Task 9 – Final Technical Report

Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia (SFRARR Central Asia disaster risk assessment)

FINAL VERSION

08 December 2022

RED – Risk Engineering + Development – Pavia, Italy

Revision History

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RED Risk Engineering + Development

Executive Summary

The countries of Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan in Central Asia are highly prone to natural hazards, more specifically, floods, earthquakes, and landslides. These natural hazards occur with different likelihood in these countries and they cause different risk profiles. For example, according to the Global Facility for Disaster Reduction and Recovery (GFDRR)[1], Kazakhstan is most vulnerable to flood events, mainly driven by rainfall and snow melt, which cause annual losses of over USD $419 million and affect almost one million people per year in all Central Asia. Similarly, earthquakes, although less frequently, affect at least twice the population affected by floods. Finally, landslides can also cause significant loss of life and trigger disruptions to transport networks, especially in the mountainous areas of Uzbekistan, Tajikistan and Kyrgyz Republic. Climate change, urbanization and population growth are expected to exacerbate risks posed by weather related events in the future.

To face these challenges, the European Union, in collaboration with the World Bank and the GFDRR, created the program "Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia" (SFRARR). The target countries are the same mentioned above, that is Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan. Finally, the overarching objective of the program is to improve financial resilience and risk-informed investment planning, aiming to advance disaster and climate resilience in Central Asia. To achieve this objective, the program was structured as follows:

1. Quantifying regional disaster risks and contribute to capacity building in the region on risk identification,
2. Increasing awareness and capacities for financial resilience at national and regional levels,
3. Mapping exposure to support activities in risk analysis, disaster risk management and awareness.

Within the framework of the SFRARR project, the "***Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia***" was conceived to help handle and achieve the parent project objectives. This project was carried out by a consortium formed by RED (Risk, Engineering and Development, Pavia, Italy), OGS (National Institute of Oceanography and Experimental Geophysics, Udine, Italy), ERN (Evaluación de Riesgos Naturales, Mexico City, Mexico), UNESCO Chair (UNESCO Chair on Prevention and Sustainable Management of Geo-Hydrological Hazards of the University of Florence, Italy), AKUA (Akua Capital, Mexico City, Mexico), and experts from a wide range of locally-based research and engineering institutions (LLP "Institute of Seismology" of the Ministry of Emergency of Kazakhstan, Institute of Seismology of the Academy of Sciences of Uzbekistan, Tashkent State Transport University, Institute of water problems, hydropower and ecology, National Academy of Sciences of Tajikistan, Institute of Seismology of the National Academy of Sciences of Kyrgyz Republic and consultants from Turkmenistan). The project was conceived to build on the quantification of risk estimates and on

[1] https://www.gfdrr.org/en/disaster-risk-country-profiles

risk management principles to improve the understanding of how natural disaster risks affect the region. Specifically:

1. *Risk assessment*. Earthquakes, flood and landslide risk was assessed to obtain a diagnosis of the risk profile of each country. A regionally-consistent exposure was assembled and harmonized from multiple fragmented datasets at different spatial scales (regional, national, local). Earthquake risk assessment was carried out following a probabilistic approach. Flood risk was assessed using a hybrid stochastic and physically-based model to develop a probabilistic modeling framework. Landslide risk assessment was performed based on an integrated geo-statistical methodological approach.
2. *Capacity building*. The objective was to increase the current experience and expertise of regional institutions and governments in Central Asia. To do so, an ensemble of regional workshops was carried out involving technical and scientific communities of the five countries to build and enhance the natural hazard and risk assessment capacity. A total of eight fully online workshops were carried on facing different topics. Five workshops, one for each country, were dedicated to exposure, while three were dedicated, at regional level, to hazard, vulnerability, and risk, respectively.
3. *Potential DRM and DRFI solutions*. Technical recommendations DRM and DRFI solutions are presented on the basis of the risk assessment outcome. In addition, one document for each country (Country Summary; World Bank, 2022i) has been produced as part of the deliverables to summarize the findings.

It is worth noting that state-of-the-art methodologies have been used for all the components of the risk assessment (hazard, exposure and vulnerability) supported by a significant amount of regional and local data that allowed to obtain robust and accurate risk estimates. However, given the objectives of the project and the methodology used, the results of the study should not be used for engineering design of specific defense structures aimed at reducing the risk of natural catastrophes. The main objectives of the study, in fact, are on one hand to build local capacity on all the components of risk assessments presenting the latest technologies available for large-scale applications and on the other hand to provide a robust and accurate basis for the development of DRM and DRFI solutions.

The main recommendations for DRM interventions for the Central Asia countries are listed thereafter.

- For earthquake risk mitigation:
    - Update seismic hazard studies (for which the results of Task 2 of this project can provide valuable information);
    - Identify high hazard zones to prioritize the implementation of risk reduction actions;
    - Carry out campaigns to retrofit critical infrastructure especially those with a high concentration of population, such as hospitals, bridges, public buildings and schools;
    - Carry out campaigns to strengthen assets in sectors with higher concentration of earthquake risk and provide fiscal incentives to encourage retrofitting of residential and commercial assets;
    - Based on the knowledge of high seismic hazard areas, carry out detailed evaluation of the performance of key lifelines, such as power generation, transmission and distribution systems, water distribution systems, and transportation network, that are present in those areas.
    - Implement good construction practices that reduce the vulnerability of buildings;

    - Implement early warning systems and educate the population on the actions to be taken in the event of a seismic event, which helps to reduce the loss of lives.
- For flood risk mitigation:
    - Identify flood hazard zones: the maps shown in the results of Task 3 provide information on the main flood hazard zones;
    - Identify high-risk zones to prioritize the implementation of risk reduction actions;
    - Carry out campaigns to reduce flood risk for assets in sectors with higher concentration of population;
    - Based on the knowledge of high flood hazard areas, carry out detailed evaluation of the performance of key lifelines, such as power generation, transmission and distribution systems, water distribution systems, and transportation network, that are present in those areas.
    - Implement flood control measures to reduce risk (either grey infrastructure or nature-based solutions);
    - Implement flood early warning systems.

Regarding the management of the financial costs of natural catastrophes, the Loss Exceedance Curves and related metrics (e.g., average annual loss) produced by the present study are the main tool available to policymakers, who can:

- Measure the effectiveness of the DRFI policy through time (e.g., 5 or 10 years);
- Identify the components of an effective Strategy (i.e., the combination of instruments to be used through time and the portions of the risk of the Loss Exceedance Curve that is transferred to the capital markets (e.g., as contingent debt), to the insurance markets (as an insurance policy), or inter-temporally into the future (retained as a self-insurance or reserve fund)). This approach is commonly known as "risk-layering" and it allows policymakers to select the most appropriate disaster risk financing instrument available for each one of the risk segments as represented in the loss exceedance curve.
- Estimate the costs and benefits of each component of the strategy and the strategy as a whole.
- Use the information included in this report to support the development of an insurance program for coverage (either mandatory or optional) of damages caused by earthquakes, flood and landslides to private assets

Governments can set up dedicated financial instruments (contracts that allow Governments to transfer a predefined portion of the risk to a third party, e.g., a multilateral or private bank or an insurance company) based on the Loss Exceedance Curves, such as:

- Contingent Debt, such as those potentially offered by the World Bank, as a mechanism to provide loans contingent to the occurrence of earthquakes and floods;
- Insurance, as a contract offered to a Sovereign Government and reinsured in the reinsurance markets;
- Reserve Fund for self-insurance.

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1 Background Information

Central Asia is subject to frequent natural disasters including earthquakes, floods and landslides. Furthermore, climate change and a growing population and urbanization have contributed to an increase in the frequency and severity of losses caused by natural disasters in the last two decades (Pollner et al., 2010; Reyer et al., 2017; Yu et al., 2019). Natural disasters can affect different countries at the same time, for example, the seismic events in the Ferghana Valley (Namangan oblast of Uzbekistan) affect the territory of Uzbekistan, Kyrgyzstan and Tajikistan (Bindi et al., 2014). The transboundary nature of natural disasters in Central Asia requires a shared approach at regional level to support, plan and coordinate Disaster Risk Management (DRM) and Disaster Risk Financing and Insurance (DRFI) strategies. Currently, the availability of risk information for DRM and DRFI activities remains variable across the region and has largely been generated in previous projects with the focus on a single country, rather than with regional consistency in mind. Moreover, few of the studies carried out have quantified disaster risk for different perils in a harmonized way, and, to the authors' knowledge, none have done so for the whole region using probabilistic methods applied with the sufficient fidelity required to robustly inform the development of DRFI solutions. Each country can benefit by a regional approach. The latter provides common analytics and metrics, training and sharing of knowledge and technology, and co-development of solutions for national and regional/transboundary risks. The goal of the project is to improve financial resilience and risk-informed investment planning towards natural disaster and climate resilience in Central Asia.

Specifically, the project has two main objectives:

1. Conduct probabilistic risk assessment for earthquake, fluvial and pluvial flood, and landslide for the World Bank and national governments to consider engagement in the region on DRFI solutions, and to inform DRM/DRR activities. The methodology and output metrics of risk assessment is carried out consistently over the entire region. The models developed comprise the necessary model components and uncertainty quantification of a catastrophe loss model in order to inform dialogue on the development of DRM and DRFI solutions and to be used to potentially structure and operationalize them.
2. Build capacity of local experts, institutions, and research groups with a role in DRM and emergency planning on exposure mapping and development/use of disaster risk information and its components. Capacity building is carried out throughout the project with local technical experts participating in the project as partners and as members of a regional scientific and technical working group. Training on exposure mapping are important components of this capacity building.

The project is organized in tasks listed herein in Table 1. Technical reports for every task have been delivered throughout the project and are summarized in the following sections.

Table 1. Project's tasks list

TASK #	TASK NAME	
T1	Inception report	
	T1.1	Inception report preparation
T2	Earthquake hazard assessment (World Bank, 2022a)	
	T2.1	Data collection
	T2.2	Modelling
	T2.3	Validation and model output
T3	Fluvial and pluvial flood hazard assessment (World Bank, 2022b)	
	T3.1	Modelling
	T3.2	Data Collection
	T3.3	Validation and model output
T4	Development of an exposure dataset (World Bank, 2022c)	
	T4.1	Methodology
	T4.2	Validation
	T4.3	Modelling output
T5	Development and validation of physical vulnerability or fragility relationships and casualty relationships (World Bank, 2022d, 2022e)	
	T5.1	Methodology - flood
	T5.2	Methodology – earthquake
	T5.3	Validation
	T5.4	Modelling output
T6	Earthquake and flood risk assessment to support Disaster Risk Management and Financing activities (World Bank, 2022f)	
	T6.1	Methodology
	T6.2	Validation
	T6.3	Modelling output
T7	Landslide scenario assessment (World Bank, 2022g)	
	T7.1	Methodology
	T7.2	Validation
	T7.3	Modelling output
T8	Capacity Building and Knowledge Transfer (World Bank, 2022h)	
	T8.1	Planning of the capacity building activities
	T8.2	Participation to project inception workshop (W1)
	T8.3	Interim workshop on hazard modelling (TW2)
	T8.4	Interim workshops on exposure mapping (TW3 ÷ TW7)
	T8.5	Interim workshop on vulnerability analysis (TW8)
	T8.6	Interim workshop on risk modelling (TW9)
	T8.7	Participation to final project workshop (W10)
T9	Final reporting	
	T9.1	Final reporting (this report and Country Summaries; World Bank, 2022i)

The project started on October 31st, 2020 and will be completed by November 30, 2022 with the delivery of the final version of the reports of Task 9.

2 Technical Report

2.1 Task 2 - Earthquake Hazard Assessment

2.1.1 Objective

Central Asia countries are subject to high level of seismicity and several damaging earthquakes have occurred in recent and historical times. In this study (World Bank, 2022a), we describe some results of a novel probabilistic seismic hazard model for Central Asia, developed with the contribution and resources of local scientists, involved in the initiative promoted by the World Bank. The seismic hazard of five Central Asian countries (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan) is assessed using a probabilistic approach (e.g., Cornell, 1968; McGuire 2004) as formalized in Field et al. (2003).

2.1.2 Data

The methodology adopted for the construction of the earthquake source model for Central Asian countries follows a classical approach, which extensively relies on the analysis of the most recent and up to date geological and tectonic information from the scientific literature and on the available earthquake record log from global bulletins and local earthquake catalogue compilations.

First, an ad-hoc moment magnitude, Mw, harmonized earthquake catalogue was developed for the region, consisting of 77376 events and in the range $3.0<Mw<8.5$ (Figure 1). Regarding the active faults, the most significant existing compilations at regional level are the GEM Global Active Fault Database (GEM GAF-DB, Styron and Pagani, 2020) and the Active Fault Database of Eurasia (hereinafter AFEAD, Bachmanov et al., 2017), which review and summarize most of the information available from published scientific studies for the target area.

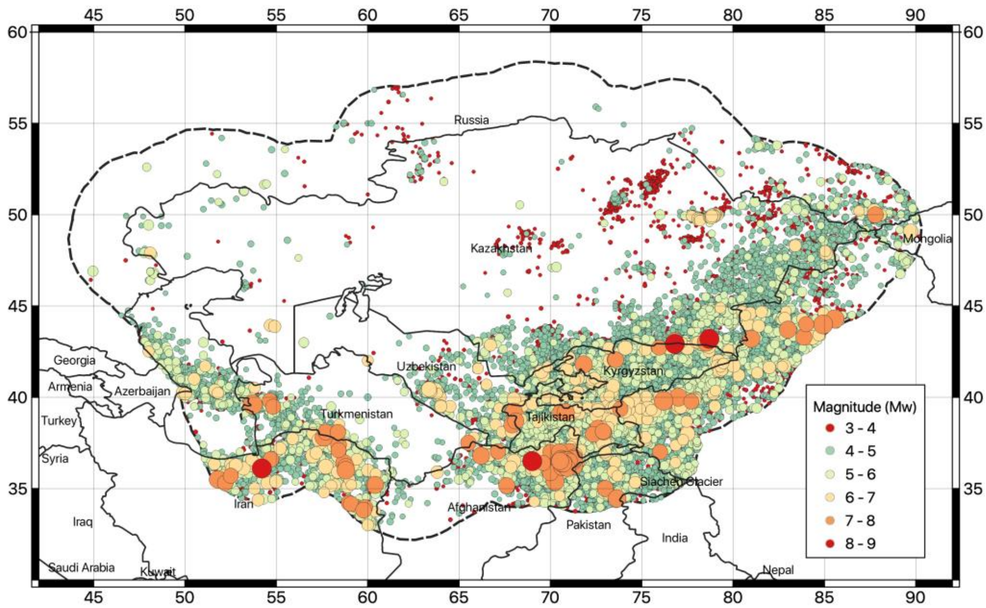


Figure 1. Geographical distribution of earthquake hypocenters (Mw>3) of the newly developed complete Mw harmonized catalogue for Central Asia

2.1.3 Methodology

The developed seismic source model consists of a combination of distributed seismicity (homogenous area sources and gridded smoothed rates) and finite faults, the former calibrated on occurrence analysis of a regionally harmonized earthquake catalogue, homogenized in Mw scale, while the latter was derived from a thorough evaluation of direct geological information from active fault databases and the scientific literature. The advantage of such a hybrid source model is a more realistic representation of the spatial pattern of seismicity, which is hardly replicable just using standard (homogenous) source zones.

