbe, in particular, had experienced widespread damages during the M=7.4 Karatag earthquake in 1907.

The reason for the high seismic hazard specifically near Dushanbe is also related to its location between two fault systems: Gissaro-Kokshaal fault and Ilyak fault . The last seismic zoning map of Dushanbe (now considered as a standard) was established in 1975 (Cogan et al., 1975, with minor updates added in 1980). It is important to note that, despite the rapid growth and expansion of the city of Dushanbe and the construction of high buildings (with 20 floors and more), the standard seismic microzonation map of Dushanbe has not changed since 1975.

We estimate that those previous studies did not sufficiently quantify the local effects of soils on the seismic hazard, mainly the macro-seismic conditions (relative distance of districts to fault lines) were considered for the zonation. New data for the seismic microzoning were compiled on the basis of previous works and new instrumental data were obtained with the support of GFZ, Potsdam (Germany).

This study uses as input the PGA values on rock indicated in the map. For typical soil sites (considering the soil response map) some numerical calculations will be completed to assess local PGA values marked by topographic and soil amplification.

Acknowledgements

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REFERENCES

Abdrakhmatov, K., Havenith, H.B., Delvaux, D., Jongmans, D. and Trefois, P. (2003). Probabilistic PGA and Arias Intensity maps of Kyrgyzstan (Central Asia). J. Seis., 7, 2, 203–220.

Abdrakhmatov, K. E. (2009). Establishment of the Central Asia Seismic Risk Initiative (CASRI). ISTC Project No. KR 1176. Final Project. Technical Report, 02.01.2006 to 04.30.2009.

Akkar, S. and Bommer, J. (2007). Prediction of elastic displacement response spectra in Europe and the Middle East. Earthquake engineering and structural dynamics. Earthquake Eng. Struct. Dyn. 2007; 36:1275–1301

Babaev, A. M., G. V. Koshlakov and K. M. Mirzoev (1978). Seismic regionalization of Tajikistan. Dushanbe, Donish, 68s

Cogan, L. A. Mirzobaev, J.M., Oripov, G.O. and Romanov, A. (1975). Map of the seismic zonation of Dushanbe. Soviet Academy of Science, Moscow (in Russian).

Ischuk, A., Bjerrum, L.W., Kamchybekov, M., Abdrakhmatov, K. and Lindholm, C. (2018). Probabilistic seismic hazard assessment for the area of Kyrgyzstan, Tajikistan, and eastern Uzbekistan, Central Asia. B. Seis. Soc. America, vol. 108, no. 1, 130–144.

Markovsky A.P. and Verkhov V.I. Geological map of the Tajik SSR. Scale 1:500000. Published by VSEGEI, Moscow, 1974

Pilz, M., D. Bindi, T. Boxberger, F. Hakimov, B. Moldobekov, S. Murodkulov, S. Orunbaev, M. Pittore, J. Stankiewicz, S. Ullah, F. Verjee, M. Wieland, P. Yasunov, and S. Parolai (2013). First Steps toward a Reassessment of the Seismic Risk of the City of Dushanbe (Tajikistan). Seismological Research Letters, 84, 6; doi: 10.1785/0220130040.

Wathelet, M. (2005). GEOPSY Geophysical Signal Database for Noise Array Processing. Software, LGIT, Grenoble, Frankreich. www.geopsy.org, (27.05.2019).

Zolotarow, G. S., W. S. Fachorenko, W. I. Lipmija, D. Hergow, N. A. Rohdijow, and P. Jaodokowa (1987). Polygon-Based Engineering and Geological Map of the Dushanbe Region, Soviet Academy of Science, Moscow, Russia (in Russian).

Thank You

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