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[1]Deutsches GeoForschungsZentrum GFZ, Section 2.1, Telegrafenberg, 14473 Potsdam, Germany

[2]Central Asian Institute for Applied Geosciences, Timur Frunze rd.73/2, 720027, Bishkek, Kyrgyzstan

[3]Institute of Seismology, 720020, Asanbay 52, Bishkek, Kyrgyzstan

[a] International University for InnovationTechnologies, Gorky street 1/17, Bishkek, 720048, Kyrgyzstan

[c] Institute of Geology, Earthquake Engineering and Seismology, 267 Ayni str., Dushanbe, Tajikistan

[d] Data Center IGR NNC RK L. Chaikinoy str. 4, Almaty 050020 Kazakhstan

1 Introduction

Central Asia is one of the areas of the world most prone to earthquake hazard [1]. Within the last century, most of the capitals of the region have been seriously damaged (if not completely destroyed) at last once, for instance Ashgabad (Turkmenistan) in 1948 and Almaty (Kazakhstan) in 1887 and 1910 [2]. Most of the countries in Central Asia (Kyrgyzstan, Kazachstan, Tajikistan, Turkmenistan, Uzbekistan) show moreover a high vulnerability from both the structural and social points of view. Therefore, a urgent need to update the estimation of hazard and risk for Central Asia is recognized [2],[3]. GEM (Global Earthquake Model, [4]), through its regional project EMCA (Earthquake Model Central Asia, [5]), recently started research activities, jointly with local partners, in order to provide up-to-date hazard and risk estimates and also to suggest new approaches and methodologies for improving the assessment of on-site conditions. This short report describes the first attempt at obtaining a preliminary cross-border risk model for Central Asia starting from datasets that were already available at the beginning of the EMCA Project.

1.1 Seismic Hazard

A preliminary hazard model for Central Asia has been computed starting from a catalogue of macroseismic intensities collected within the framework of CASRI Project [6]. The considered catalogue contains information about 2700 documented intensities spanning an area of about 1.9×10^6 km² covering Kyrgyzstan and Tajikistan and part of Uzbekistan, Kazahkstan and China (see Figure 1).
Following the approach described by Albarello e D'Amico [7], [8], a probabilistic hazard model has been computed over a two-dimensional grid (with resolution of 0.2×0.2 degrees) of virtual points covering the considered area. In following this methodology, first the seismic history at each site is first constructed from the available macroseismic information. For the case of earthquakes lacking direct observations in terms of felt intensity, the probability of exceeding a given intensity value (virtual assignments) can be estimated from the epicentral information and applying an Intensity Prediction Equation derived for the area [8]. Then, the probability of exceedance over a regular grid of sites is computed, starting from the intensity observations available for the same earthquake at neighboring localities and applying the Bayes's equation. In terms of completeness of site seismic history, the statistical approach of Albarello et al. [7] is considered.