2.1.3.1 Distributed seismicity source model

The implementation of the homogenous area source model was primarily done on the base of the aforementioned ad-hoc developed Mw harmonized earthquake catalogue for the region, accounting also for all existing information from the scientific literature and past studies available for the target region, including geological and seismotectonic interpretations (description of fault systems and their relation to the local stress and deformation regimes), existing seismicity analyses and previous earthquake hazard assessments from past regional projects (e.g., GSHAP, Giardini et al., 1999, and EMCA) and published studies (e.g., Abdullabekov et al., 2012; Ischuk et al., 2018; Silacheva et al., 2018). We then applied a variant of the smoothing procedure implemented by Poggi et al. (2020), which has the advantage of preserving the overall rate balance of each discrete zone (Figure 2).

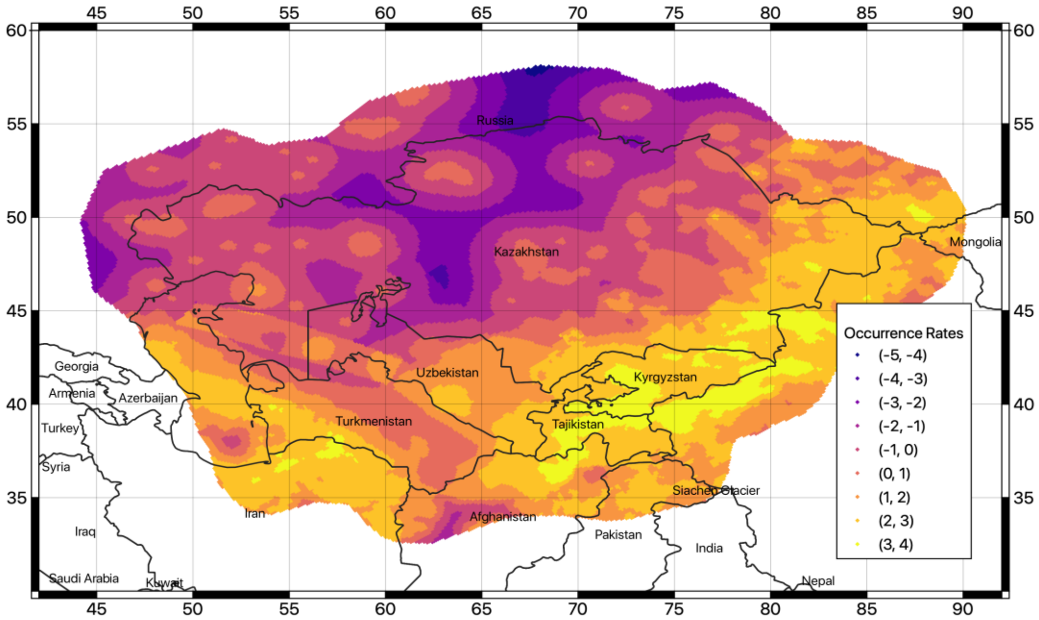


Figure 2. Spatially distributed occurrence rates using the smoothing approach to the shallow-depth source layer. Units are expressed as the base 10 logarithm of the annual occurrence rate (per grid cell) of events larger than zero.

2.1.3.2 Finite fault source model

Starting from a regional dataset of potentially active faults, which incorporates information from geological studies, scientific literature and local databases, the fault source model is then built assuming an occurrence model and appropriate seismicity parameters (e.g., scaling relations, aseismic coefficient and seismogenic depths) using an ad-hoc Python tool developed within the Model Building Toolkit of the Global Earthquake Model foundation (GEM).

The fault source model presently contains 1444 selected individual fault segments (Figure 3), covering the most part of the active shallow crust presently interested by active seismicity. It must be noted, however, that the model is under continuous development, and it will be progressively integrated with any local information made progressively available, which is essential to fill existing data gaps and to solve geological interpretation issues currently under scientific debate.

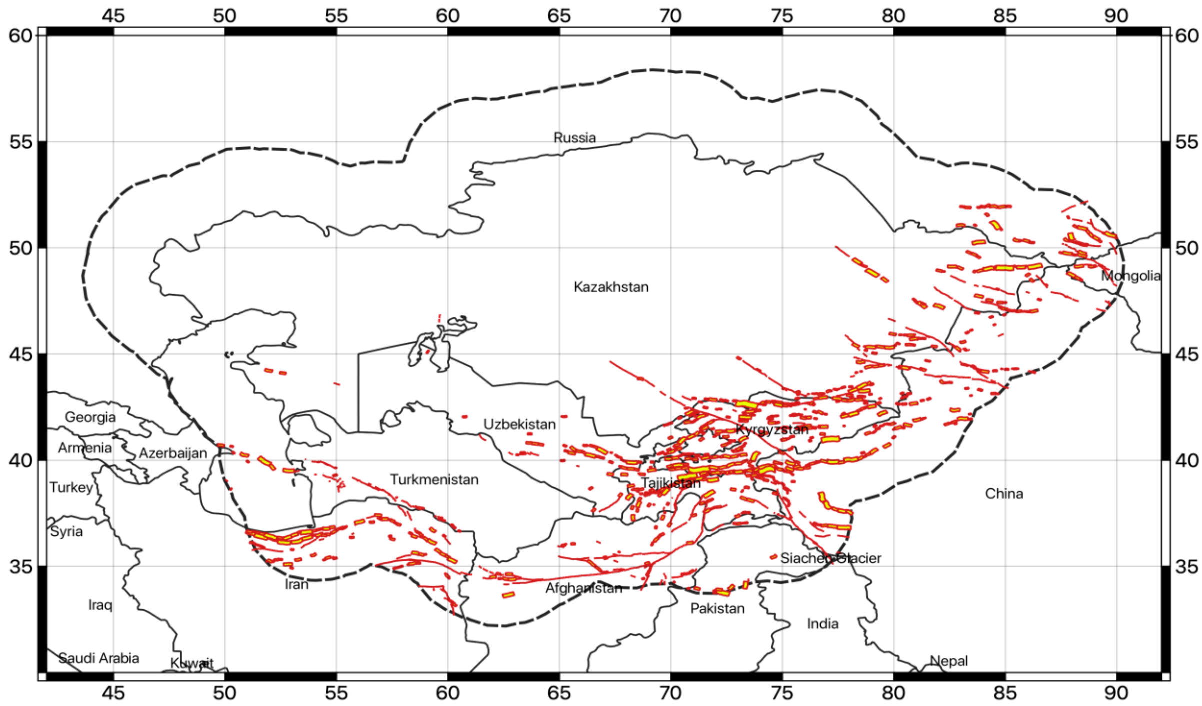


Figure 3. 3D geometry of the faults in the final source model. Surface traces are shown in red, while the surface projection of the fault plane is in yellow.

2.1.3.3 Ground motion model

Following the indirect selection criteria recommended by Cotton et al. (2006) and the studies recommended by the local experts of the consortium, we identified five most representative ground motion prediction equations (GMPEs) for the study region (Table 2). Ground motion models are defined for standard active shallow crust (AS), stable crust (SC) and deep seismicity (DS) tectonic environments.

Table 2. Selected ground motion prediction models grouped by tectonic region applicability.

Tectonic Id	Ground Motion Prediction Model	Weight
AS	Campbell and Bozorgnia (2014)	0.5
	Chiou and Youngs (2014)	0.5
SC	Pezeshk et al. (2011)	0.5
	Atkinson and Boore (2006) – Modified 2011	0.5
DS	Parker et al. (2022) – for subduction interface	1

2.1.3.4 *Logic tree*

To account for epistemic uncertainty of key model parameters, a logic-tree approach was used (Figure 4). From the technical point of view, the implemented logic-tree is split between the two main components of the model: source characterization and ground motion modeling. Each component includes different branching levels, representing either an independent uncertainty type (as for the case of b-value and Mmax) or the permutation of alternate models applied in different regions (as for the case of GMPE regionalization).

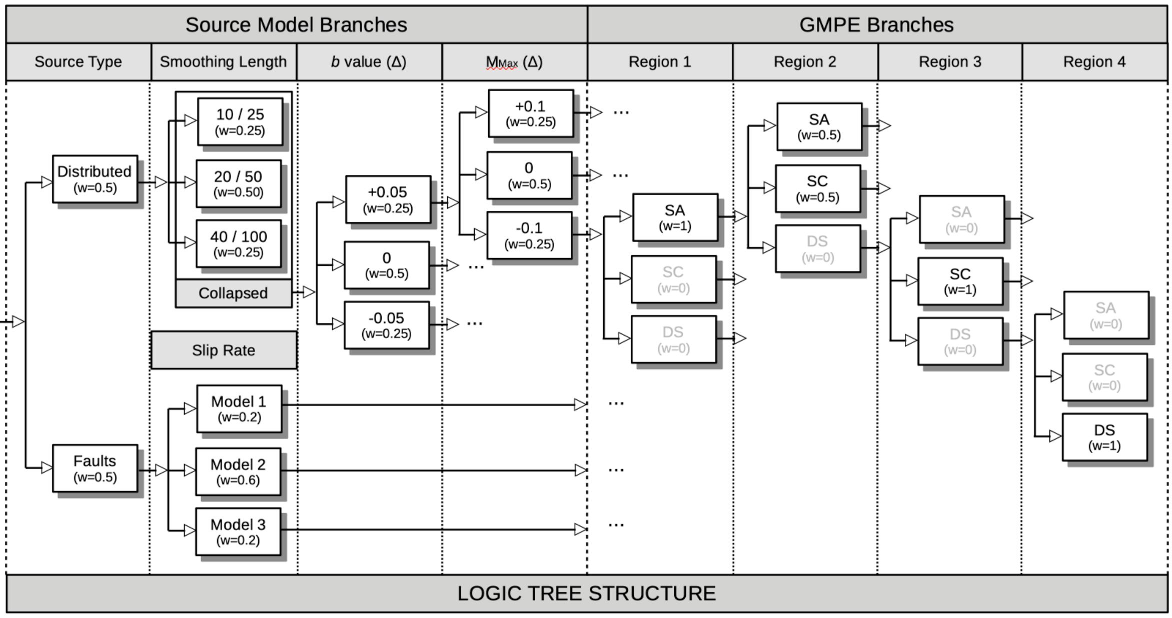


Figure 4. Diagram representation of the logic-tree structure of the Central Asia hazard model, which includes 4 branching levels to account for both the source model and ground motion model uncertainties.

2.1.4 Results

Ground motion probability of exceedance (PoEs) for a given observation time are computed for PGA and for 5%-damped response spectral acceleration at 0.1s, 0.2s, 0.5s, 1s, 2s and 3s (vibration periods allowed by the selected ground motion models). Output of the calculation are a) mean and quantile (0.05, 0.15, 0.5, 0.85 and 0.95) hazard curves for each Intensity Measure Type (IMT) and site, b) Uniform Hazard Spectra (UHS) and c) hazard maps computed for return periods of 25, 50, 100, 250, 475, 500 and 1000 years, corresponding to 86, 63, 39, 18, 10, 9 and 5% probability of exceedance in 50 years, respectively. All calculations for this study were performed using Version 3.11 of the OpenQuake engine, which can be accessed at https://github.com/gem/oq-engine/tree/engine-3.11 (last access 16/08/2021).

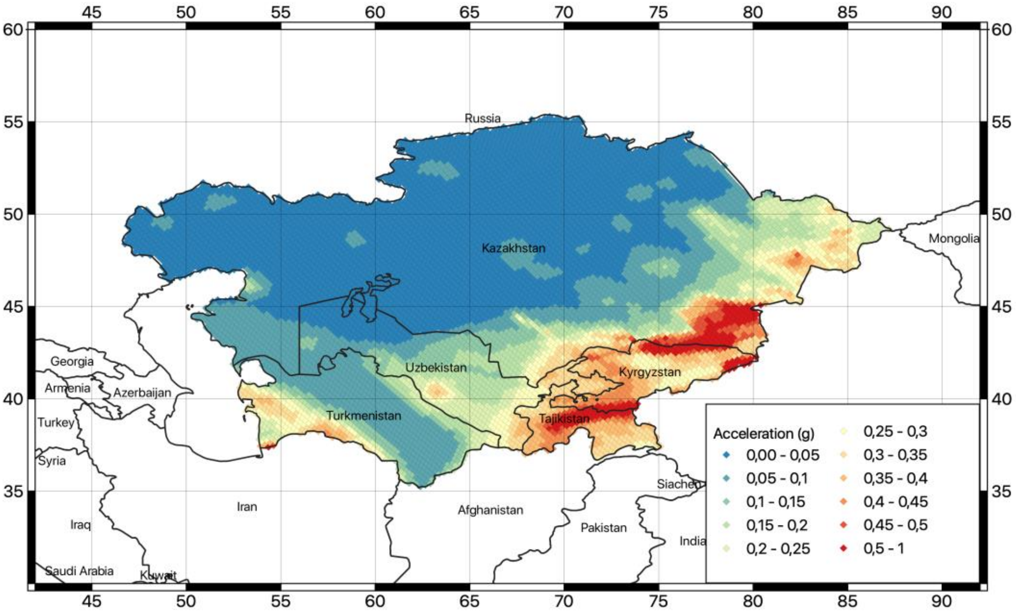


Figure 5. Map of the computed peak ground accelerations (PGA) with 5% probability of exceedance in 50 years (corresponding to about 1000 years return period) for rock conditions (Vs30 of 800m/s).

The current model provides a comprehensive view of the seismic hazard in the Central Asian countries by leveraging data not available in previous studies. Although the current model does not cover - yet - a level of detail usually required to develop national hazard models, such as those utilized for underpinning national building codes, it provides nonetheless the essential information needed for such an application. Extending the present model to national level and for city scenario clearly represents a natural follow-up, as soon as new local information (e.g., studies on nearby faults and site response analyses, weak, and strong ground motion recordings) are available. Nevertheless, the findings of this study can be used, albeit with caution, to estimate seismic hazard and to stimulate awareness of seismic hazard in local governmental institutions.

2.2 Task 3 - Fluvial and pluvial flood hazard assessment

2.2.1 Objective

Central Asia is highly exposed and vulnerable to a broad range of natural hazards which frequently result in economic and human losses. Flood hazard is significant in the region, with floods being the most frequent natural disaster in the period 1988-2007 according to a recent analysis provided by the Central Asia and Caucasus Disaster Risk Management Initiative (CAC DRMI, 2009). Despite the aridity of large areas in some of the target countries, natural phenomena linked to extreme precipitation can cause significant damage every year: collectively, floods inflict the second highest overall economic losses ($52 million).

A robust estimation of possible loss due to flood is necessary for developing and implementing successful regional DRM strategies as advocated for by the past World Conferences for Disaster Risk Reduction (DRR) (UNDRR, 2019). In order to support the development of regional disaster risk financing and insurance (DRFI) solutions, and to inform DRM/DRR activities in the region, in this study (World Bank, 2022b) we assess fluvial and pluvial flood hazard to be used as input to characterize flood risk in Central Asia. We adopted a hybrid stochastic and physically based approach, which takes into account the scale of the phenomenon, the data available (both input data and calibration/validation data) and potential future modification to the hazard triggered by climate change.

For the purpose of this study, we distinguish two common types of floods: fluvial flood, which occurs when excessive rainfall over an extended period of time causes a river to exceed its capacity, and pluvial flood, which occurs when heavy rainfall creates a flood event unrelated to an overflowing water body.

2.2.2 Data

Both the hydrological and the hydraulic model require daily or sub-daily hydrometeorological data as well as spatially distributed information such as soil characteristics, land use, elevation, and the presence of hydraulic structures and reservoirs. With the aim of obtaining a homogeneous and regionally consistent hazard assessment, we integrated the ground local data, available from historical observations and previous national and regional studies, with spatially distributed global datasets.

2.2.2.1 Local Data

Table 3 shows a complete inventory of the data requested/obtained from the local partners.

