https://doi.org/10.5194/nhess-2023-135
Preprint. Discussion started: 10 August 2023

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Estimating emergency costs for earthquakes and floods in Central Asia based on modelled losses

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Abstract

Estimating the emergency costs for disasters is of high relevance in the design of any comprehensive disaster risk management strategy. These costs usually include the ones associated to the immediate response aimed to provide the required safety and emergency attention, and those of debris removal. Over the time, and in different regions of the world, several research efforts have been carried out for the quantification of the emergency costs and have been usually associated with those of the direct losses. Also, the previous studies have been typically carried out in the aftermath of large disasters, and to the best of our knowledge, no specific quantification of the emergency costs have been carried out in Central Asia. This paper presents a methodology, which has been applied in five countries in Central Asia using historical and synthetic events, to estimate the emergency costs as a function of modelled direct losses for earthquakes and floods, taking into account the demographic and building characteristics. The methodology allows the prospective estimation of the total emergency costs, so that they can be considered in the planning and budgeting of the emergency and recovery phases, as well as in disaster risk financing initiatives. It was found that the average emergency response costs for earthquakes and floods in Central Asia show good agreement with those previously estimated at other locations as a function of the direct losses; however, this methodology allows differentiating between different types of events allowing a better description and understanding of these needs.

Short summary

This paper presents a methodology to estimate the total emergency costs based on modelled damages for earthquakes and floods, together with the demographic and building characteristics of the study area. The methodology has been applied in five countries in Central Asia, being the first time that these estimates are made available for the study area, and are intended to be useful for regional and local stakeholders and decision makers.

1 Introduction

A comprehensive disaster risk management strategy is often described as a cycle consisting of four main stages: mitigation, preparedness, response, and recovery, as schematically shown in Figure 1. The disaster risk management cycle illustrates the ongoing process by which governments, businesses, and civil society in general can plan for, and mitigate, the impact of disasters, as well as the actions that allow to react during and immediately following a disaster, besides taking the necessary steps to recover after a disaster has occurred.

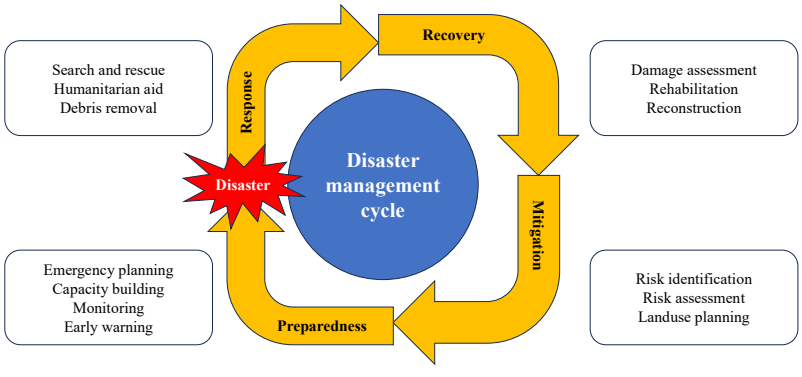

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Figure 1: Schematic representation of the disaster risk management cycle

In the aftermath of a disaster, the immediate response measures aim at maintaining and/or reestablishing public safety by performing search and rescue operations, and by adopting the necessary measures to cover the basic humanitarian needs of the affected population (Poser and Dransch, 2010). As per the definition by the World Bank (2021) the emergency response costs can be defined as "*those costs incurred by the responders (in this case the government) immediately after a disaster occurs; they are associated with immediate relief activities, debris removal, etc.*" In general, the costs for emergency response are substantial and important for the choice and definition of comprehensive disaster risk management strategies (e.g., identifying equipment needs), although have been largely under researched (Pfurtscheller and Schwarze, 2008) and have not, generally, been estimated in a forward-looking manner. This paper describes a methodology to estimate the emergency costs for earthquakes and floods based on the population and building characteristics as well as the modelled losses obtained in the framework of the *Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia* (SFRARR) project, which details, methodology and complete results are described in detail by Salgado-Gálvez et al., (2023), and Coccia et al., (2023).