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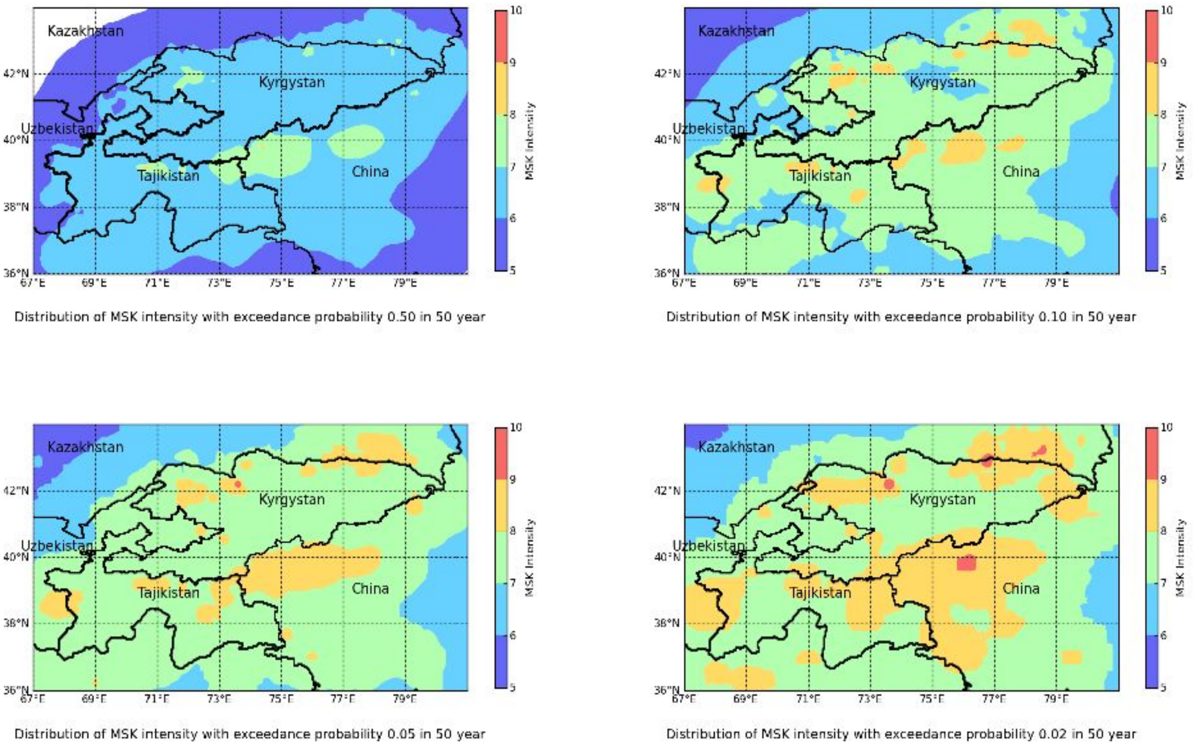

Figure 1: Seismic hazard in Cntral Asia shown with respect to four different exceedance probabilities in 50 years.

1.2 Seismic Vulnerability

The vulnerability model describes the elements at risk (exposure) and to what extent they would be affected by an earthquake (fragility). Usually, different elements contribute to the main vulnerability model, but for sake of simplicity we will focus on structural and social components, where the structural exposure refer mostly to the residential building inventory, and the social exposure refers to the population.

1.2.1 Social exposure

Several datasets provide information on the distribution of population on a global scale [9],[10]. In order to analyse the density of population at a higher resolution we considered the publicly available GRUMP v3 database [11]. Figure 2 shows the distribution of the population density (inhabitants per km²) within the considered geographical area over a 0.04×0.04 degrees spatial grid. This dataset successfully combines several source of information into a single, reliable, high spatial resolution description.

The considered area, according to the GRUMP v3 database, hosted more than 44 million inhabitants in the year 2000. Information about the population density, at the same spatial resolution, is also available within the same database for the years 1990 and 1995.
Analysing the apparent trend in the urbanisation of the area is possible to forecast the distribution of the population. A linear regression model has been used to this purpose in order to obtain a population density distribution to the year 2012. Figure 3 shows the apparent change in population

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density, within the considered geographical region. Large changes are observable particularly along the Fergana basin and along the border between Uzbekistan and Kyrgyzstan between the towns of Namangan, Andizhan and Osh.

It is possible to discern that while the Kyrgyz side of the basin experienced a decrease in the population density, in Uzbekistan the population density is apparently increasing.