Table 3. Local data inventory

Country	Daily Discharge	Annual maximum discharge	Hydraulic Protection	Reservoirs
Kazakhstan	7 stations (records of variable lengths between 2001 and 2015)	120 stations (records of variable lengths between 1910 and 2018)	Location and length of some riverbanks hydraulic structures on the Sir Darya River	Volume and year of construction of main reservoirs
Kyrgyz Republic	No data obtained because cost was too high compared to the benefit	65 stations (records of variable length between 1930 and 2018). Some of these data were purchased from KyrgyzHydroMet	Record of hydraulic protection works from 2018 at the Oblast level	Data on reservoirs' volume and construction year for 5 main reservoirs
Tajikistan	No data obtained because cost was too high compared to the benefit	14 stations (variable lengths), purchased from TajykHydroMet	No data	Volume and construction year for 13 reservoirs
Uzbekistan	2 stations (2015-2019)	46 stations (2005-2019)	No data	Volume and year of construction of main reservoirs
Turkmenistan	6 stations (2015-2020)	11 stations, variable record between 1936-2020 (monthly maxima available)	No data	Volume and year of construction of main reservoirs

2.2.2.2 Global Data

Table 4 summarizes the global datasets that were used to integrate and/or replace missing consistent local information.

Table 4. Global data

Data Type	Source	Use within the project
Digital Elevation Model	MERIT DEM MERIT Hydro (Yamazaki et al., 2019)	Input to TOPKAPI, CA2D. Input to derive additional data products
Soil Type	FAO Harmonized World Soil Database (Nachtergaele et al., 2012)	TOPKAPI parametrization
Land Use	GlobeLand30 (UN-ESCAP Statistics Division; UN_ESCAP ICT and Disaster Risk and Reduction Division, 2015)	TOPKAPI and CA2D parametrization.
Observed Discharge records	Global Runoff Data Centre (GRDC)	TOPKAPI calibration and extreme values distributions
Precipitation	ERA5-Land: 1981-2020 (Muñoz-Sabater et al., 2021) KNMI Climate Explorer (Trouet and Van Oldenborgh, 2013)	Input to TOPKAPI and CA2D pluvial simulations
Temperature	ERA5-Land: 1981-2020	Input to TOPKAPI
Reservoirs and Dams	Global Reservoir and Dam Database (GRanD) (The Global Water System Project, 2011)	Extreme Values Analysis and Regionalization
Hydraulic defenses	FLOPROS database (Scussolini et al., 2016) WorldPOP HBASE (Tatem, 2017; Wang et al., 2017)	Defended hazard maps

2.2.3 Methodology

In this study, the flood hazard of five Central Asian countries (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan) is assessed by means of a physically based numerical modelling toolset and a stochastic catalogue of flood footprints (Figure 6). The numerical modelling toolset is composed of two elements: the hydrological model (TOPKAPI) and the hydraulic model (CA2D). A statistical correction of extreme values and their regionalization were also performed based on the availability of a historical records of daily and annual maxima discharges.

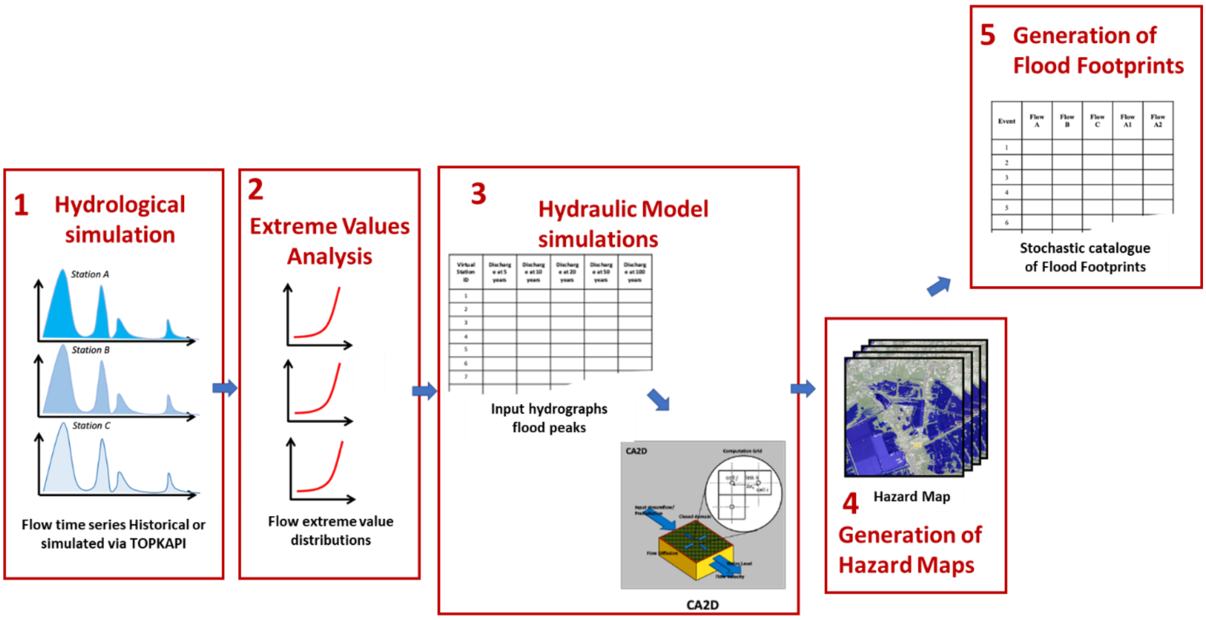


Figure 6. Fluvial flood hazard assessment: schematic representation of methodology

The TOPKAPI (TOPographic Kinematic APproximation and Integration) model is a fully-distributed physically-based hydrological model that can provide high resolution information on the hydrological state of a catchment (Ciarapica and Todini, 2002). The TOPKAPI model requires as input both precipitation and temperature meteorological data, plus a description of the soil characteristics that can be derived from the land use (to derive crop factors and surface roughness) and soil type maps (to derive soil permeability and depth).

CA2D (Dottori and Todini, 2011) is a full physically-based hydraulic model specifically designed for high-performance computing applications, based on the cellular automata (CA) approach and the diffusive wave equations, to simulate flood inundation events involving wide areas. The model is based on the state-of-the-art of large-scale hydraulic modelling and has been tested extensively on several case studies. The CA2D model has an internal preprocessor that allows the user to provide as input only the Digital Elevation Model and the surface roughness map. The network (comprising nodes and links) is automatically generated, and specific conditions (such as flood protections) can be included where present. In addition, input meteorological data must be provided in the form of hydrographs at specific points and/or of rainfall maps.

The two models are linked together as shown in Figure 6: (1) the TOPKAPI hydrological simulation results informs the (2) Extreme Value Analysis and regionalization, which produces a stochastic description of streamflow from which peak flows values are extracted (1-in-5, 10, 20, 50, 100, 200, 500, 1000, 2000 years floods) and used as input for the (3) CA2D hydraulic model, which simulates the channels routing as well as the 2D inundation processes to derive the (4) hazard maps. Finally, the hazard-consistent stochastic catalogue of flood footprints for the region is produced.

While hazard maps provide the probability and depth of inundation at a given location, they are unable to describe the likelihood of concurrent flooding across multiple sites, limiting their capability of assessing risk over the full range of plausible scenarios, including the most extreme ones which are the very thing governments must consider for risk mitigation purposes and insurers must quantify for pricing and liquidity. A flood hazard catalogue serves this purpose, by providing a stochastic ensemble of 10,000 years of all hypothetical floods, with related annual frequency of occurrence, that may occur in the region of interest. To ensure spatial coherence in the stochastic catalogue, the spatial correlation of the river flow at each gauge/station is determined by computing a cross correlation matrix on all the available (observed/simulated) flow time series.

The Extreme Value Analysis and regionalization process consists of two steps: a) a correction of the TOPKAPI simulated discharge based on the historical record of observed data, which allows for better representing the extreme values simulated during the period 1981-2020, and b) the estimation of General Extreme Value distribution for several locations along the drainage network to derive the peak flows with different return periods.

Pluvial flood hazard was estimated applying a similar methodology (Figure 7), where, to reduce the computational effort, a geomorphological technique was combined to the CA2D hydraulic simulations. First, annual maxima precipitation for different durations derived from ERA5-Land gridded data, which are available from 1981 to present, were corrected based on their comparison with the station data from the KNMI Climate Explorer dataset. This correction was necessary to take into account the unavoidable discrepancy between point data and gridded data. In fact, the latter represents the average precipitation over an area of about 100 km^2 and does not describe well the extremes that may occur in smaller sectors. The corrected ERA5-Land annual maxima precipitation was eventually used to derive Intensity-Duration-Frequency curves, from which the precipitation at different return periods was extracted to feed the CA2D hydraulic model. The CA2D model was applied to several areas and the output were used to calibrate the geomorphological technique based on the Compound Topographic Index to extend the simulation to the entire region.

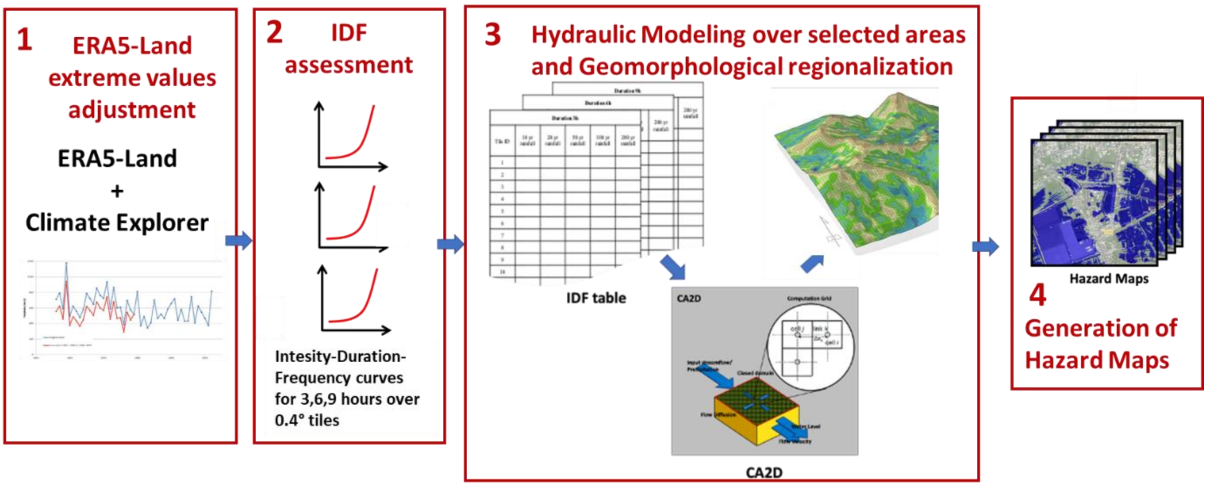


Figure 7. Pluvial flood hazard assessment: schematic representation of methodology

2.2.4 Results

The results presented for this task constitute the first attempt to date at assessing flood hazard in Central Asia at a regional scale using a uniform methodology and a homogenized dataset that includes both global and local data sources. The cooperation with local partners was productive and gave the consortium access to a set of unprecedented local datasets and information as well as technical advice. The partnership with local governmental institutions and authorities also offers the potential for integration with national models. Therefore, the main strength of this project is the combination of state-of-the-art global flood modeling techniques with an unprecedented use of local data and knowledge that allowed for a sound hazard assessment over such a wide area.

The proposed modelling approach is also potentially suitable for the implementation of Disaster Risk Financing applications based on parametric triggers (e.g., CCRIF for the Caribbean and Central America regions, ARC for the continent of Africa).

The main limitation remains the general lack of water depth observations for validating the hydraulic model output as well as specific data on hydraulic defense structures, their location, level of protection and maintenance. We understand the impossibility of sharing sensible information and believe we made the most accurate assumptions given the available data.

Despite these limitations, every step of the modelling scheme has been validated using the best data available. The meteorological input was obtained from the ERA5-Land dataset, produced by ECMWF and thoroughly validated all over the globe. The results of the hydrological model (i.e., the river flows used in 2D flood simulations) have been compared with available flow observations both in terms of reproducing certain historical events and in probabilistic terms (i.e., by comparing observed and simulated flows at certain levels of frequency). From this point of view, the validation has been very thorough, as several flow gauges exist in the area, some with very long records, at least on major rivers. Furthermore, a procedure to adjust flow hazard curves to observed levels was put in place, ensuring good fit between observations and simulated values. For this reason, flow estimates can be considered credible and reliable to the best of the knowledge in the area. The 2D flood model has been validated based on the flood footprint of one event, occurred in Tajikistan in 2005, and a good agreement was obtained between the model results and the surveyed inundated area. While a single event only provides for a limited validation, the added uncertainty stemming from the flood model is reduced compared to the errors potentially enclosed in the estimates of precipitation and flow (both validated with local observations). The residual errors have been estimated through the assessment of the uncertainty, which has allowed to produce maps of upper and lower bunds of a confidence interval. For all these reasons, the flood maps can be considered reliable and sound. Future developments in the input datasets, in the digital elevation resolution or in the availability of data can surely help reducing the uncertainty further, but this hazard assessment certainly draws a credible picture of the flood hazard in the region.

The final deliverables of this task are:

a) Fluvial and pluvial flood hazard maps for current climate over the entire Central Asia area including Kazakhstan, Kyrgyz Republic, Uzbekistan, Tajikistan, and Turkmenistan for selected return periods (5, 10, 20, 50, 100, 200, 500, 1000 years); fluvial flood hazard for current climate is assessed in both undefended and defended scenarios and a variability range is also provided for the undefended case.
b) A hazard-consistent stochastic catalogue of fluvial flood footprints, which is essential for characterizing risk and supporting DRM strategies.
c) Fluvial flood hazard maps for the same selected return periods obtained taking into account the impact of climate change for a 2080 scenario. Fluvial flood hazard for current climate is assessed in both undefended and defended scenarios and a variability range is also provided for the undefended case.

d) Hazard curves at five selected locations.
e) Flood footprint for one historical scenario used to validate the CA2D hydraulic model.
f) Flood footprint for three realistic scenarios across the region representing potential flood events with 100-year return period that may occur in populated and flood-prone areas.

2.3 Task 4 - Exposure Data Development

2.3.1 Objective

Exposure assessment has a paramount role in disaster risk reduction because it allows to assess the number and type of assets which can potentially be damaged or disrupted. In addition, it provides a financial indicator on the exposed assets value, which can support regional disaster risk reduction and financial risk mitigation activities. However, when this project started, a regionally consistent exposure database was not available, despite past research had produced a similar example for residential buildings only (Pittore et al., 2020).

In this study (World Bank, 2022c), we assembled the first regionally consistent exposure database that comprises multiple assets, including population, buildings of different types (e.g., residential, commercial, industrial), transportation and supply network and croplands.

In order to map and classify each exposed asset, we collected the available information which was fragmented across different datasets at different spatial scales (regional, national, local). We combined existing information with the aim of grasping the specific characteristics of each country (e.g., country-based reconstruction costs). A strong harmonization effort was performed in order to combine all collected exposure data and support regionally consistent risk assessment activities.

2.3.2 Data

The exposure development relies on two main data types: regional scale datasets (usually available online, but at lower spatial and temporal resolution) and national/local data (gathered by local partners). Existing datasets were identified following the suggestions of the Regional Scientific-Technical Council (RSTC) and the World Bank specialists. In addition, all local partners devoted a strong effort to gather reliable and up-to-date country-based exposure data.

Table 5 shows the main global and regional existing datasets used for the exposure development. These data were used as a starting point to develop the regional layers and were enriched and enhanced using the country-based on local-scale data.