Despite that different researchers and initiatives have attempted to estimate the emergency costs for different regions of the world and for different hazards, no previous analyses of this type are available for Central Asia, which is the main motivation for this study. The methodology was applied to five countries in Central Asia (Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan), making use of historical and counterfactual earthquakes and floods for which, considering the building characteristics and a set of demographic indicators, together with the modelled direct damages on the building stock.

Among the different research efforts that have been carried out in the past, usually in the aftermath of large disasters, to quantify the emergency costs, the following are to be highlighted because of the major findings. French (1993) investigated the damages to public properties caused by the 1989 Loma Prieta, and the 1987 Whittier Narrows earthquakes in California, USA, finding that emergency response costs accounted for 13% of the total damages for the Whittier Narrows earthquake, and for 31% for the Loma Prieta earthquake, concluding that emergency response costs are proportionally larger for more severe earthquakes, especially if the hardest hit areas are densely populated.

Penning-Rowsell and Wilson (2006) assessed the severe 2000 autumn floods in the United Kingdom and according to the results of their analysis, the emergency costs amounted to 15% of the direct economic flood losses. Similarly, the Rapid Assessment Methods (RAM) for floodplain management used in Australia estimated the emergency response costs as 49.5% of the indirect losses, which are assumed to be equivalent to 30% of the direct losses (AIDR, 2002).

As indicated with the previous examples, the emergency response costs have been often associated to a percentage of the total economic losses, and following that approach, in an analysis carried out by the World Bank to assess the macro-fiscal impacts of earthquakes and floods in the European Union Member States (World Bank, 2021), the emergency response costs were added to those of direct asset losses, as a percentage of the total ground-up losses to residential, commercial, industrial, public buildings, schools, and hospitals. The final percentages used by the World Bank were 20% for the case of earthquakes, and to 15% for floods, regardless of the country, the size of the event and the damage extent in the study area.

In Mexico, it was established that the emergency response costs in the State of Oaxaca after the 2017 M_W8.2 earthquake were approximately 18% of the total losses, and 4.6% for the State of Chiapas. On the other hand, for the for the 2017 M_W7.1 Puebla earthquake these costs were estimated at approximately 4% of the total losses in México City (CENAPRED, 2019). Much of these costs was associated to demolition activities and debris removal from damaged or collapsed residential units, and did not

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quantify the expenses incurred by police, army, and navy forces to deliver supplies to communities that live in mountainous areas of the Oaxaca-Chiapas region, which is of difficult access, and for which logistical costs were significant.

The proposed methodology in this paper explicitly accounts for the particularities of the region, including its building stock characteristics, population density, and the way that a given earthquake or flood may affect each region (i.e., size of the event and extent of the damages). This methodology is intended to be used as part of a comprehensive risk assessment, so data for the hazard, vulnerability and exposure components are required. The methodology accounts for debris disposal costs based on modelled building damages and approximates the emergency services and immediate relief cost requirements based on the population that lives on each damaged building. The way the methodology is defined allows for a better estimation of emergency response costs depending on the intensity of an event, and as part of a fully probabilistic risk model it allows for its use in a more comprehensive risk and budget planning strategies that include reserves or parametric insurance products that account for the immediate relief needs after a disaster. Also, it has the potential to be included in the framework of fully probabilistic risk assessments, such as the one developed by Ordaz (2000) which is implemented in R-CAPRA (ERN, 2022), the tool used to estimate the earthquake and flood losses in this project.

2 Methodology

The proposed methodology aims at estimating the total emergency costs for earthquakes and floods in five countries of Central Asia, as a function of the modelled direct damages in the building stock that were obtained in the framework of a regional risk assessment funded by the European Union and implemented by the World Bank. The total emergency response costs are assumed to be representative of the costs for providing the first response to the affected communities in the aftermath of a disaster (i.e., safety and emergency services), and for debris removal. For this, the same idea proposed in previous studies elsewhere of linking the emergency costs for both hazards to the direct is followed, but tailored to the particularities of the region, such as the number and characteristics of the building, occupancy values, and population density, as well as explicitly accounting for the size of the event and the damage extent.