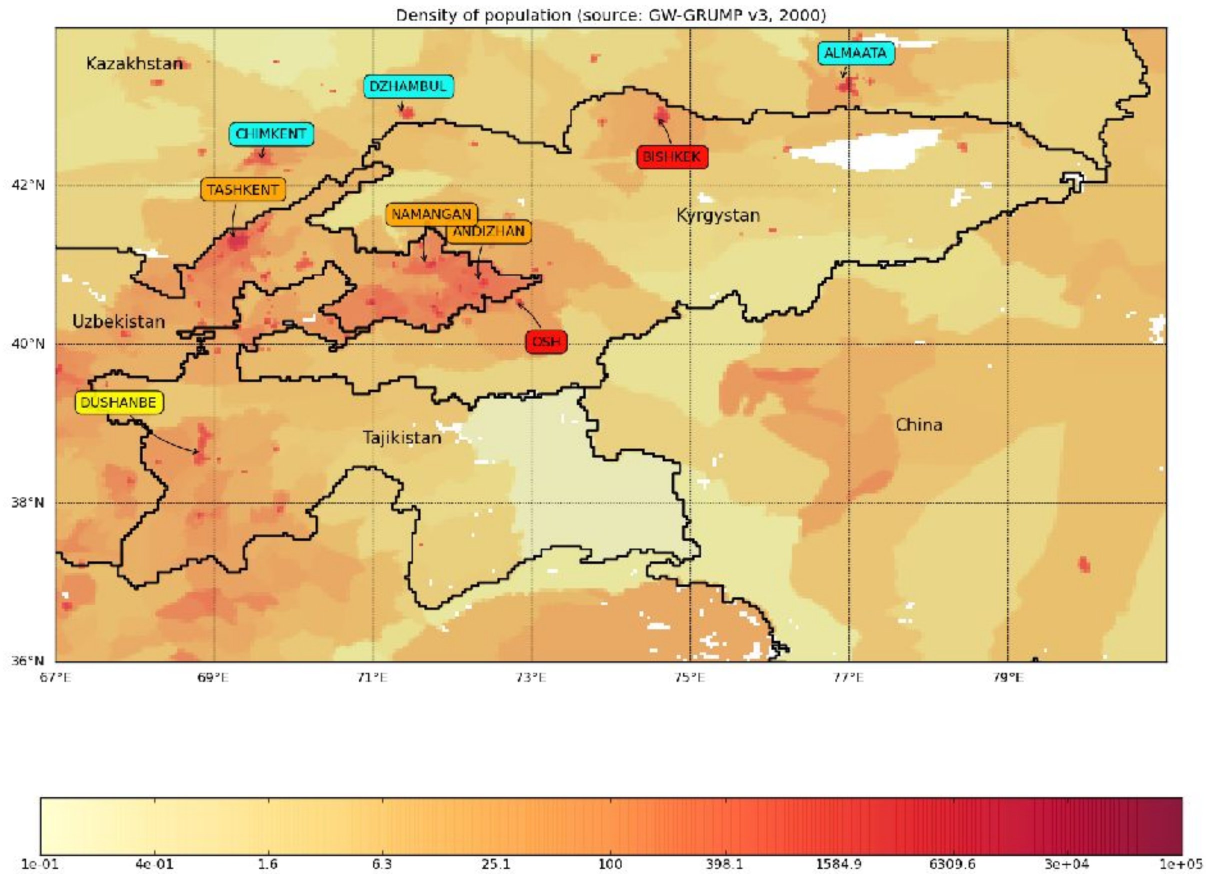

Figure 2: Density of population in the considered area (inhabitants / km²) adjourned to 2000

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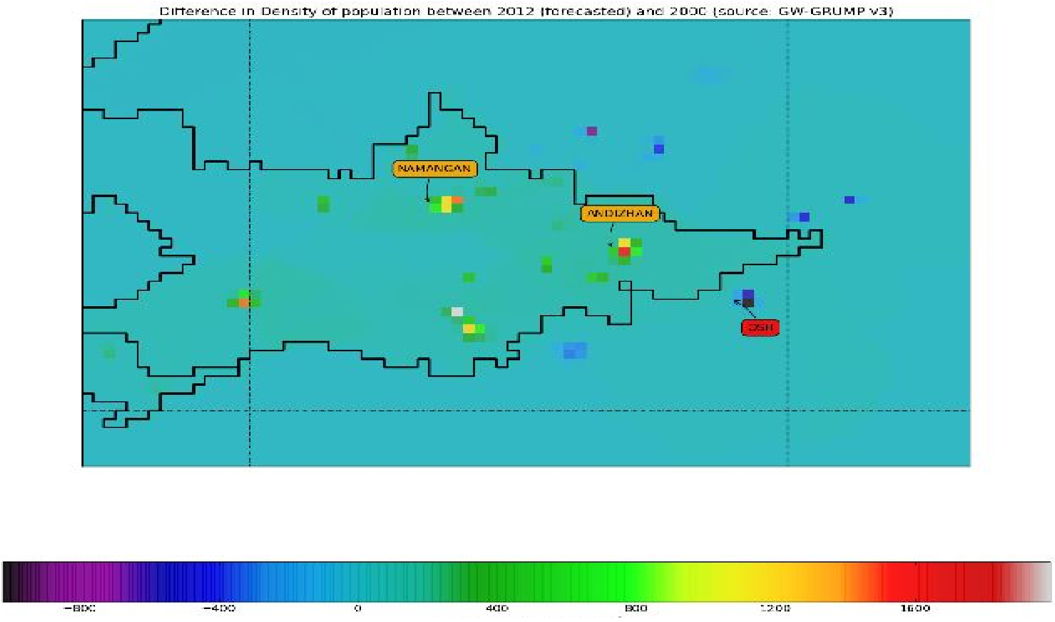