Table 5. Main global and regional exposure data collected during the project

Data Type	Source
Population grid	Facebook (https://data.humdata.org/organization/facebook))
Residential buildings	Pittore et al., 2020
School buildings	Unicef, https://projectconnect.unicef.org/map/countries
Healthcare facilities	Healthcare facilities database (https://www.healthsites.io/)
Croplands	Crop dominance layer (Teluguntla P. G. and Yadav, 2015); Global land cover fraction (https://lcviewer.vito.be/download)
Transportation and airports	OpenStreetMap database (https://www.openstreetmap.org) International airport database (World Bank) Global airport database (http://www.partow.net/miscellaneous/airportdatabase/index.html)
Power supply infrastructure	Global power plant database (Byers et al., 2021) Global power grid (World Bank)
Dams	Grand global dams database (Lehner et al., 2011, last updated 2019) Aquastat database (Aquastat, 2013)

Table 6 shows the main country-based data collected during the project. These data were collected with the support of local partners and used to update, enrich and increase the reliability of regional-scale data.

Table 6. Main country-based exposure data collected during the project

Data Type	Source
Population	Population, age and gender statistics at oblast scale obtained from the last available census.
Residential buildings	Number of buildings and/or households in each oblast and/or main cities. Statistics on buildings material were available in some countries. Description of different building typologies provided by local partners.
School buildings	Number of schools in each *oblast* and/or main city.
Healthcare facilities	Number of hospitals in each *oblast* and/or main city.

Croplands	Wheat, cotton and total cereals area in each Oblast; Yield and production in each Oblast.
Transportation	Country-based road and railway maps. Information on main road, railway and bridge types.
Reconstruction costs	Country-based reconstruction costs provided for most assets including residential buildings, schools, hospitals and transportation assets.

In addition to existing datasets, several other data sources were used, such as national and regional labor statistics and economic indicators. A full list of data collected during the project is available in the Exposure development report.

2.3.3 Methodology

The exposure assessment developed in this project is based on the combination the regional-scale information with country-based data. Global and regional-scale database have a large coverage, but often with a lower spatial resolution. National data, in turn, are usually collected by national institutions with higher spatial resolution and therefore have a higher reliability. Country-based data are therefore paramount in order to enhance the regional-scale datasets including the specific characteristics of exposed assets in each country. In addition, remote sensing data can increase the resolution and allow inspecting specific exposed assets and inferring their characteristics.

Population

In particular, for the population, we updated the Facebook high-resolution dataset using the country-based demographic information. This was performed using recent data (relative to 2019 or 2020) for main cities and, when possible, *oblasts*. The final dataset was produced at a resolution of 100m.

Residential buildings

As for residential buildings, we refined the exposure maps provided by Pittore et al. (2020) using country-based data. The database by Pittore et al. (2020) has a variable resolution ranging from a few hundred meters in urban areas to several km in rural areas. It was developed specifically for earthquake risk assessment purposes, for which the spatial resolution was appropriate, but its resolution is insufficient to perform risk assessment for fluvial and pluvial hazard. During this project, we increased the layer spatial resolution in order to produce a residential buildings exposure layer on a 500-m-resolution grid. First, the country-based information on buildings typologies fractions in each *oblast* (collected during the initial phase of the project) was used to update the existing variable-resolution exposure layer (Figure 8, blue arrow). Then, the updated number of residential buildings in each polygon was distributed on an equally-spaced 500m-grid based on the population layer developed for Central Asia during the assignment (Figure 8, black arrow). The different distributions of building types in urban and rural areas were taken into account (Wieland et al., 2015).

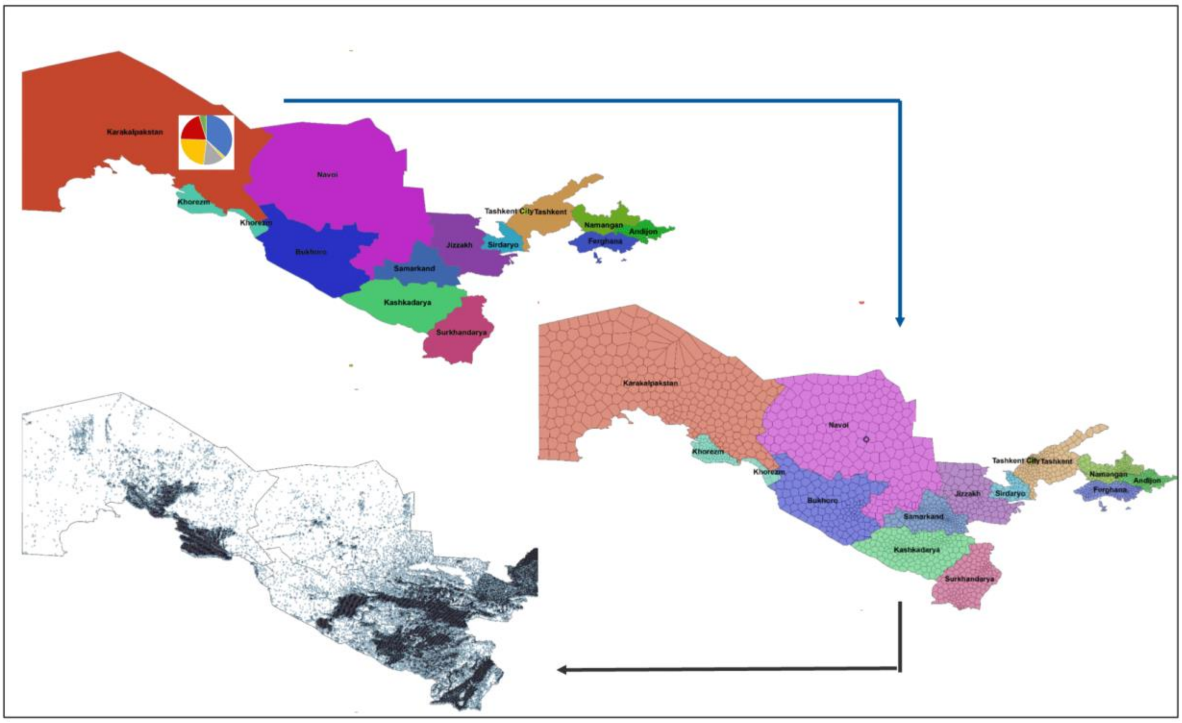


Figure 8. Schematic view of the procedure adopted to update the existing residential buildings layer with country-based exposure information and increase its spatial resolution to a 500-m equally spaced grid. The illustrative example shows the exposure development main steps for Eastern Uzbekistan.

Non-residential buildings

Non-residential buildings exposure maps were assembled based on existing spatial datasets and statistics (e.g., from the UNICEF database for schools). However, for some exposed asset types such as industrial and commercial buildings, there were no digital maps or spatial information to be used as a starting point. Also, in some cases, the available data was aggregated at national or sub-national spatial scale (e.g., number of school buildings per oblast). The spatial distribution of assets was then inferred using proxies (e.g., population density, employees per economic sector). In other cases, exposure layers were assembled based on non-digital maps (e.g., supply infrastructure).

Croplands

Agriculture is very relevant for the economy of most Central Asian countries. In particular, the primary sector (agriculture, forestry and fishing) accounts for the 26 and 24% of Uzbekistan and Tajikistan's GDP, respectively (World Bank, 2020). For croplands, we started from the spatial distribution of crop classes (Teluguntla et al. 2015) and the land cover cropland fraction. The former, available at 1-Km resolution, allows to identify the areas where crops are present, and the second, which has a higher resolution (100m), allows discarding cells with low fraction of cropland coverage. Having identified the areas where cotton and wheat crops are present, the country-based information was distributed spatially. Note that country-based values of yield and price were used.

The exposure assessment requires to define specific typologies for each exposed asset type. For each exposed asset type, we defined typologies (codified by taxonomies) to classify the assets according to their main characteristics following the Ged4ALL taxonomy system (http://riskdatalibrary.org/resources). In case pre-defined typologies were available, such as the residential building typologies defied in Pittore et al. (2020), we updated them with the information collected by local partners. Reconstruction costs were also updated based on country-based values. In other cases, such as non-residential buildings or transportation infrastructure, no prior official information on reconstruction costs was available. We defined the costs based on country-based information provided by local partners and compared them with existing datasets for other geographic areas.

Performing a regionally-consistent exposure development requires the harmonization of the exposed assets characteristics, which might vary across the study area. During the exposure assessment, common typologies (e.g., it uses the same residential building typologies across the region) were defined, also based on previous projects. However, relevant differences were maintained, for example using country-based buildings reconstruction costs and cropland yield.

Validation was performed using two types of data: local-scale data provided for specific study areas and satellite imagery and aerial images. The potential of remote sensing tools was discussed during the whole exposure development process and in particular during country-based workshops. This was demonstrated with respect to buildings, infrastructure and croplands providing specific examples during lectures and tutorials.

Exposure layers were also developed for the year 2080 based on the combination of three Shared Socio-Economic Pathways (SSPs) defined for Central Asia (Pedde et al., 2019). The three selected scenarios envisaged socio-economic development based, respectively, on three main drivers: sustainability (SSP1), unequal investments and economic disparities (SSP4) and exploitation of fossil fuels together with increased energy consumption (SSP5). The outcomes of the exposure projections showed that, despite a general population decrease, a strong urbanization and economic growth is expected in Central Asia.

Specific details on the exposure assessment performed for each asset type can be found in the Exposure development report (deliverable D4a of this project).

2.3.4 Results

The adopted approach combines the most recent datasets and technologies, which allowed the development of high-resolution regional scale datasets that comprise local-scale official data (e.g., population census). Results of the exposure development process are digital maps for Central Asia that contain the exposed assets classified according to the metrics defined in the exposure assessment.

The final deliverables of this task are:

a) Exposure development report with complete description of the data used, the methodology adopted for exposure assessment and the results obtained. For each exposed asset type, aggregated exposure data are provided by country and, in some cases, by *oblast*. The report describes the validation process and discusses the reliability of the results in relation to data gaps. It also includes a description of the capacity building activities carried out during the assignment.

b) Exposure spatial layers for the different exposed assets:

- Population
- Residential buildings
- Non-residential buildings (commercial, industrial, healthcare, education)
- Croplands (wheat and cotton)
- Transportation system (roads, railways, bridges)
- Airports and airstrips
- Primary commodities and extraction sites
- Supply infrastructure (oil, gas, water)
- 2080 spatial layers of projected residential buildings exposure under the three selected scenarios

Spatial layers are provided in form of *shapefiles* and *csv*, and have associated descriptive metadata to ensure interoperability.

Figure 9 shows an example of the exposure maps produced at regional scale for cotton and wheat croplands at a 500-m resolution.

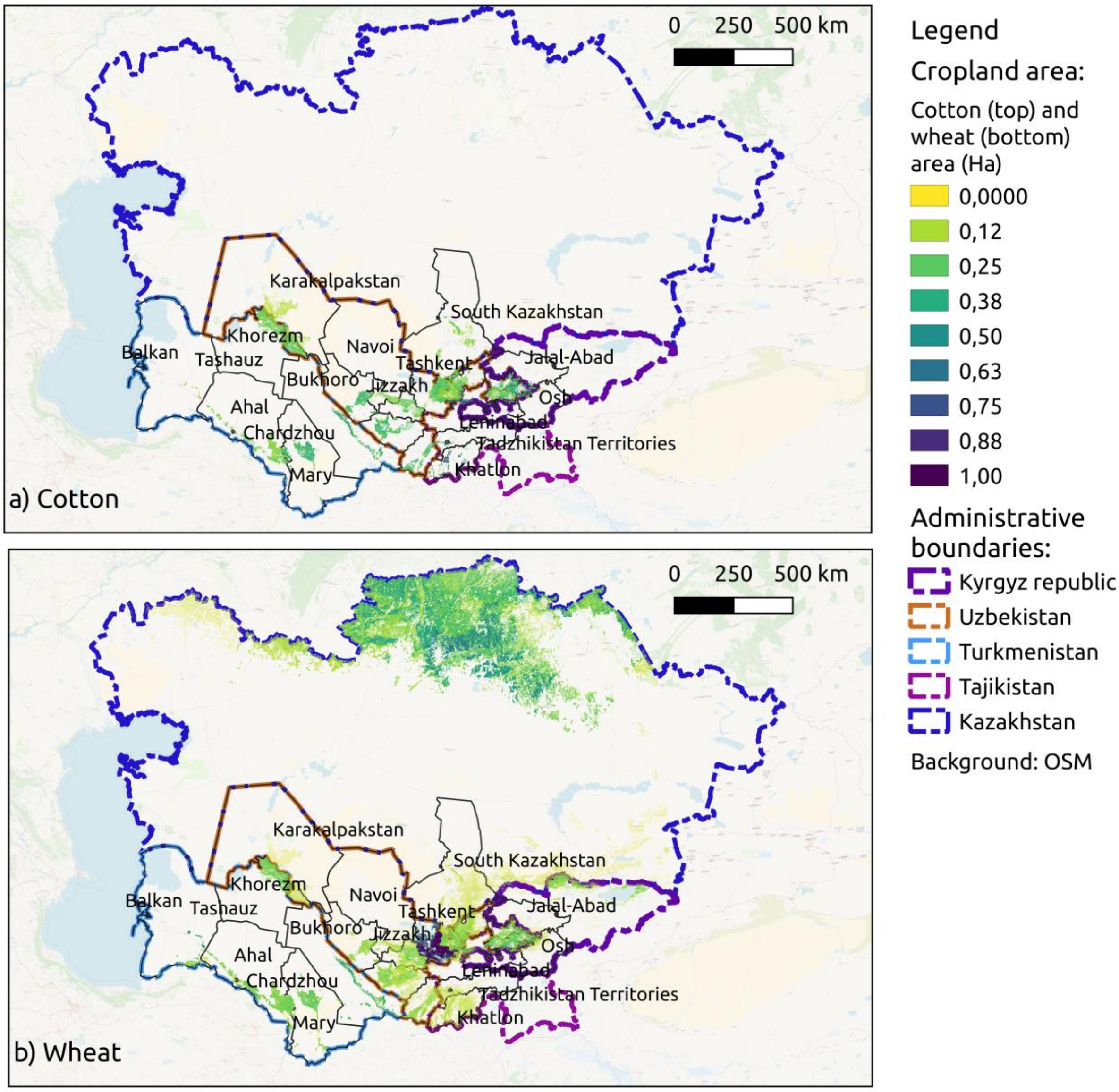


Figure 9. Exposure maps produced for wheat (top) and cotton (bottom) croplands.

Figure 10 shows a detail of the exposure maps produced at regional scale for residential buildings. The map shows the spatial distribution of one building type (Unreinforced masonry) in Central Asia at a 500-m resolution.