The methodology requires the same inputs as any probabilistic risk assessment, namely hazard (in the form of synthetic earthquakes or floods), an exposure database for the study area that includes attributes about the characteristics of the buildings (i.e., building classes/typologies), total built area, occupancy levels per building, and number of buildings (individually or grouped), and physical vulnerability functions that provide a relationship between a given hazard intensity measure (e.g., ground acceleration or flood depth), and the expected losses (or damages). For this study, the earthquake and hazard data used were the developed by Poggi et al., (2023) and Coccia et al., (2023) for earthquakes and floods, respectively; the exposure model for residential buildings to the one developed by Scaini et al., (2023), and the vulnerability functions for earthquakes and floods to the ones developed by RED (2023).

2.1 First response costs in the aftermath of a disaster (emergency and safety services)

The first response costs are those associated with the emergency and safety services required by the affected population because of the occurrence of a disaster. As such, the needed resources have a direct relationship to the size of the affected population. Physical vulnerability can be described using different approaches, such as fragility curves (Kircher and McCann, 1983) and vulnerability functions. The risk assessment carried out in Central Asia made use of the latter representation, given the possibility to provide a continuous, quantitative, and probabilistic relationship between the hazard intensity measure and the direct losses at each exposed asset. Because of this, the risk assessment carried out for earthquakes and floods in this project

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allowed estimating the mean damage ratio (MDR) for each exposed asset, which corresponds to the expected loss normalized by the replacement cost of the asset.

Since there is a close relationship between vulnerability functions and fragility curves (Ordaz, 2009), from the modelled MDR for the residential units in the earthquake and flood risk assessments, a damage state, *DS*, is assigned to each building, using the values shown in Table 1 and considering 6 possible *DS* (from none to collapse). It is assumed that only people residing on buildings with a MDR of 0.20 or higher (equivalent to a building with substantial to heavy damage) are considered to require emergency and safety services immediately in the aftermath of the event. It is also assumed that all people residing in the same building are equally affected.

Table 1: Mapping between MDR and *DS*

DS	*DS* Description	MDR
DS0	None	0
DS1	Slight	0.005
DS2	Moderate	0.050
DS3	Substantial to heavy	0.20
DS4	Very heavy	0.45
DS5	Collapse	0.80

Depending on the *DS* of each building, a cost per capita is assigned to the first response costs, *CR*, which are directly proportional to the damage level (i.e., as the damage in the building increases, the first response costs do so), as shown in Table 2.

Table 2: Cost of emergency services as a function of *DS*

DS	Cost of emergency services ($USD/per capita)
DS0	0.0
DS1	0.0
DS2	0.0
DS3	100
DS4	500
DS5	500

The expected costs of first response at each building, CFR_B, in the study area are calculated as:

$$CFR_B = CR \vee DS \cdot N_R \quad (1)$$

where $CR \vee DS$ represents the first response costs per capita given a *DS*, and N_R the number residents at each building. The total cost of emergency and safety services (i.e., first response costs), T_{FR}, due to the occurrence of the disaster, is equal to the sum of the individual values of emergency services and safety services for all affected buildings in the study area, which can be calculated as:

$$T_{FR} = \sum_{p=1}^{n_p} CFR_B \quad (2)$$

2.2 Cost of debris removal

Debris removal and disposal can account for a significant portion of the total emergency response costs. Indeed, the collapse and damage of buildings after a disaster generates a great amount of debris and waste that not only could impede a quick

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emergency response on the affected areas, but also could represent a significant emergency response cost, as earthquake or flood debris can be too heavy to be managed by individuals, and often requires specialized equipment and personnel. Major disasters can generate debris and waste equivalent to 5 to 15 times the annual waste generation of the affected community after a single event, overwhelming the existing capacity and impacting the recovery efforts (Brown et al., 2011). Determining the amount and type of debris is also relevant for the preparedness activities within the disaster management cycle to plan for the personnel and equipment needs.