Figure 3: Expected variation of density of population between years 2000 and 2012 in the Fergana basin.

1.2.2 Social Fragility

A direct correlation between social fragility, in terms of probability of casualties, and intensity of ground-shaking has been the subject of several studies [12],[13]. Different models have been proposed, usually based on the statistical analysis of past earthquake-induced losses in different countries. The PAGER system [14] in particular uses a pre-defined set of casualty-functions derived by an empirical approach to provide almost real-time estimates of losses at a global level. Those functions are described by two parameters (*teta* and *beta*) and are clustered by country or by geographical zone. Where no specific data where available, fragility functions have been based on proxies, for instance using equivalent datasets from similar or neighbouring countries. Within the PAGER framework, the Central Asian countries (Kirgyzstan, Tajikistan, Turkmenistan and Uzbekistan) have been considered as a homogeneous group. For this group, the number of earthquakes considered is shown in table 1.

The empirical earthquake fatality rate, or social fragility function, is based on statistically aggregating all the fatal earthquakes that have occurred since 1973 [14], and estimating the casualty rate (total casualties for the given population) in terms of macroseismic intensity.

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Country	Total shaking deaths by all earthquakes since 1900	Total fatal (one or more deaths) earthquakes since 1900	Maximum shaking deaths (10 or more) due to any single earthquake since 1900
Kazakhstan	467	4	117
Kirgyzstan	102	2	51
Tajikistan	27050	7	15000
Turkmenistan	3668	3	1223
Uzbekistan	na	na	na

Table 1: List Central Asian Countries with 10 or more fatalities due to any single earthquake since 1900

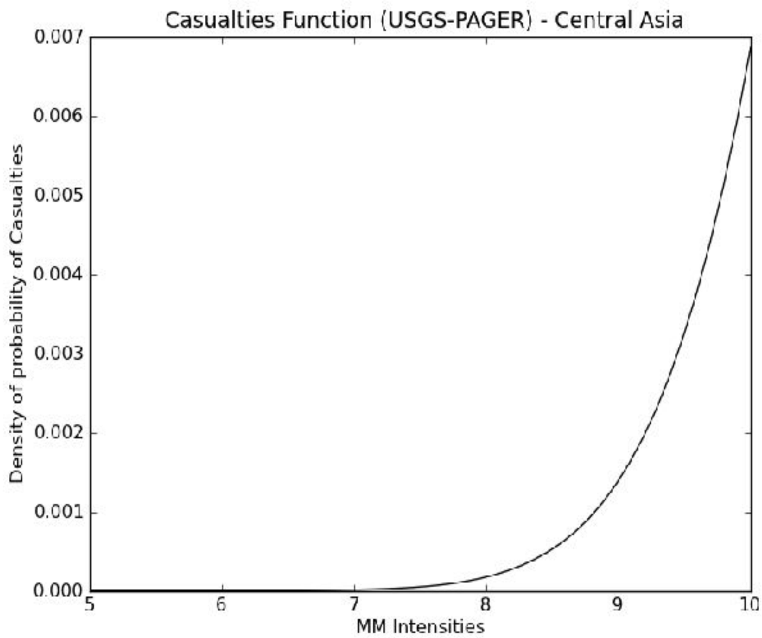

figure 4: PAGER casualties model from Central Asia

The social fragility function, also called fatality rate ν is defined as in formula 1:

$$\nu(I)=\Phi\left[\frac{1}{\beta}\ln\left(\frac{I}{\theta}\right)\right] \quad (1)$$