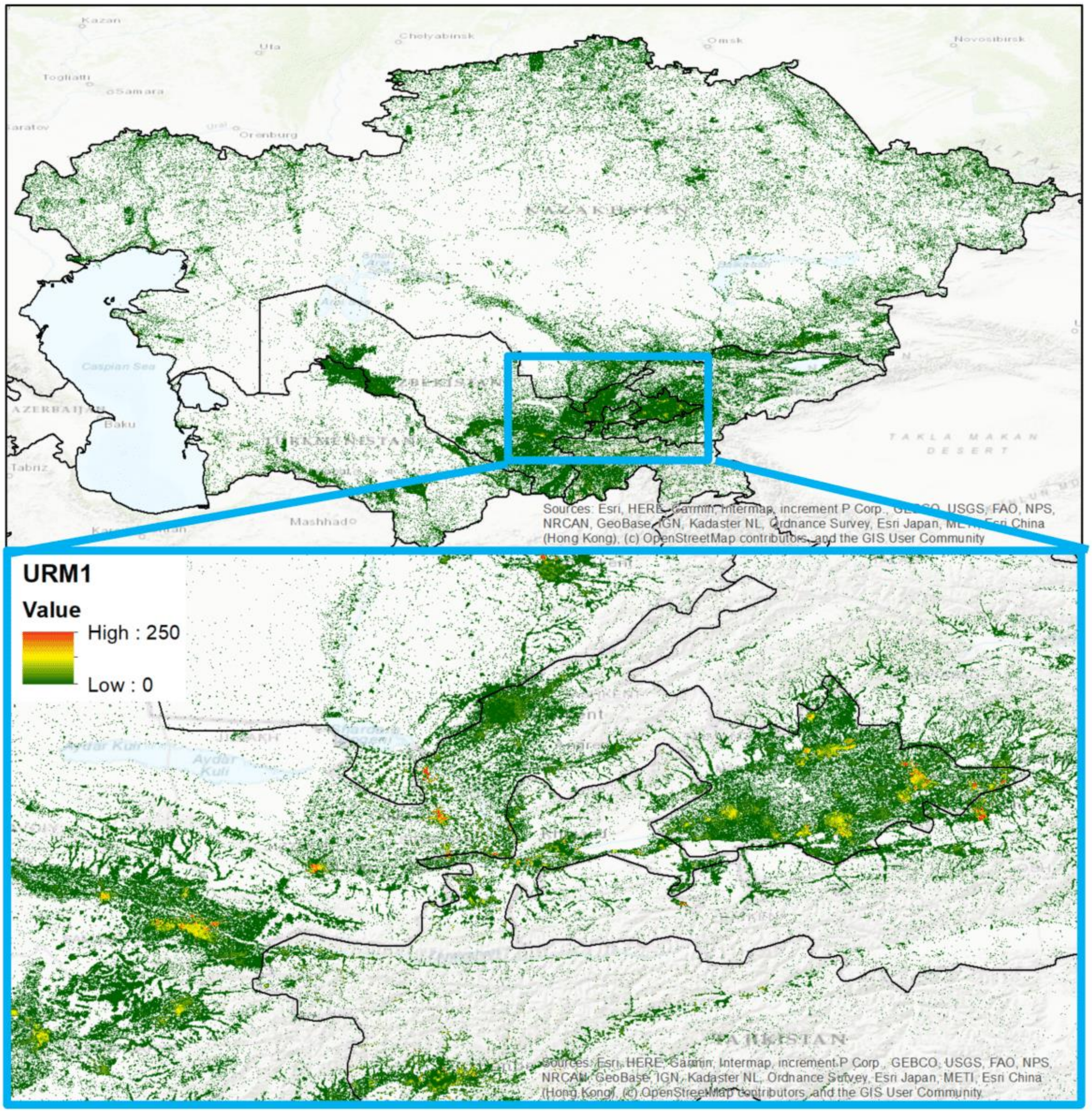


Figure 10. Exposure maps produced for residential buildings. The map shows the number of buildings in each 500-m cell belonging to one typology (unreinforced masonry, URM1) in the entire Central Asian region (top) and on a selected area (bottom).

2.4 Task 5 - Validation and Development of Physical Vulnerability or Fragility Relationships and Casualty Relationships – Earthquake Vulnerability

2.4.1 Objective

This task focused on deriving a regional vulnerability model to be used for the seismic risk assessment of residential and non-residential assets and infrastructure in Central Asia. To complete this task, we first carried out a comprehensive review of the existing literature regarding the fragility and vulnerability functions that can be adopted for this region. This included both international and local studies. The data collection activity showed large heterogeneities in the data, including the diversity of the definition of the damage states in different studies, the use of different intensity measures faced for the derivation of a harmonized regional model. So, a harmonization of all the collected international and local data and references was needed. After the harmonization of all the vulnerability functions (i.e., by using the same intensity measure and, to the extent possible, the same damage state definitions), we defined a method to combine them in order to obtain a vulnerability function distribution specific for all the predefined structural classes (as per the taxonomy defined in Task 4). In the following subsections, we briefly describe the data, the methodology and some of the selected results of this task (World Bank, 2022d).

2.4.2 Data

To define the vulnerability curves that represent the seismic performance of each class, several important databases of the fragility and vulnerability functions were considered. These include:

- A World Bank project (World Bank, 2016) conduced for Kyrgyz Republic (here after called SRKR16).
- A large database of fragility and vulnerability curves including 511 different building classes recently generated within the framework of SERA project (2019).
- Local studies provided by the local partners.
- Vulnerability functions from GLOSI (Global Library of School Infrastructure, 2014).
- Other existing literature.
- HAZUS (FEMA, 2003) (only for infrastructures).

2.4.3 Methodology

2.4.3.1 Residential buildings

To derive the final regional vulnerability curves for each residential building class of the taxonomy (defined in Task 4), the vulnerability functions retrieved from the available studies are mapped to each single class. Table 7 lists the studies that correspond to the 15 residential building classes. The functions from the different references were harmonized to the same intensity measure, peak ground acceleration, and when fragility curves were reported, the functions were combined with an appropriate consequence function (e.g., Kappos et al., 2006), compatible with the damage scale assumed in the original reference. The harmonization allowed to make a direct comparison of the information provided in the different references considered.

Table 7. List of studies used for definition of vulnerability curves for the residential buildings

NO.	EMCA MACRO-TYPOLOGY	EMCA SUB-CLASS	RELEVANT STUDIES
1	EMCA1	URM1	▪ SRKR16-1.1 ▪ SERA: (MUR)-(H2-H4)-(DNO) ▪ Literature: Ahmad et al. (2011) and Karantoni et al. (2011) ▪ Local: TKM, KGZ, UZB ▪ GLOSI: UCM-URM7_MR_LD
2		URM2	▪ SRKR16-1.2 ▪ SERA: (MUR)-(H1-H2)-(DNO) ▪ Literature: Karantoni et al. (2011) ▪ GLOSI: UCM-URM1_LR_LD
3		CM	▪ SRKR16-1.3 ▪ SERA: (MCF)-(CB)-(DUL) ▪ Literature: Kostov et al. (2004) ▪ Local: TKM, KGZ
4		RM-L	▪ SRKR16-1.4 ▪ Literature: Kostov et al. (2004) ▪ SERA: (MR)-(H1) ▪ Local: TKM, UZB
5		RM-M	▪ SRKR16-1.4 ▪ SERA: (MR)-(H2-H3) ▪ Local: UZB
6	EMCA2	RC1	▪ SRKR16-2.1 ▪ SERA: (CR)-(LFM)-(H3-H7)-(DUL) ▪ Local: KGZ
7		RC2	▪ SRKR16-2.2 ▪ SERA: (CR)-(LDUAL)-(H4-H9)-(DUL) ▪ Local: KGZ
8		RC3	▪ SRKR16-2.3 ▪ SERA: (CR)-(LFINF)-(H2-H5)-(DUL) ▪ Local: TKM, UZB
9		RC4	▪ SRKR16-16: SRKR16-2.4 ▪ SERA: (CR)-(LWAL)-(H4-H11)-(DUL)
10	EMCA3	RCPC1	▪ SRKR16-, SRKR-3.4 ▪ Local: TKM, KGZ, UZB
11		RCPC2	▪ SRKR16-3.1, SRKR-3.2 ▪ Local: TKM, KGZ, UZB
12	EMCA4	ADO	▪ SRKR16-4.1 ▪ SERA: (MUR)-(ADO) ▪ GLOSI: LBM_A_LR_LD ▪ Local: TKM, KGZ
13	EMCA5	WOOD1	▪ SRKR16-5.1 ▪ Local: KGZ
14		WOOD2	▪ SRKR16-5.1 ▪ Local: KGZ
15	EMCA6	STEEL	▪ SRKR16-6.1 ▪ Local: TKM

We made a statistical analysis of all the functions collected and mapped to each building class of the taxonomy to determine the mean vulnerability and the associated uncertainty for a given level of intensity measure. A summary of the procedure is briefly listed below:

1. For each cluster of curves (e.g., SERA) and for a given building class (e.g., EMCA1-URM1), multiple curves may have been available. To avoid overweighting one reference with more available curves than others, we first computed the average of all functions in a cluster (i.e., belonging to the same reference or typology of references) as the representative of the cluster for that class. Such an average function of the cluster was computed averaging the damage ratios corresponding to each intensity measure level.
2. In the second step, for each taxonomy, we computed the mean and dispersion of the representatives of the clusters for a given PGA value. This gave us an idea about the central value of all the available data points. At this stage, when computing the mean, all the functions were equally weighted.
3. A parametric lognormal function is then defined for each of the vulnerability class as the final vulnerability function to use in the regional seismic risk assessment.
4. Uncertainty is also determined for each vulnerability function computed above. A coefficient of variation (CoV) is provided in the final database for the discrete mean loss ratios and IM level. At each IM value, the CoV is computed by dividing the standard deviation by the mean LRs of the data. This CoVs, together with the mean values, can be considered to define the parameters of a Beta distribution ranging between 0 and 1 to describe the uncertainty in damage assessment corresponding to each IM level.

2.4.3.2 Non-Residential buildings

Given the lack of specific vulnerability information/references for non-residential buildings and the similarities among residential and non-residential building typologies, the vulnerability functions for the non-residential buildings were generated using the final functions derived for residential buildings in the previous section. For each non-residential building class[2], we considered a weighted average of the residential vulnerability functions based on the building fractions identified in the exposure modelling component for each different building occupancy type. In order to derive a single model for the entire region, we further used a weighted average based on the population of the countries to combine these functions. Weighted average curves are computed averaging the loss ratio values corresponding to each IM level. Thus, the final curves for non-residential buildings are non-parametric functions. Uncertainty is also considered for the non-residential vulnerability curves combining the uncertainties derived for the residential building functions.

2.4.3.3 Infrastructure

We adopted the fragility curves from HAZUS (FEMA 2003) to assess the vulnerability of the transportation system[3]. It should be noted that similar approach was also used in the framework of the SRKR16 project carried out for the Kyrgyz Republic (World Bank, 2006). Note that no specific data about the road vulnerability were available from the local context. Given that, in general, roads and infrastructure most of the times are built by international companies following

[2] Industrial, Commercial wholesale and services, Commercial retail, Hospitals, Clinics, Other healthcare facilities, Urban Schools, Rural Schools (as in Table 6 of the deliverable D5a on earthquake vulnerability)

[3] Motorway, trunk, primary road, secondary roads, tertiary roads, light rail, monorail, rail (as per deliverable D5a)

international standards, it is reasonable to expect small difference in construction practice and consequently in earthquake vulnerability between Central Asia and US. Having said that, the roads in Central Asia could be expected to be slightly more vulnerable than in the US, but it is not possible to quantify a priori the differences. Hence, for this reason, we adopted the US-based HAZUS functions in this study. This assumption could lead to a slight underestimation of the losses in the final risk estimates, although given the low vulnerability of the roads compared to the other assets analyzed within the scope this study, this is not expected to significantly affect the final overall risk assessment.

2.4.3.4 Human loss

In this study we selected the fatality rates provided by HAZUS (FEMA, 2003) and we combined them with the collapse fragility functions proposed in SRKR16 to define the human loss functions. The fatality consequence model proposed by HAZUS was selected since it is the most recent among the ones analyzed and it provides rates applicable to all building typologies. Such fatality rates were combined with the fragility functions extracted from SRKR16 for Kyrgyz Republic since this was the only local reference providing fragility functions rather than vulnerability curves. Moreover, the main feature of this study is that it takes into account all the building typologies. The vulnerability model derived according to the described methodology is capable to predict the fatalities as function of the number of occupants of the buildings and of the experienced peak ground acceleration.

2.4.4 Results

Figure 11, Figure 12 and Figure 13 show the comparison of the functions obtained for different assets of the residential, non-residential and infrastructure assets, respectively. The human loss functions for the residential building classes are shown in Figure 14.

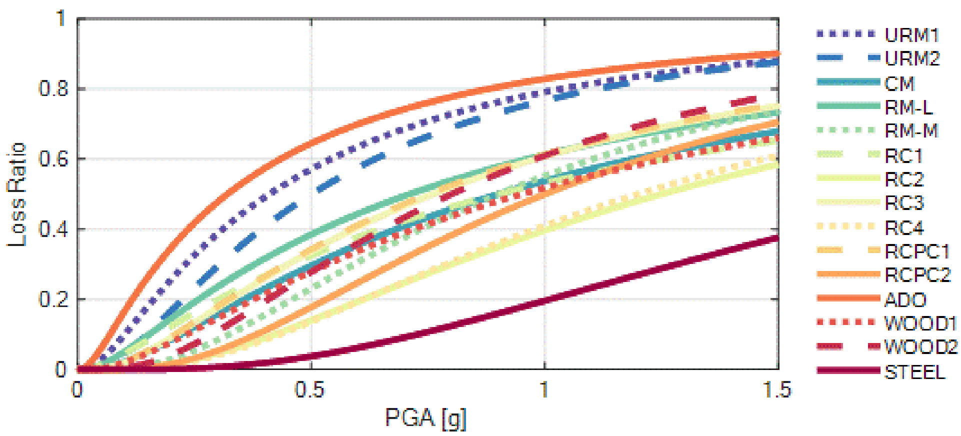


Figure 11. Comparison of the proposed vulnerability functions for different classes of residential buildings (with URM = unreinforced masonry, CM = confided masonry, RM = reinforced masonry, RC = reinforced concrete, RCPC = RC walls, ADO = adobe, WOOD = timber structure, STEEL = steel structure, as in Table 16 of the deliverable D5a)

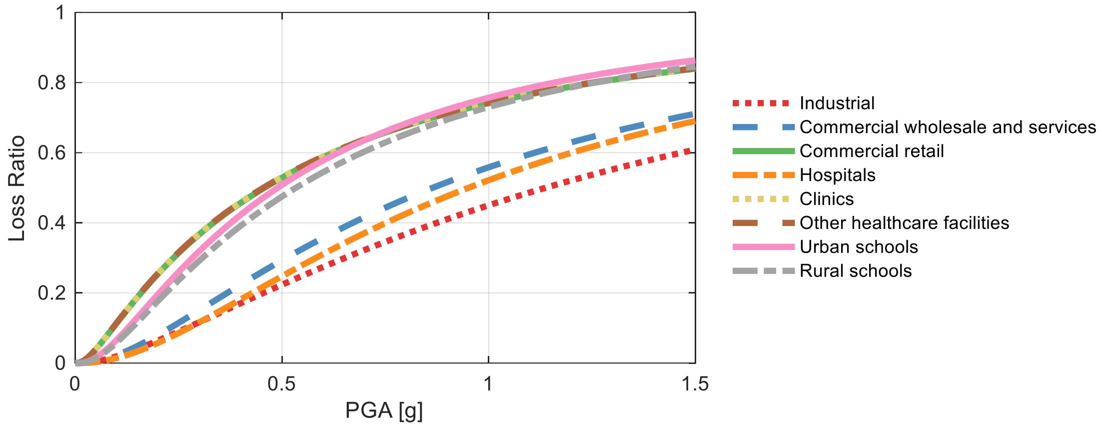


Figure 12. Comparison between the proposed vulnerability functions among different classes of the non-residential buildings