Some major disasters that have generated large amount of debris include the 2010 Port au Prince (Haiti) earthquake, which generated 20 million m^3 of debris (DesRoches et al., 2011), the 2008 Sichuan (China) earthquake and the 1995 Kobe (Japan) earthquake that generated over 20 million tons of debris (Hirayama et al., 2010; Brown et al., 2011), the 2007 Pisco (Peru) earthquake that caused around 10 million m^3 of debris (Mesta et al., 2020), and 15 m^3 of debris per affected household after the 2015 Gorkha (Nepal) earthquake (Khanal et al., 2021).

Previous works have been published with methodologies to estimate the amount of debris after a disaster (see for instance, FEMA, 2007; Hirayama et al., 2010; Xiao et al., 2012; Tabata et al., 2016; García-Torres et al., 2017; Poudel et al., 2018; Mesta et al., 2020), where most of these account for the quantity of debris and waste generated as a function of the *DS* of the building, hence a good estimation of debris removal cost requires an estimation of building damage in the study area, as *DS* will depend on the vulnerability of the building stock. For this project, region-specific vulnerability functions were developed to explicitly account for the building characteristics, local construction practices and use of building codes (RED, 2023).

Besides the *DS*, the amount of debris (measured in weight) that a building generates after a disaster is a function of several building characteristics, such as: the typology, the floor area, and the weight per floor area (or material intensity). Then, in this methodology, for a given typology the fraction of the building stock that turns into debris depends on the modelled *DS*.

The quantification of materials used in a building can only be empirically measured during the construction and demolition stages, whereas for the case of existing buildings these can only be estimated by assigning material intensity (MI) coefficients. Compiling MI data is resource intensive, and most estimates are based on a handful of data points only, resulting in large uncertainties that are hard to quantify. As building physical attributes can vary as a function of local construction practices, preferences, and traditions, as well as budgetary constraints, building code level and enforcement, as well as the construction period, MI coefficients are virtually unique to every building, and therefore, the representativeness of MI values for building archetypes is limited (Sprecher et al., 2022).

Nevertheless, different efforts have been made to compile data of MI coefficients for different archetypes and for different regions, at different scales. For instance, Tanikawa and Hashimoto (2009) made this compilation for two cities of Japan and the UK, Wiedenhofer et al., (2015) for the 25 Member States of the European Union; Condeixa et al., (2017) for Rio de Janeiro, Brasil; Kleemann et al., (2017) for Vienna, Austria; Ortlepp et al., (2018) for Germany and Poudel et al., (2018) for the Kathmandu Valley in Nepal; Miatto et al., (2019) compiled these data for the city of Padua in Italy, whereas Mesta et al., (2019) for Chiclayo in Peru. Sprecher et al., (2022) for the Netherlands.

MI data for Central Asia were not found during the literature review carried out for this study, although after reviewing the MI values for different areas of the world, there appears to be consistency in the values between building typologies. As such, it was considered as reasonable to use the MI values proposed by HAZUS (FEMA, 2020). When a building typology included in the exposure model for Central Asia was not listed by HAZUS, the values were taken from other available references in the

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literature. For instance, it was the case of adobe buildings which are not common in the USA, but have a non-negligible share in Central Asia, and had been previously analyzed in Peru by Mesta et al., (2020). For a given *DS*, a debris weight per floor area, known as debris intensity, *DI*, was estimated based on the building type and its MI.

The *DI* values used in this study are shown in Table 3.

Table 3: *DI* values for the different building typologies in Central Asia[1]

	Debris Intensity (ton/m²)			
Typology	**DS2**	**DS3**	**DS4**	**DS5**
CM	0.06020258	0.30301497	0.74545494	1.28413507
RM_L	0.05239874	0.26399578	0.65180888	1.1280583
RM_M	0.05616611	0.28283263	0.69701732	1.2034057
URM1	0.04402441	0.2232436	0.52016619	0.97413431
URM2	0.04402441	0.2232436	0.52016619	0.97413431
RC1	0.00100104	0.00700731	0.03503654	1.15496808
RC2	0.00100104	0.00700731	0.03503654	1.15496808
RC3	0.00100104	0.00700731	0.03503654	1.15496808
RC4	0.00100104	0.00700731	0.03503654	1.3056629
RCPC1	0.00100104	0.00700731	0.03503654	1.3056629
RCPC2	0.00100104	0.00700731	0.03503654	1.3056629
ADO	0.0749758	0.38019514	0.88586934	1.659
WOOD1	0.00260487	0.02199068	0.1242694	0.36166755
WOOD2	0.00260487	0.02199068	0.1242694	0.36166755
STEEL	0	0	0	0.73732818