Where Φ is the standard normal cumulative distribution function, β and θ are the parameters of the distribution and I is a discrete value of shaking in MMI (Modified Mercalli Intensity) scale (usually defined in the range V-X and expressed in numeric values). Throughout the rest of this report we will consider MMI and MSK intensities as being equivalent and will refer simply to i*ntensity.*

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1.2.3 Structural exposure

With structural exposure we define the set of assets exposed to seismic hazard. The type of asset considered are residential buildings. Damages to the residential buildings due to strong ground-shaking are likely to produce human losses (fatalities and injuries) and a considerable amount of economic losses.

Modeling the exposure for the purpose of seismic risk assessment in the Central Asian region is a challenging task. On the one hand, in spite of the fact that the building stock of the five neighboring countries under consideration (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) is represented by many similar structural types designed and built in accordance with common regulations during the Soviet period, at the present time there is no consistent approach to the vulnerability classification of buildings in the region. On the other hand, the spatial distribution of cities and settlements, as well as the age of the building stock in the region are far from uniform and there is considerable difference in the exposure composition of the existing building stock between rural and urban areas. A comprehensive inventory of assets for Central Asia, on a regional scale is therefore currently not available. The USGS´s PAGER System includes a description of building inventory worldwide [11][15] in terms of the most common typologies of residential building, derived by the information listed by EERI´s WHE (*World Housing Encyclopedia*) [16], but little information is available on the composition of the building inventory stock of the different countries. Amongst the Central Asian countries, Kyrgyzstan is the best covered by the WHE reports. In table 2 a summary of the main information available in the EESRI WHE reports is shown. Within the GEM project, a global exposure database is being implemented, based on a new taxonomy.

Housing Type	PAGER Type	No. of Stories	No. of Units	Occupancy (family per unit)	Occupancy work hours	Occupancy night hours	Rural/ Urban	Inventory Description	EMS-98 (min -likely- max)
Precast reinforced concrete frame with cruciform and linear beam elements (series 106)	PC2H	9-12	60 (36-120 families per building)	1 / 2	> 20	> 20	Urban	Common in urban areas built after 1975	B-C-D
Single-family brick masonry house	UFB4	2	1	1	< 5	5-10	Both	Most common throughout the country	B-C-D
prefabricated concrete panel buildings with monolithic panel joints	PC1	5-9	60 (40-80)	1	> 20	> 20	Urban	About 35-40% of multistory building stock	D-E-F
Reinforced concrete frame buildings without beams (serie KUB)	PC2M	5-12	36 (10-120)	1	> 20	> 20	Urban	Exists in urban areas of the country	A-B-C
Buildings with cast-in-situ load-bearing reinforced concrete walls	CH2	4-18	54 (20-90 families per building)	1	> 20	> 20	Urban	Widespread in urban areas	D-E-F
Two-story unreinforced brick masonry building with wooden floors	UFB2	2	8-16	1	10-20	>20	Urban	5% of urban building stock	A-B-C
Houses with mud walls and thatch roofs	M2	1	1	1	< 5	5-10	Both	Common in the country	A -A -A

Table 2: Building typologies for Kyrgyzstan, from EERI WHE Reports.