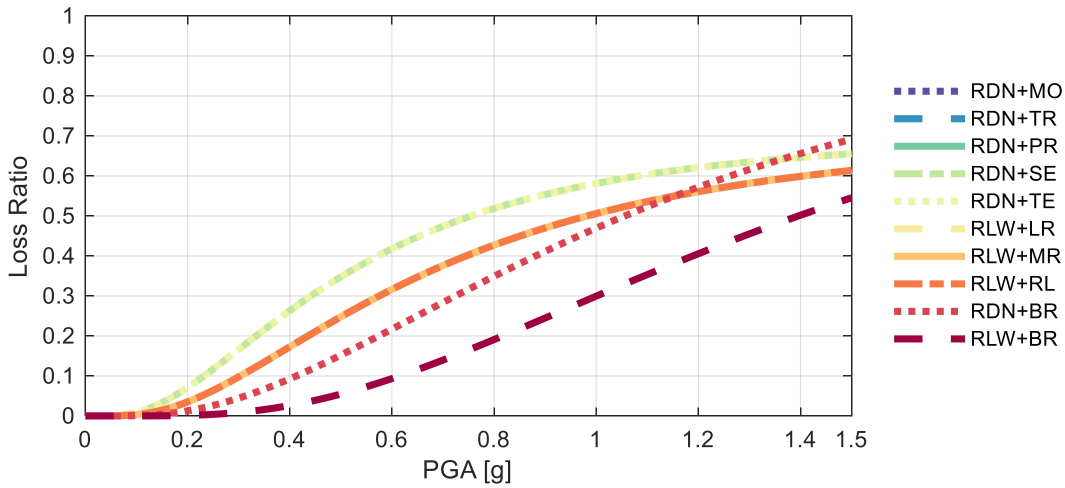


Figure 13. Comparison between different vulnerability functions considered for infrastructure assets. The chart includes two groups of coincident curves: Group 1='RDN+MO', 'RDN+TR', 'RDN+PR', 'RLW+LR', 'RLW+MR', and 'RLW+RL' and Group 2='RDN+SE' and 'RDN+TE' that have the same vulnerability curves, as discussed above (with RDN = road network, MO = motorway, TR = trunk, PR = primary, RLW = railway network, LR = light rail, MR = monorail, RL = rail, SE = secondary, TE = tertiary)

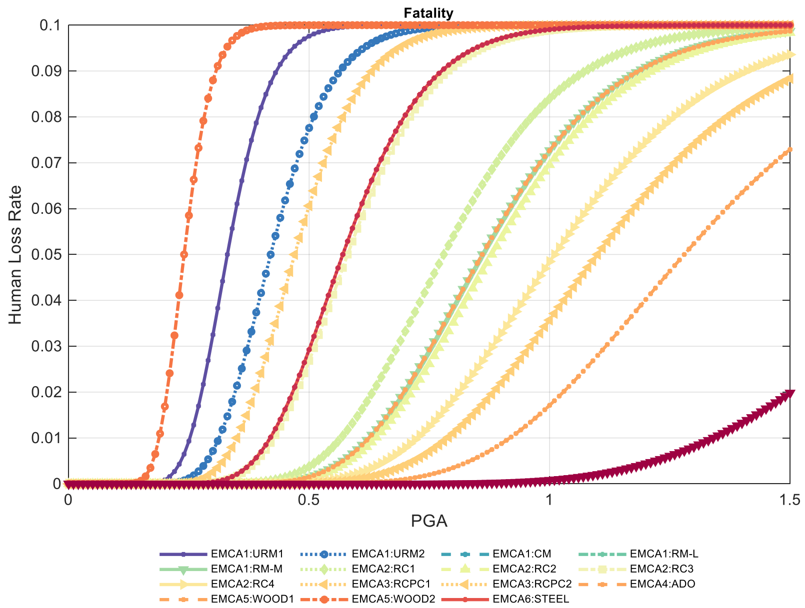


Figure 14. Human loss vulnerability functions for the residential buildings.

2.5 Task 5 - Validation and Development of Physical Vulnerability or Fragility Relationships and Casualty Relationships – Flood Vulnerability

2.5.1 Objective

The objective of this task is to develop relationships between a flood intensity measure and an estimation of the level of damage an asset experiences. These relationships, expressed between 0 and 1 (where 0 is no damage and 1 is total damage, which, for the purpose of the present model, is expressed as the total reconstruction cost), are called vulnerability curves and, sometimes, damage curves or damage functions.

The assets subject to flood risk, and for which flood vulnerability should be assessed, are grouped into four categories (buildings, infrastructure, crops and population). More information regarding the definition of the asset classes can be found in the specific exposure characterisation report (developed within the project as part of Task 4, World Bank, 2022c). When possible and when data support such a decision, different vulnerability functions have been considered (World Bank, 2022e) for the five Central Asia countries (for example, for each category of the residential buildings, five vulnerability curves have been derived, one for each of the five target countries).

The development of a regional model cannot be done without the contribution of experts from the local scientific community. Partnership with local governmental institutions and authorities is also an essential step to facilitate model acceptance and for potential integration with national models. Following this concept, the consortium has engaged with the local communities for building and extending awareness of risk and for enhancing the technical capacity of experts in the use of open tools and resources. Institutions and consultants based in all five countries are part of the consortium, and, as such, are involved in all aspects of the project development. For most of the tasks required for the development of flood vulnerability, the local partners have provided their knowledge and expertise and advised on matters related to specific characteristics of the assets at risk in their respective countries. In cases where the expertise of the local partners involved in the project needed to be integrated with knowledge from other professional figures, engagement with such figures has been undertaken by the local partners, who have looked for the right persons and interacted with them. As an example, data on unit repair and removal costs were retrieved also thanks to interactions with local architects and engineers who were not part of the team of the consortium but were sought out and interviewed by the local partners.

2.5.2 Data

Most of the data collected for the development of the flood vulnerability module regarded buildings. For example, the distributions of certain building characteristics were obtained from the literature, for example for:

- Number of floors (height of the building);
- Basement height;
- Ground floor level;
- Building type (apartment, detached, semi-detached).

The component-based approach also requires unit costs for each component. These are the costs per unit (usually per m, m^2 or m^3) of cleaning/removing/replacing each of the component. These costs have been collected onsite by local advisors and engineers through inquiries with engineers and architects involved in the design and pricing of buildings and from engineering manuals or real estate catalogues (for example, the ENiR - Uniform norms and prices for construction, installation and repairing works).

In this project, different unit costs for each country have been estimated separately, to reproduce the differences in costs of repair/removal among countries. Data have also been homogenised to remove outliers and maintain a meaningful proportion between cost of components and the buildings' value. All costs have been converted from local currency into EUR.

2.5.3 Methodology

In this flood risk model, the sole intensity measure used to assess damage by flood is the water depth. Therefore, the vulnerability curves developed in this study are always expressed in terms of water depth vs damage ratio (i.e., the level of damage, between 0 and 1). Water depth is widely considered as the intensity measure with the highest correlation with the flood damage (Kreibich et al., 2009). However, other variables may play a role in the determination of the damage caused by a flood, such as flood duration, current velocity, deposits, contamination by pollution and salinity of water. While these variables cannot be considered explicitly in the present risk model due to the large extension of the geographical domain and the complexity/resolution of the hazard model, the vulnerability curves developed in this study do take into account some of these ancillary intensity measures indirectly, as a secondary modifier or in a statistical manner. In particular, the local slope has been used as a proxy for the flow velocity and the flood duration. The geographical domain of the model has been reclassified into three geomorphological areas:

- Plains: where the terrain slope is less or equal to 1%;
- Hills: where the terrain slope is larger than 1% and less or equal to 15%;

- Mountains: where the terrain slope is larger than 15%.

Vulnerability curves for each category asset at risk have been differentiated based on where the asset is located (i.e., on plains, hills or mountains), accounting indirectly for the effect of flow velocity and flood duration. The slope has been calculated based on the 90m digital elevation model MERIT-Hydro (Yamazaki et al., 2019).

No specific flood vulnerability curves for buildings developed for the five target countries exist in the literature to the authors' knowledge after an ad-hoc literature review process, and, for this reason, new curves have been developed within the frame of the present project. A component-based flood vulnerability model, called INSYDE, has been used to develop vulnerability curves (Dottori et al., 2016). A scheme of the methodology is provided in Figure 15 to define the building components and building characteristics; to estimate damage, for each component, in case of flood; to sum the damage and normalize by the total replacement cost.

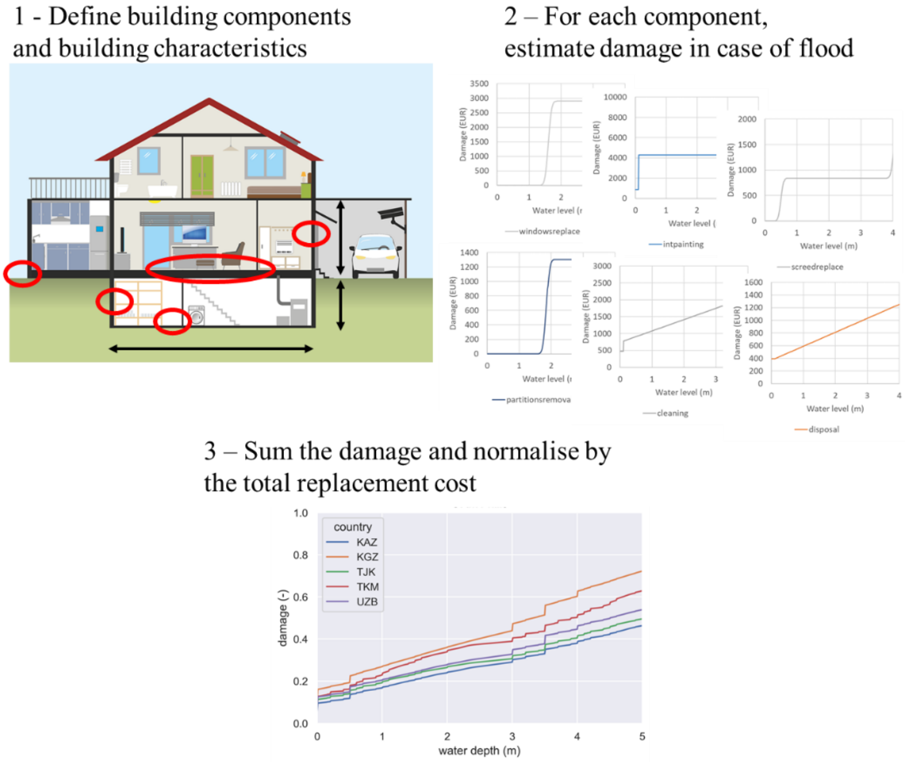


Figure 15. Scheme of the methodological approach for buildings.

Regarding infrastructure, given the lack of specific country-level vulnerability curves, in this project the vulnerability for roads and railways has been modelled using the vulnerability curves for infrastructure/roads provided by the Global Flood Depth-Damage database (Huizinga et al., 2017). since it has a widespread level of acceptance within the risk modelling community. More specifically, we have used the curve provided for Asia. While this curve is dominated by South-East Asian data, it is also very similar to the curve for Europe, to which the road and railway systems of Central Asia share similarities.

Regarding crops, according to the Water Use Efficiency Monitor in Central Asia platform, WUEMOCA (CAWA, 2019; Sychev and Mueller, 2018), the most common ones in the target countries are cotton, wheat, rice, alfalfa, vegetables, maize and sunflower. From an economic point of view, cotton and wheat are overwhelmingly the most relevant cash crops in the area. The cotton curve has been derived as the average of the cotton vulnerability curves found in the literature. The wheat curve has been derived from similar crops (no specific wheat curves were found, but vulnerability curves for other cereals exist) and slightly adjusted based on agronomic considerations (i.e., considering similarities and differences with other crops that might make wheat more or less vulnerable compared to other crops).

Regarding human vulnerability, the methodology proposed by Milanesi et al. (2016) was used to establish the relationship between water depth and probability of failure depending on a person's gender and age. The human body is conceptualized as a set of cylinders and its stability to slipping and toppling is assessed by forces and moments equilibrium. Moreover, a depth threshold to consider drowning is assumed. The model also considers explicitly local slope, thus allowing for the characterisation of vulnerability both in floodplains and in mountainous areas. The physical basis of the model allows to identify two stability thresholds, derived respectively for children and adults.

2.5.4 Results

Some of the resulting vulnerability curves are shown as follows, grouped by category and geomorphological area (Figure 16, Figure 17 and Figure 18). The ISO country codes used in the legend are:

- KAZ: Kazakhstan
- KGZ: Kyrgyz Republic
- TJK: Tajikistan
- TKM: Turkmenistan
- UZB: Uzbekistan

For other curves, the reader is referred to the specific flood vulnerability report (deliverable D5a on flood vulnerability).

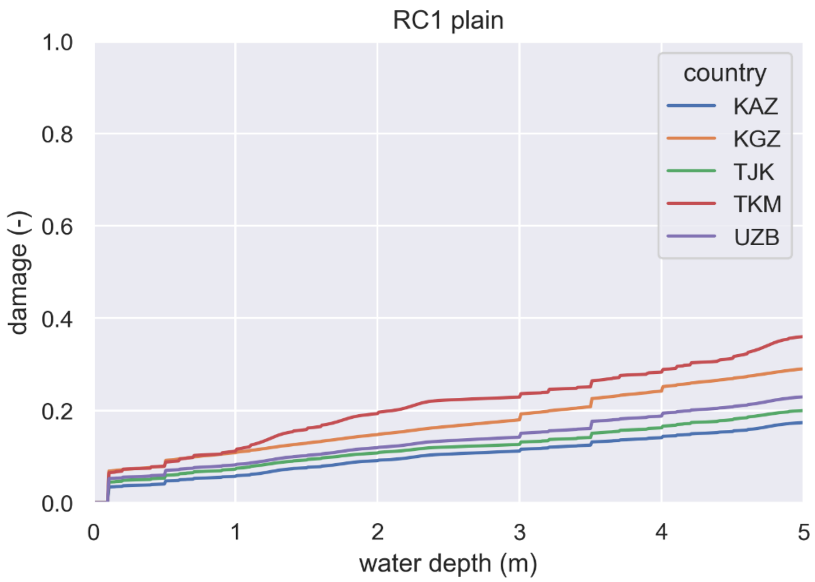


Figure 16.Vulnerability curves for category "RC1: RC (reinforced concrete) frame without ERD (earthquake resistant design)" and geomorphological area "plains".

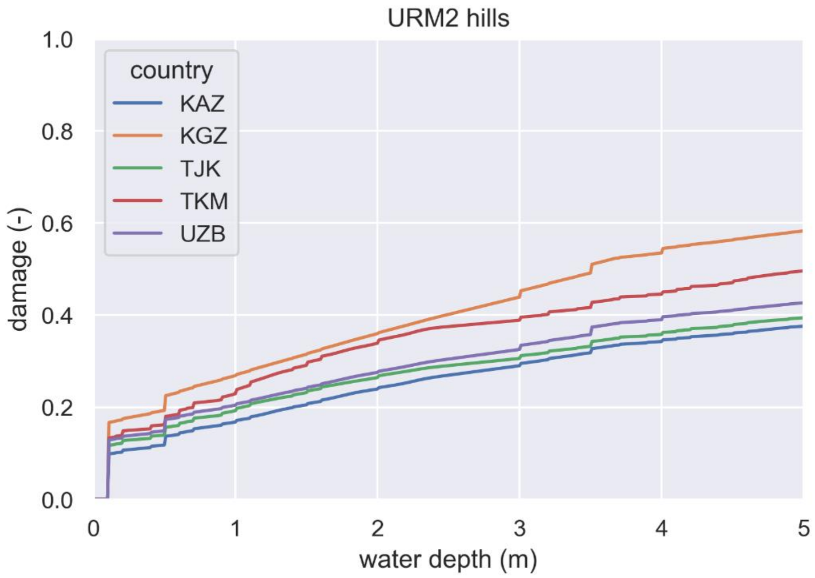


Figure 17. Vulnerability curves for category "URM1: Unreinforced masonry" and geomorphological area "hills".