The exposure model for Central Asia groups multiple buildings into gridded cells, and at each of them the number of buildings by building class, as well as the total built areas are known. Therefore, the expected weight of the debris generated by each building for a given event, W_d, in tones, can be calculated as:

$$W_d = DI \vee DS \cdot FA \quad (3)$$

Where *DI V DS* is the debris intensity for a given *DS* and building class, and *FA* corresponds to the total built area per building, in m^2. The total weight of debris generated for a given event, TW_d, is computed as the sum of weights in all the affected exposed assets (i.e., those with physical losses larger than zero) using the geolocated modelled damages per building, which can be calculated as:

$$TW_d = \sum_{p=1}^{n_p} W_d \quad (4)$$

where p is the building of interest and n_p the total number of buildings simultaneously affected by a given event. The total cost of debris removal, T_{CD}, for a single event is computed as the multiplication of the total weight of debris generated and the cost of debris removal, *CD*, per ton of material, which is calculated as:

$$T_{CD} = TW_d \cdot CD \quad (5)$$

CD, per ton of material, depends on several factors, including the cost of labor and distance to the disposal site. Because of the lack of information for the study area, a unique value of $30US/ton was used, which is based on typical solid waste management costs, as a function of the income level of the five countries in the study area (Kaza et al., 2018).

[1] CM: confined masonry; RM: reinforced masonry; URM: unreinforced masonry; RC: reinforced concrete frames; RCPC: pre-cast reinforced concrete; ADO: adobe

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This value was found to be consistent with the aggregated costs for debris removal reported after several disasters worldwide and could be considered an estimate of the debris removal costs as part of the emergency response. It should be noted however that debris removal costs can significantly increase immediately following a disaster due to the lack of personnel, machinery and resources available, particularly if the affected area is very large and densely populated. There is also a great variability on the costs of debris removal depending on the income level of the country, as this activity is very labor intensive.

2.3 Emergency response costs

The emergency response cost (ERC) is estimated as the sum of the first response costs (T_{FR}) and the total cost of debris removal (T_{CD}), for each event.

$$ERC = T_{FR} + T_{CD} \quad (6)$$

A final factor is included in this methodology, representing the population density (PD), since as observed in the two 2017 Mexican earthquakes, as well as in the analysis carried out by French (1993), ERC increases in areas where the affected population is higher, which are generally the case of densely populated areas. Therefore, the Total Emergency Response Cost, $TERC$, is computed as:

$$TERC = ERC \cdot PD \quad (7)$$

where PD is a factor that amplifies the total costs in densely populated zones and indirectly covers the demand surges that are known to occur during large disasters. PD is assumed to be equal to 2 in areas with more than 15,000 people per km^2, and 1 elsewhere.

3 Application of the proposed methodology in Central Asia

The methodology presented in this paper has been applied to Kazakhstan, the Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan, for which emergency response costs for earthquakes and floods were estimated, using as a starting point the datasets for earthquake and flood hazard, built environment exposure and earthquake and flood vulnerability functions developed in the framework of the *Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia* -SFRARR- project. To estimate the emergency costs, only buildings and population data sere used from the exposure model. For the case of earthquakes, the emergency costs were estimated for the seven (7) events used in the validation and calibration procedure of the model (see full details in Salgado-Gálvez et al., 2023), which details are shown in Table 4, whereas for the case of floods, since there were no enough data for historical events the validation and calibration procedures were carried out using feasible events with given return periods, and chosen from the synthetic flood catalog (see full details in Coccia et al., 2023).