1.2.4 Structural Fragility

Empirical models of structural fragility, combining intensity of shaking with probability and extent

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of consequences, are available on a global scale ([17]) in simplified form, but they need a description of the building inventory in the selected geographical area following some kind of taxonomy.
Significant efforts to develop a harmonized approach have been made during the CASCADE project, when, using the EMS-98 vulnerability classification [18], the first preliminary vulnerability composition models (as percentage of buildings corresponding to different vulnerability classes) were constructed for several cities and rural settlements of all the five Central Asian countries (Tyagunov et al, 2010) [19], the outcomes of which will be used within the framework of the EMCA project. At the same time, taking into account that EMCA aims to map seismic risk in terms of probable human losses, we have to upgrade the concept of the vulnerability composition modeling of built-up areas, taking into consideration the number of people exposed to seismic risk. Therefore, we construct the vulnerability composition models, including inhabitants of buildings corresponding to different vulnerability classes. Correspondingly, for these purposes, information about the living floor space and the number of inhabitants of different types of buildings is collected and used. For the current stage (while the data collecting process is underway) we define the vulnerability composition models in terms of quantities used in the EMS-98, namely, few (0-20%), many (10-60%), most (50-100%). The vulnerability composition models (as a percentage of inhabitants of buildings corresponding to different vulnerability classes), which are used for the preliminary calculation of risk, are presented in Table 1. These estimates will be updated and refined during the course of collecting additional data.

	A	B	C	D	E	F
Urban areas	few	many	many	many	few	few
Rural areas	many	most	few	few	-	-

Table 3: Vulnerability composition models (including inhabitants) for residential building stock of Central Asian region.

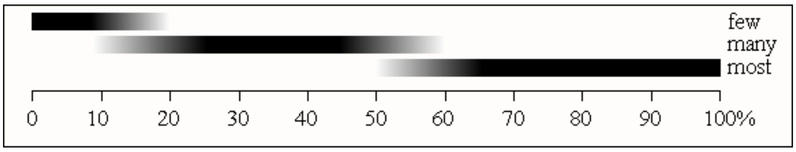

Figure 5: Description of qualitative attributes in EMS-98

The vulnerability compositions listed in table 3 can be used to qualitatively describe the relationship betweeen intensity of shaking and expected fatalities, as exemplified in eq. 2.

$$Fatalities(I) \propto \sum_{V} P(D_5|V,I) \cdot N_b \cdot \sum_{bt} P(bt|V) \cdot O(bt) \quad (2)$$

Where $P(D_5|V,I)$ is the probability of damage state 5 (according to the EMS-98 scale, i.e. such a damage state is usually defined as total collapse) for a building of vulnerability *V* (in the EMS-98 scale) subject to a ground shaking of intensity *I* (in MMI), N_b is the total number of buildings in the considered region or geocell, $P(bt|V)$ is the frequency of building type *bt* given its vulnerability is equal to *V*, and $O(bt)$ is the average number of people in the building type *bt* (occupancy). For sake of semplicity we omit all grid-based or geographical indices.
This relationship applies regardless of the scale, but it should be applied to the set of the biggest geo-cells where no relevant change of the considered parameters is expected.
Herein, expected fatalities depend therefore on the probability of damage grade 5 occurring to buildings of vulnerability *V*, and on the percentage of the population which lives in these buildings. We can then isolate from eq. 2 the part relative to the fraction of population ExpDens*(V)* occupying

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buildings of vulnerability *V* (defined through the specific ccupancy *O(bt)*),

$$ExpDens(V) = \sum_{bt} P(bt|V) \cdot O(bt) \quad (3)$$

which is estimated in table 3 for rural and urban areas in Central Asia (source: local expert judgement).

$$Fatalities(I) \propto N_b \sum_{V} DPM_5(V, I) \cdot ExpDens(V) \quad (4)$$

Summarizing in eq. 4, the expected number of fatalities depends on the fraction of people exposed and on the probability of damage state 5 occurring, the latter usually described by an entry in the Damage Probability Matrix (DPM) [20].
Of course, this representation is simplified in many ways (for instance, it does not consider damage state 4) and we still lack information on the total number of buildings composing the considered inventory N_b . Ongoing join activities within the EMCA project aim at further analysing those relationships and finding better estimates.