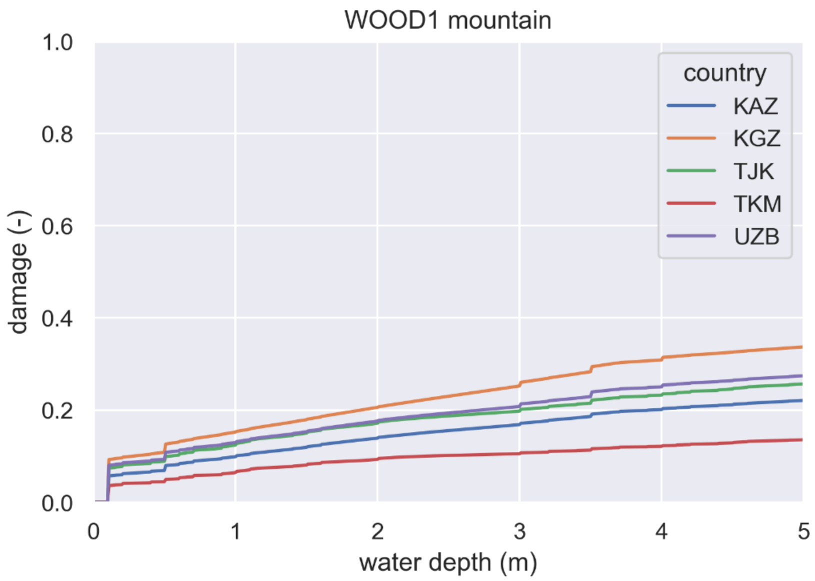


Figure 18. Vulnerability curves for category "WOOD1: Timber structure" and geomorphological area "mountains".

2.6 Task 6 - Earthquake and Flood Risk Assessment

2.6.1 Objective

A fully probabilistic risk assessment for floods (pluvial and fluvial), and earthquakes has been carried out for five countries of Central Asia for supporting regional and national risk financing and insurance applications, including potential indemnity and/or parametric risk financing solutions for the structuring of a regional program (World Bank, 2022f). A common and consistent risk assessment methodology for the five countries and across multiple hazards and asset types has been adopted to obtain strategic financial solutions consistent across geographical areas and across economic sectors can be obtained.

However, it must be noted that this assessment does not have sufficient detail to inform planning and design of specific risk management infrastructure; rather, the output information will inform and enable the World Bank to initiate a policy dialogue. Currently, the availability of risk information for DRM and DRFI activities remains variable across the region and has been provided by previous projects focusing on a single country. Moreover, few of these studies have quantified multi-hazard disaster risk, and, to our best knowledge, none have done so for the whole region using probabilistic methods applied with the sufficient fidelity required to robustly inform the development of DRFI solutions.

2.6.2 Data

The probabilistic risk assessment methodology employed in this project requires the following analytical steps:

- Probabilistic seismic hazard analysis (PSHA): the output of the PSHA for the risk assessment consists of a stochastic earthquake catalog with a duration of 10,000 years, which given the scope of the project, was a long enough timespan providing a proper balance between risk results stability for long return periods and the computational effort. This stochastic earthquake catalog contains several events, each of them characterized by location, depth, magnitude, and geometry of the rupture to allow for the estimation of the probability distribution of the ground motion intensities (i.e., acceleration) produced by the event in the surrounding region. For generating the stochastic earthquake catalog, a PSHA was developed for the area under study, which details are described in the technical report of Task 2.

- Probabilistic flood hazard analysis: a probabilistic flood hazard analysis including fluvial events was performed yielding a stochastic catalog with a duration of 10,000 years that complies with the hazard representation requirements for the use of the proposed risk assessment framework, which details are described in the technical report of Task 3. The length of the stochastic flood catalog was defined using the same rationale as in the case of earthquakes, finding that the 10,000-year timespan provided a good balance between the reliability of risk results for long return periods and the computational effort.

- Definition of the inventory of exposed assets: for the five countries in the study area of this project, an industry exposure database (IED) was developed, including information about the location of the exposed assets, their replacement cost, and their structural characteristics (e.g., construction material, height, structural system). The exposure module covers the following lines of business:

- Population
- Building stock
  - Residential buildings
  - Non-residential buildings (schools, healthcare facilities, industrial and commercial buildings)
- Infrastructure
  - Transportation system (roads, railways, and bridges)
  - Airports and airstrips
  - Supply infrastructure
- Croplands

Two types of exposure databases were developed for this project. The first one aims at providing a reliable representation of today's exposure in the analysis area, whereas the second one provides a projection of the exposure to year 2080. The full details of the development of the IEDs can be found in the report of Task 4.

- Development of earthquake and flood vulnerability models: a vulnerability function defines the probability distribution of economic and human losses for different levels of ground motion intensity or water depths. A vulnerability function is assigned to each class of asset included in the IED, for each hazard, from a database of vulnerability functions derived for buildings and the different types of infrastructure in the five countries covered in this project. More details about the development of the earthquake and flood vulnerability models can be found in the report of Task 5.

- Loss computation: the loss module allows estimating the economic and human losses in the five countries in the IED for each of the possible future events in the stochastic catalogs for earthquakes and floods. Since the hazard and vulnerability representations is the same for the two hazards, the same arithmetic can be used to estimate the future losses. In a nutshell, the human and economic losses for each exposed asset are computed by convolving the hazard intensity measure (i.e., ground acceleration or flood depth) distribution at the site of interest with the corresponding damage function. This procedure provides a distribution of the mean damage ratio (i.e., the repair cost divided by the asset replacement cost). The mean damage ratio is then multiplied by the total value of the asset to obtain the distribution of losses for the asset caused by an earthquake or a flood event. The total loss for each event is then obtained summing up the losses for all the exposed assets. Since each event has an annual occurrence probability, the losses for all the events in the stochastic catalogs are combined using the formulation described in the following section, to provide a probabilistic estimate of future possible losses induced by these two hazards in each of the five countries.

2.6.3 Methodology

Since catastrophic events tend to have low frequencies of occurrence, the relationships between different loss levels and their occurred frequencies cannot be established by solely analyzing the historical data. For example, in the analysis area for this project, the complete historical data regarding floods and earthquakes only cover the last 150 years. The risk assessment has been performed using the CAPRA platform (www.ecapra.org), which is an open-source and free platform for multi-hazard probabilistic and deterministic risk assessment. The CAPRA Platform provides different advantages such as: multi-peril assessment, implementing the probabilistic framework described next, allows the use of geographical information (for the exposure and hazard components) and the outputs of the analysis are aligned with the risk metrics required in this project (LEC, AAL, PML, etc.) for economic and human losses, besides being capable of producing GIS-compatible geospatial data layers with metadata, describing estimated loss (AAL and selected return period losses) per ADM1 unit, as well as identifying the location of key industrial sites, critical and supply infrastructure and the corresponding hazard intensity values at those locations, either in raster or vector formats.

The implemented risk assessment methodology is event-based and peril-agnostic, meaning that the same arithmetic can be applied regardless the hazard. The objective of a probabilistic risk assessment is to provide a long-term relationship between losses (e.g., economic losses or fatalities) and their occurrence frequencies. Figure 19 shows the general framework for the risk assessment methodology, where the loss module combines the outputs of the hazard, exposure, and vulnerability modules yielding estimates of the economic losses and fatalities induced by earthquakes and floods in the study area.

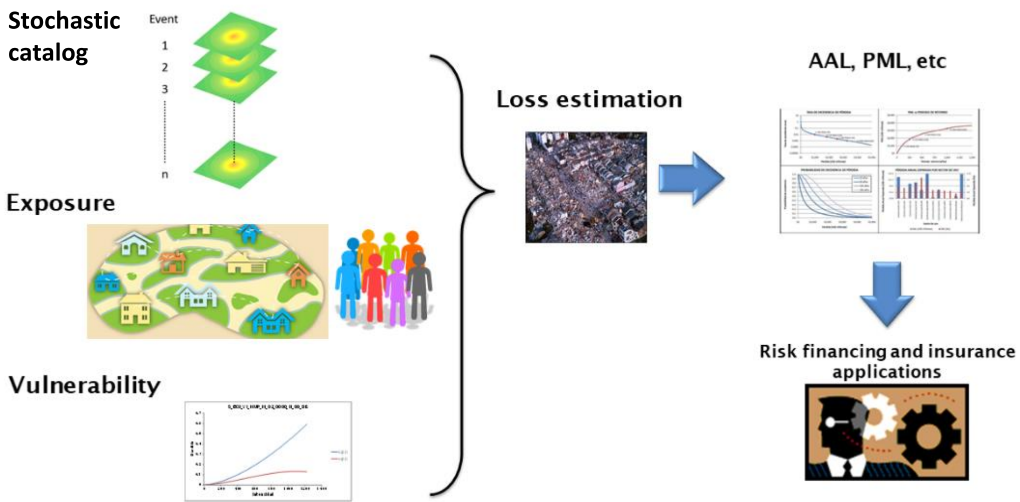


Figure 19. Risk assessment methodology for a specific hazard, the procedure has been applied separately to earthquake and flood hazards

The probability density function of the loss for each event is computed by aggregating losses from each individual exposed asset. Since loss is computed as a random variable, it must be aggregated in a proper and probabilistic way. The following expressions are used to calculate the expected value of the loss, $E(l|Event_i)$, and its corresponding variance, $\sigma^2(l|Event_i)$, for each event:

$$E(l|Event_i) = \sum_{j=1}^{NE} E(l_j) \quad \text{(Eq. 1)}$$

$$\sigma^2(l|Event_i) = \sum_{j=1}^{NE} \sigma^2(l_j) + 2\sum_{\substack{k=1 \\ k<j}}^{NE-1} \sum_{j=2}^{NE} cov(l_k, l_j) \quad \text{(Eq. 2)}$$

where NE is the total number of exposed assets, $E(l_j)$ is the expected value of the loss at the j^{th} exposed element given the occurrence of the i^{th} event, $\sigma^2(l_j)$ is the variance of the loss at the j^{th} exposed element given the occurrence of the i^{th} event, and $cov(l_k, l_j)$ is the covariance of the loss of two different exposed elements. The covariance is calculated using a correlation coefficient $\rho_{k,j}$ and also takes into account the standard deviations for losses in different assets.

$$\sigma^2(l|Event_i) = \sum_{j=1}^{NE} \sigma^2(l_j) + 2\sum_{\substack{k=1 \\ k<j}}^{NE-1} \sum_{j=2}^{NE} \rho_{k,j}\sigma(l_k)\sigma(l_j) \quad \text{(Eq. 3)}$$

Disaster risk should be expressed in terms of an exceedance curve, which specifies the occurrence frequency of events that reach or exceed a specified value of loss. This annual loss frequency is also known as the exceedance rate, and it can be calculated using the following equation, which is one of the many ways adopted by the total probability theorem.

$$v(l) = \sum_{i=1}^{N} \Pr(L > I|Event_i) \cdot F_A(Event_i) \quad \text{(Eq. 4)}$$

where $v(l)$ is the exceedance rate of the loss l, $\Pr(L > I|Event_i)$ is the probability that the loss is larger than l given the occurrence of the i^{th} event and $F_A(Event_i)$ is the frequency of occurrence (in annual terms) of the i^{th} event. The sum of the equation is performed for all the scenarios included in the stochastic set that produce any loss level on the exposed assets.

The loss exceedance curve contains all the necessary information for describing the process of loss occurrence considering the associated uncertainties in the analysis process. The approach to derive the loss exceedance curve is the following:

1. For a given event of the stochastic catalogues, the probability distribution of losses is determined for each of the assets exposed;
2. Based on the probability distribution of the losses of each asset, the probability distribution of the sum of these losses is computed, taking into account the correlation between the loss at different sites;
3. Once the probability distribution of the total loss is determined for the scenario, the probability that the loss exceeds a given value l is calculated;
4. The probability determined in (3), multiplied by the annual frequency of occurrence of the event, is the contribution of the scenario to the rate of exceedance of the loss l.

The above calculation repeated for all the scenarios in the earthquake and flood stochastic catalogues yield the loss exceedance curve for each hazard.

2.6.4 Results

The results of the earthquake and flood risk assessments are presented in terms of a loss exceedance probability curve (EP curve) and by the year loss tables (YLT), disaggregated at administration units 1 (ADM1, which is equal to Oblast level) and administration unit 0 (ADM0, which is equal to country level). Furthermore, return period loss estimates and Average Annual Loss (AAL) at ADM1 and ADM0 levels, and for the whole region are provided in tabular format for return periods ranging from 5 to 1000 years. Since for preparedness and mitigation plans it is important to estimate the possible losses (economic and human) that a scenario event causes in current exposure, scenario losses for as-if scenarios, that are realistic and representative, as per the results of the earthquake hazard disaggregation and the flood hazard analyses have also been calculated. The loss results are presented both in terms of expected values and their confidence intervals. Finally, for population, key industrial sites, critical and supply infrastructure the exposure level to different hazard intensity thresholds has been estimated.

The Terms of Reference (ToR) requires providing tabulated results (absolute and relative to exposed values) of Annual Average Loss (AAL) and return period losses for 5, 10, 25, 50, 100, 250, 475, 500, and 1000 years at ADM1, country, and regional levels. These results are available for the four exposure databases developed in Task 4, the one corresponding to the current conditions (year 2020) and the three different projections to year 2080 (SSP1, SSP4 and SSP5)[4].

Table 8 shows the absolute and relative earthquake risk results at country level and at regional level for the current exposure scenario (year 2020). Regional level refers to the aggregated results for the five Central Asia countries. Although the largest absolute losses are found for Uzbekistan, these values do not indicate that the largest earthquake risk in the region is in that country. In relative terms (per mille), it can be seen from the same table that Kyrgyzstan and Tajikistan have larger losses due to a combination of the higher earthquake levels at locations with exposure concentrations and to the different regional earthquake vulnerability. From Table 8 and all others that provide results of AAL's, it can also be seen that this metric is additive, meaning that the regional AAL is the sum of the individual AAL's calculated for each of the five countries. However, the same additive property does not hold true for specific return period losses, meaning that the regional loss for a given return period is different (lower) than the sum of the individual losses for that same return period calculated for each country.

[4] Only for the residential sector

Table 8. Losses for different return periods (first 9 lines) and AAL (last line) for earthquake risk at Regional and Country level. Grey columns show the absolute value in USD and red columns shown the relative losses in per mille. 2020 total exposure.

Tr (years)	Absolute values ($Million USD)						Relative values to the total replacement cost (per mille)					
	Regional	KGZ	KAZ	TJK	TKM	UZB	Regional	KGZ	KAZ	TJK	TKM	UZB
5	$1,796.9	$183.6	$303.4	$247.0	$37.5	$1,280.1	1.07	3.18	0.54	3.27	0.68	1.38
10	$3,030.7	$335.0	$647.6	$415.8	$71.5	$2,380.3	1.81	5.80	1.15	5.51	1.29	2.57
25	$5,403.2	$640.0	$1,548.7	$738.3	$149.3	$4,548.4	3.22	11.09	2.76	9.78	2.70	4.91
50	$7,929.2	$964.3	$2,629.4	$1,081.7	$241.9	$6,872.9	4.73	16.71	4.68	14.33	4.38	7.41
100	$11,330.5	$1,396.9	$4,066.1	$1,533.1	$361.8	$10,064.7	6.75	24.20	7.23	20.31	6.54	10.86
250	$17,365.5	$2,173.7	$6,527.8	$2,320.1	$553.8	$15,912.5	10.35	37.66	11.61	30.74	10.02	17.17
475	$22,518.3	$2,840.6	$8,627.0	$3,017.6	$707.5	$20,842.3	13.42	49.22	15.35	39.98	12.80	22.49
500	$22,954.7	$2,897.5	$8,807.1	$3,078.6	$720.2	$21,252.2	13.68	50.20	15.67	40.79	13.03	22.93
1000	$29,174.9	$3,724.2	$11,425.7	$3,999.7	$901.9	$26,970.9	17.39	64.53	20.33	52.99	16.32	29.10
AAL	$1,923.9	$191.5	$350.8	$237.9	$34.4	$1,109.3	1.15	3.32	0.62	3.15	0.62	1.20

Table 9 shows the absolute and relative earthquake risk results at country level and at regional level for the projected exposure scenario (year 2080), with the Shared Socio-economic Pathway 1: sustainability (SSP1, for details see Task 4 technical report).