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Table 4: Historical earthquakes in the region of study used for validation

ID	Country	Date (DD/MM/YYYY)	Mw	Latitude	Longitude	Depth
1	KGZ	05/10/2008	6.7	73.44	39.31	40
2	KGZ	19/08/1992	7.3	73.63	42.07	25
3	UZB	20/07/2011	6.3	71.42	40.16	20
4	UZB	26/05/2013	6.2	67.4	39.2	18
5	TJK	07/12/2015	7.2	72.78	38.211	22
6	TJK	29/07/2006	5.6	68.828	37.255	34
7	KAZ	23/05/2003	6.0	80.515	42.905	10

3.1 Emergency response cost assessment

3.1.1 Earthquakes

Table 5 shows the results obtained for the emergency response costs for earthquakes in Central Asia. Results indicate that the lower total emergency response cost ratio, with respect to the modeled losses for the residential buildings, corresponds to the 2013 Uzbekistan event, whereas the largest ratio was found for the Tajikistan 2015 earthquake.

Table 5: Direct losses and emergency cost estimates for seven historical earthquakes in Central Asia

ID	Event	Residential Losses ($MUSD)	Debris Removal Cost ($MUSD)	Emergency services and safety services ($MUSD)	Total Emergency Response Cost (TERC) ($MUSD)	C as Direc Loss
1	KGZ_2008-10-5	18.1	0.9	2.0	2.8	16%
2	KGZ_1992-8-19	348.9	24.4	47.4	71.9	21%
3	UZB_2011-7-19	1,042.9	66.9	15.1	82.0	8%
4	UZB_2013-5-26	155.5	3.3	3.7	7.0	5%
5	TJK_2015-12-7	18.5	2.2	2.2	4.4	24%
6	TJK_2006-7-29	115.7	6.9	14.7	21.6	19%
7	KAZ_2003-5-23	27.4	2.6	1.2	3.8	14%
					Average=	15%

For the case of the historical events affecting the Kyrgyz Republic it can be seen that the *TERC* are higher, both in terms of the total costs and relative to the direct losses for the 1992 event. For the 2008 event the affected population was relatively low, and the area with the highest modelled damages was relatively small (in line with the size of the event). For the case of the 1992 earthquake, and despite the sparsely populated area where it occurred, a significantly larger amount of population was affected as the area with significant shaking was also much larger if compared to the 2008 event.

For Uzbekistan, the relative *TERC* are considerably lower than for the other countries, which is explained by the larger exposure affected by the events, but also by the lower earthquake vulnerability in this country, which means that the debris generated by building damages and the population that requires emergency services in the aftermath of the event are also lower.

The 2015 earthquake in Tajikistan is the historical event with the highest relative *TERC*. This event, while affecting a sparsely populated area, produced very strong shaking that led to many buildings reaching higher *DS*, that consequently led to higher relative emergency response costs.

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At regional level, after calculating these costs for the seven historical events shown in 5, it was found that, on average, *TERC* represents 15% of the modeled residential losses, which is a value in line with those reported in the literature for other regions in the world. However, the methodology presented herein can differentiate the expected *TERC* depending on the intensity of the event and the characteristics of the affected population, besides having explicitly considered the hazard, exposure, and vulnerability characteristics of Central Asia.

3.1.2 Floods

TERC for floos was estimated for a recreation of the Hamadoni 2005 historical flood and the three counterfactual scenarios defined for the Kara-Unkur River, the Parkent River, and the Turkmenabat region. Results are shown in Table 6 from where it can be seen that, on average, the ratio between the TERC and the modelled losses was around 21%.

Table 6: Estimation of emergency response cost for one historical and three possible floods

ID	Event	Residential Losses ($MUSD)	Debris Removal Cost ($MUSD)	Emergency services and safety services ($MUSD)	Total Emergency Response Cost ($MUSD)	TERC as % of Direct Loss
1	Hamadoni 2005 flood	7.3	0.7	1.4	2.1	29%
2	Kara-Unkur River	3.5	0.3	0.2	0.6	17%
3	Parkent River	11.4	1.1	0.0	1.2	10%
4	Turkmenabat	58.8	5.9	10.0	15.9	27%
					Average=	**21%**

It can be seen that the event with the highest *TERC* as a percentage of the direct residential losses corresponds to the Hamadoni flood, where a significant amount of the affected assets was located near the highest flood depths, which caused more serious damage and in turn produced larger *TERC*.