1.3 Estimating Seismic Risk

Considering the limitation of a structural fragility approach to loss estimation, and in order to provide a preliminary description of seismic risk in terms of expected human losses, the hazard model described in section 1 has been applied.
A regular grid of resolution 0.04×0.04 degrees has been defined over the considered spatial extent. This grid has the same spatial resolution as the population density distribution of GRUMP v3 dataset. Two distribution of ground-shaking relative to an exceedance probability of 0.1 (10%) and 0.02 (2%) over 50 years have been considered (figures 6 and 7 respectively). For each ground-shaking distribution, the expected losses in terms of casualties have been computed using the social fragility function described (eqn. 1, section 1.2.2), where the social exposure has been modeled after the forecasted population density computed in section 2. Note that the considered fragility function is affected by a strong uncertainty due to the lack of data dealing with casualties in the considered regions. Furthermore, the empirical fatality rate is likely to be influenced by strong events affecting urban areas, which caused more losses due to high intensity of shaking and urbanisation rate. Smaller events that occur with much higher probability are likely to generate fewer losses in urban areas than in rural locations, but often are not properly reported.

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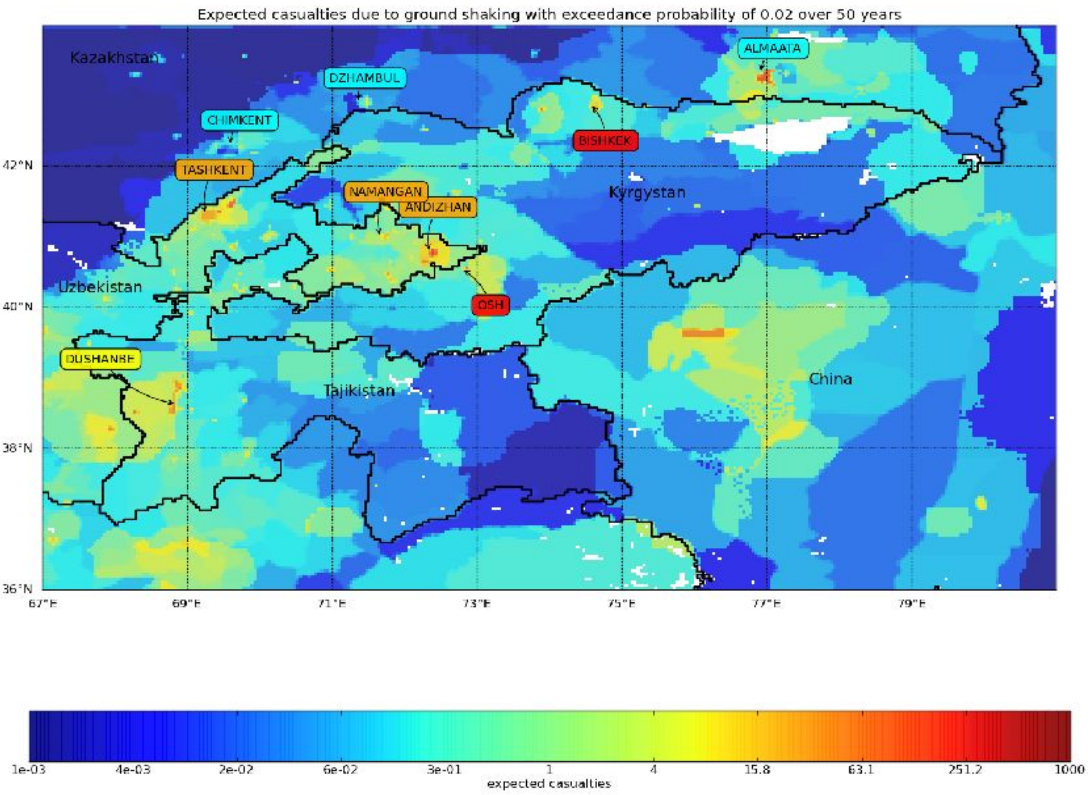

Figure 6: Map of expected casualties for a ground-shaking distribution with exceedance probability of 2% over 50 years – Population density estimated at year 2012