For the three counterfactual scenarios, the one for the Turkmenabat region stands out with similar *TERC* percentages as the Hamadoni flood. In this case, a significant amount of exposure exists in the margins of the Amu Darya River, so for a significant flood event like the one represented by that event, with certain land zones reaching water depths of more than 3m, a considerable amount of population would require emergency and safety services, as the expected *DS* of many buildings would be significant.

For the cases of the Parkent River and Kara-Unkur River flood scenarios, the highest flood depths reached for the events was not as high as those reached in the Turkmenabat scenario, or the Hamadoni flood, which in turn made it that the percentage of exposed assets that reached the *DS* that require the use of emergency and safety services was also lower. This is more evident for the case of the Parkent River, where while total residential losses were higher than the Hamadoni flood, since a larger amount of assets were affected, the *TERC* were considerable lower since most of affected assets only suffered minor damages.

4 Conclusions and Discussion

A methodology to estimate the emergency response costs for earthquakes and floods in Central Asia has been proposed, making use of the different components developed in the framework of a fully probabilistic multi-hazard risk assessment for five countries in the region. The methodology accounts for debris disposal costs based on building damage levels and approximates

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the emergency services and immediate relief cost requirements based on the characteristics of the population that lives on each of the damaged buildings, which values were obtained from a detailed exposure model specifically developed for this project.

Instead of using a flat percentage of the direct losses to estimate emergency response costs, regardless the characteristics of the event, this methodology accounts for the vulnerability of the exposed assets, and the hazard extent in order to determine the total emergency response cost, *TERC*. While a larger population exposed to moderate shaking is expected to produce larger direct losses than a smaller population exposed to very intense shaking, the relative costs for the emergency services would be much higher on the second case as it would require the disposal of a larger amount of debris, besides a larger percentage of the population needing first response services.

The methodology was applied to five countries in Central Asia, where little to no information exists about the expected emergency response costs for disaster response. It can be seen that for the historical and counterfactual events considered, the average *TERC* are in line with the values previously published in the literature for other regions in the world, although this approach offers the advantage to differentiate between events that produced different levels of overall damage: more destructive events have higher relative *TERC* than events with higher losses that affected less vulnerable building stock.

While the results found in this work are promising, more data are needed to validate the results. There is a need for more and better-quality loss data in the region that disaggregates the expenses incurred by governments to attend the emergencies, more so in the case of flooding events. Region specific data for some of the parameters could further help improve the *TERC* estimations, particularly those related to debris removal. Future work will include the use of the methodology as part of a fully probabilistic risk model, allowing the estimation of *TERC*, or any other of the variables considered for its quantification, in terms of exceedance probabilities, providing decision-makers and stakeholders better tools to allocate the needed resources (e.g., personnel and equipment) in disaster response and preparedness activities.

Data availability

Data and results are available at: https://datacatalog.worldbank.org/search?q=sfrarr%20central&start=0&sort=

Acknowledgments

The Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia (SFRARR) project was funded by the European Union and was implemented by the World Bank. Authors are thankful to the World Bank Specialists, in particular Chyi-Yun and Stuart Fraser for their contributions and constructive criticism during the development of the earthquake risk model. Authors are also thankful to Dr. Sergey Tyagunov for the assistance and support in the finding and validation of local data.

Author contribution

EB: conceptualization, methodology, formal analysis, writing. CA: conceptualization, formal analysis, validation. MASG: conceptualization, validation, formal analysis, writing and editing. MOS: conceptualization, risk assessment methodology, software, validation, formal analysis, writing review and editing.

https://doi.org/10.5194/nhess-2023-135
Preprint. Discussion started: 10 August 2023

Competing interests

All authors declare that they do not have conflicts of interest of any type.

Special issue statement

This paper is to be considered in the Special Issue: Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis in Central Asia.

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