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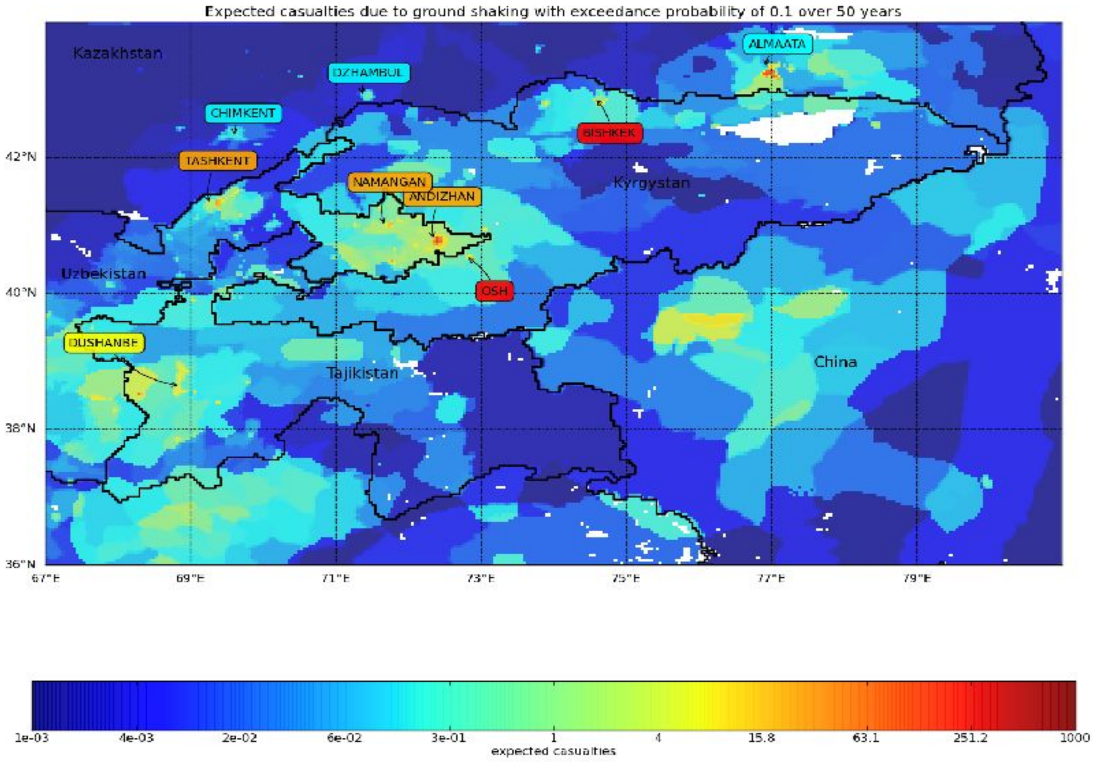

Figure 7: Geographical distribution of expected casualties for a ground-shaking distribution with exceedance probability of 10% over 50 years – Population density estimated at year 2012

1.4 Conclusions

Quantifying seismic risk over extended areas in Central Asia is a challenging task: the lack of information about structural and social vulnerability greatly affects the estimates, therefore resulting in a significant, often unknown, uncertainty. Introducing a better description of the seismic hazard allows, nevertheless, a preliminary evaluation of the expected loss in terms of human lives over a broad area, with a high resolution.

Two preliminary loss scenarios, using two different ground motion fields with probabilities of exceedance of 10% and 2% over 50 years have been computed using a simple social fragility model, based on the PAGER system. The social exposure model considered is derived from the global GRUMP v3 dataset, which has been projected to 2012 to take into account the evolution of the human settlements and urbanisation in the considered area. The considered scenarios are not considering the structural fragility of the building stock in assessing the expected loss, but we used a very simple empirical approach that is affected by a strong (partially unknown) degree of uncertainty. They have therefore to be considered mostly as qualitative graphical representations of where losses could occur and how they are related to the computed seismic hazard.

The GEM regional project EMCA is currently collecting data and local-based expert knowledge in order to provide a better understanding of the seismic vulnerability of the region and to generate an improved model of seismic hazard and a high-resolution, broad-area assessment of seismic risk in Central Asia.

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