Table 9. Losses for different return periods (first 9 lines) and AAL (last line) for earthquake risk at Regional and Country level. Grey columns show the absolute value in USD and red columns show the relative losses in per mille. 2080_SSP1 residential exposure (residential buildings only).

Tr (years)	Absolute values ($Million USD)						Relative values to the total replacement costs (per mille)					
	Regional	KGZ	KAZ	TJK	TKM	UZB	Regional	KGZ	KAZ	TJK	TKM	UZB
5	$813.6	$95.4	$131.4	$165.6	$14.0	$549.2	0.72	2.96	0.39	2.97	0.70	0.80
10	$1,389.4	$161.2	$275.3	$269.8	$26.0	$1,043.1	1.23	5.00	0.82	4.84	1.31	1.52
25	$2,530.3	$291.3	$667.6	$464.1	$52.5	$2,038.3	2.24	9.05	1.98	8.32	2.64	2.97
50	$3,771.5	$432.8	$1,210.7	$667.2	$83.9	$3,121.2	3.33	13.44	3.60	11.96	4.21	4.55
100	$5,471.9	$630.8	$1,994.1	$936.1	$125.7	$4,618.4	4.84	19.58	5.92	16.78	6.31	6.73
250	$8,608.7	$1,011.4	$3,452.2	$1,427.0	$196.4	$7,510.3	7.61	31.40	10.26	25.59	9.87	10.94
475	$11,361.2	$1,362.1	$4,792.8	$1,884.9	$256.2	$10,150.4	10.04	42.29	14.24	33.80	12.87	14.78
500	$11,596.9	$1,392.8	$4,911.9	$1,925.9	$261.2	$10,377.6	10.25	43.25	14.59	34.53	13.12	15.11
1000	$15,017.0	$1,846.3	$6,681.3	$2,550.4	$334.6	$13,602.9	13.28	57.33	19.85	45.73	16.81	19.81
AAL	$930.9	$102.8	$162.7	$161.8	$12.6	$491.0	0.82	3.19	0.48	2.90	0.63	0.72

A separate analysis to estimate the exposure to earthquake hazard of industrial sites and critical and supply infrastructure was carried out in this project. For instance, Table 10 to Table 12 show respectively: the number of industrial sites, kilometers of water and communications infrastructure, and kilometers of transport infrastructure exposed to different ranges of PGA in (g) for different return periods. Table 13 to Table 15 show respectively: the number of buildings, assets and length of assets damaged due to earthquake, for each asset group separately and combined.

Table 10. Number of industrial sites in the study area exposed to different earthquake hazard intensities at different return periods

PGA (g)		Number of Industrial sites			
Lower limit	**Upper limit**	**100yrs**	**250yrs**	**475yrs**	**1000yrs**
0.0	0.1	5,747	4,962	4,092	3,566
0.1	0.2	3,018	1,696	1,531	1,425
0.2	0.3	64	2,130	2,239	876
0.3	0.4	0	41	944	2,184
0.4+		0	0	23	778

Table 11. Kilometers of water and communications infrastructure in the study area exposed to different earthquake hazard intensities at different return periods

PGA (g)		Kilometers of water and communications infrastructure			
Lower limit	Upper limit	100yrs	250yrs	475yrs	1000yrs
0.0	0.1	284	202	163	148
0.1	0.2	208	128	119	53
0.2	0.3	28	170	142	90
0.3	0.4	0	20	81	157
0.4+		0	0	15	69

Table 12. Kilometers of transport infrastructure in the study area exposed to different earthquake hazard intensities at different return periods

PGA (g)		Kilometers of transport infrastructure			
Lower limit	Upper limit	100yrs	250yrs	475yrs	1000yrs
0.0	0.1	146,645	118,708	103,453	94,935
0.1	0.2	65,523	49,367	36,820	24,449
0.2	0.3	3,451	45,139	50,221	31,618
0.3	0.4	16	2,338	22,819	45,368
0.4+		0	84	2,321	18,995

Table 13. Number of buildings damaged (for each asset group separately, and combined), earthquake, 475ys return period

Country	Residential	Commercial	Education	Healthcare	Combined
KGZ	237,180	11,347	2,483	765	251,775
KAZ	276,998	9,999	902	504	288,403
TJK	210,776	10,209	262	275	221,522
TKM	1,238	346	30	1	1,615
UZB	75,600	3,519	615	100	79,834

Table 14. Number of assets damaged (for each asset group separately, and combined), earthquake, 475ys return period

Country	Bridges	Energy	Combined
KGZ	829	45	874
KAZ	674	7	681
TJK	702	40	742
TKM	6	0	6
UZB	116	4	120

Table 15. Length (km) of assets damaged (for each asset group separately, and combined), earthquake, 475ys return period

Country	Water & Communication	Transport	Combined
KGZ	3,969	9,701	13,670
KAZ	2,850	7,478	10,327
TJK	1,850	5,924	7,773
TKM	30	355	384
UZB	232	1,505	1,737

For the case of floods, analogous analyses were carried out (Table 16) where the fluvial flood risk results are shown (undefended case) at national and regional levels in absolute and relative (to the total replacement cost) terms for the current exposure scenario. The highest absolute fluvial risk results are found to be in Kazakhstan and Uzbekistan. However, when assessed in relative terms, Kazakhstan, Tajikistan, and Turkmenistan have similar risk values above 2‰.

Table 17 shows the same results but now considering the defended case in the fluvial flood hazard modelling, from where considerable risk reductions are found in Kazakhstan, Turkmenistan, and Uzbekistan.

The exposure database used in the flood risk assessment for the 2080 projection only includes the residential sector, although in terms of absolute losses, the differences between the current scenario (that includes all lines of business) and the 2080 scenario (only residential assets) are not as large as in earthquakes. Another source of variations in the flood risk assessment is the consideration of climate change. The full details of this analysis can be found in the technical report of Task 3, where also some considerations on the several sources of uncertainties are mentioned.

Table 16. Losses for different return periods (first 9 lines) and AAL (last line) for fluvial flood risk undefended scenario at Regional and Country level. Grey columns show the absolute value in USD and red columns show the relative losses in per mille. 2020 total exposure.

Tr (years)	Absolute values ($Million USD)						Relative values to the replacement cost (per mille)					
	Regional	KGZ	KAZ	TJK	TKM	UZB	Regional	KGZ	KAZ	TJK	TKM	UZB
5	$2,664.3	$130.7	$1,522.0	$242.0	$203.2	$867.2	1.60	2.31	2.72	3.25	3.69	0.94
10	$2,988.6	$156.6	$1,755.9	$292.7	$262.9	$1,037.9	1.79	2.77	3.14	3.93	4.77	1.12
25	$3,360.0	$185.6	$2,021.3	$349.7	$342.5	$1,240.2	2.01	3.28	3.62	4.70	6.22	1.34
50	$3,595.7	$205.3	$2,197.2	$381.8	$393.0	$1,380.9	2.15	3.63	3.93	5.13	7.13	1.49
100	$3,797.4	$224.0	$2,361.5	$409.5	$437.0	$1,527.5	2.27	3.96	4.22	5.50	7.93	1.65
250	$4,024.7	$241.4	$2,605.0	$449.1	$502.8	$1,760.0	2.41	4.26	4.66	6.03	9.13	1.90
475	$4,178.7	$249.7	$2,830.8	$480.4	$557.3	$1,897.5	2.50	4.41	5.06	6.45	10.12	2.05
500	$4,190.7	$250.3	$2,845.7	$483.0	$561.2	$1,908.5	2.51	4.42	5.09	6.49	10.19	2.06
1000	$4,354.0	$257.6	$3,004.5	$515.6	$610.3	$2,031.3	2.61	4.55	5.37	6.93	11.08	2.20
AAL	$2,190.9	$95.1	$1,165.6	$177.0	$123.0	$630.2	1.31	1.68	2.09	2.38	2.23	0.68

Table 17. Losses for different return periods (first 9 lines) and AAL (last line) for fluvial flood risk defended scenario at Regional and Country level. Grey columns show the absolute value in USD and red columns show the relative losses in per mille. 2020 total exposure.

Tr (years)	Absolute values ($Million USD)						Relative values to the total replacement costs (per mille)					
	Regional	KGZ	KAZ	TJK	TKM	UZB	Regional	KGZ	KAZ	TJK	TKM	UZB
5	$1,876.9	$124.8	$976.6	$237.6	$150.5	$612.3	1.12	2.20	1.75	3.19	2.73	0.66
10	$2,170.6	$150.0	$1,200.6	$288.3	$207.2	$786.7	1.30	2.65	2.15	3.87	3.76	0.85
25	$2,481.9	$179.2	$1,474.3	$345.7	$282.7	$993.5	1.49	3.16	2.64	4.64	5.13	1.07
50	$2,677.5	$197.7	$1,655.5	$378.0	$336.2	$1,126.7	1.60	3.49	2.96	5.08	6.10	1.22
100	$2,871.1	$215.7	$1,807.9	$404.2	$380.3	$1,253.2	1.72	3.81	3.23	5.43	6.90	1.35
250	$3,145.9	$232.4	$2,030.0	$445.4	$443.7	$1,435.5	1.88	4.11	3.63	5.98	8.06	1.55
475	$3,322.4	$240.7	$2,207.4	$479.2	$483.7	$1,542.6	1.99	4.25	3.95	6.44	8.78	1.67
500	$3,335.5	$241.2	$2,222.1	$482.0	$486.3	$1,550.7	2.00	4.26	3.98	6.47	8.83	1.68
1000	$3,519.0	$248.6	$2,387.8	$513.3	$522.2	$1,657.8	2.11	4.39	4.27	6.90	9.48	1.79
AAL	$1,513.7	$91.0	$726.6	$173.7	$89.40	$432.96	0.91	1.61	1.30	2.33	1.62	0.47

As in the case of earthquakes, the exposure of industrial sites and critical and supply infrastructure to different flood hazard levels was carried out. Table 18 to Table 20 show respectively: the number of industrial sites, kilometers of water and communications infrastructure, and kilometers of transport infrastructure in the study area exposed to different levels of flood hazard. Table 21 to Table 23 shows respectively: the number of buildings, assets and length of assets damaged due to flood, for each asset group separately and combined.

Table 18. Number of industrial sites in the study area exposed to different flood (undefended case) hazard intensities at different return periods

Flood (undefended case) hazard intensity (m)		Number of industrial sites							
Lower limit	Upper limit	5yrs	10yrs	20yrs	50yrs	100yrs	200yrs	500yrs	1000yrs
0.0	2.0	8,799	8,794	8,791	8,784	8,774	8,762	8,734	8,693
2.0	4.0	2	6	9	12	22	31	49	78
4.0	6.0	1	2	1	5	4	3	11	20
6.0	8.0	1	0	1	1	1	4	5	5
8.0+		0	1	1	1	2	3	4	7

Table 19. Kilometers of water and communications infrastructure in the study area exposed to different flood (undefended case) hazard intensities at different return periods

Flood (undefended case) hazard intensity (m)		Kilometers of water and communications infrastructure							
Lower limit	Upper limit	5yrs	10yrs	20yrs	50yrs	100yrs	200yrs	500yrs	1000yrs
0.0	2.0	91,928	91,674	91,390	90,966	90,701	90,430	90,081	89,760
2.0	4.0	172	378	590	879	1,027	1,153	1,243	1,357
4.0	6.0	28	66	122	225	303	379	521	611
6.0	8.0	4	10	22	45	77	128	193	246
8.0+		1	4	9	18	25	43	93	158

Table 20. Kilometers of transport infrastructure in the study area exposed to different flood (undefended case) hazard intensities at different return periods

Flood (undefended case) hazard intensity (m)		Kilometers							
Lower limit	Upper limit	5yrs	10yrs	20yrs	50yrs	100yrs	200yrs	500yrs	1000yrs
0.0	2.0	214,020	213,720	213,381	212,856	212,399	211,839	210,947	210,126
2.0	4.0	197	405	650	1,019	1,345	1,733	2,316	2,810
4.0	6.0	37	89	135	237	314	413	594	744
6.0	8.0	15	30	51	70	101	146	217	317
8.0+		16	41	68	103	126	153	210	288

Table 21. Number of buildings damaged (for each asset group separately, and combined), flood (undefended case), 100ys return period

Country	Residential	Commercial	Education	Healthcare	Combined
KGZ	4,009	220	18	1	4,248
KAZ	149,730	3,018	109	35	152,892
TJK	9,810	587	10	7	10,414
TKM	15,191	935	83	2	16,211
UZB	35,127	1,018	183	8	36,336

Table 22. Number of assets damaged (for each asset separately, and combined), flood (undefended case), 100ys return period

Country	Bridges	Energy	Combined
KGZ	126	0	126
KAZ	822	4	826
TJK	157	6	163
TKM	101	0	101
UZB	235	1	236

Table 23. Length (km) of assets damaged (for each asset group separately, and combined), flood (undefended case), 100ys return period

Country	Water & Communication	Transport	Combined
KGZ	38	267	305
KAZ	2,126	3,074	5,200
TJK	94	401	495
TKM	322	636	958
UZB	241	362	603

After analyzing the results obtained in this project, this last part of the section discusses the main findings. For the case of earthquake risk, several Oblasts in the Kyrgyz Republic and Tajikistan have large relative AAL's, above 3‰, such as Osh, Chuy, Jalal-Abad, Batken and Ysyk-Kol in the former, and the Khatlon Province and the Cities and Districts of the Republican Subordination in the latter. Although in all countries the largest absolute earthquake AALs correspond to the residential sector, it must be noted that it is because of its large exposed value. In relative terms, the commercial sector has the largest relative AAL's (around 5‰) in the five analyzed countries with similar values for the Kyrgyz Republic and Tajikistan. Regarding the earthquake fatalities estimation, in absolute terms the largest average number of fatalities is found to be in the Khatlon Province (Tajikistan), for the current and future scenarios (all SSPs). Other Oblasts with a high estimate of earthquake fatalities are Chuy and Osh in the Kyrgyz Republic, the Cities and Districts of the Republican Subordination in Tajikistan, and Almatinskaya in Kazakhstan. For the future risk scenarios, the overall trend is a decrease in the earthquake fatality risk with exception of the Khatlon Province for which, under the SSP4 assumption, the average annual number of fatalities increases by 20%.

For the case of flood risk (undefended case), the largest relative AALs are found in Kazakhstan and Tajikistan, with values above 6‰. In the five analyzed countries, the largest relative AALs by sector are found for the transport and agricultural sector (the two types of crops included in this assessment: cotton and wheat). For the case of cotton crops, the largest relative AALs are found in Kazakhstan, Turkmenistan, and Tajikistan always with values above 6‰. Regarding flood risk fatalities, the largest results are found, as expected for the undefended case. In this sense, the largest values are found for the Akmolinskaya Oblast in Kazakhstan and Khatlon Province in Tajikistan. On average, at Oblast level, there is a decrease of 20% of flood fatalities' risk in the defended case. Regarding future scenarios, and considering climate change, there is a variable trend at Oblast level for the flood fatalities risk, although consistent among the considered SSPs. On the one hand, there is the case of the Mangistauskaya Oblast in Kazakhstan where the increase of this metric is by seven times, although more common values are increased by a factor between 1.5 and 2.0 such as in the following Oblasts: Sirdarya (Uzbekistan), Ysyk-Kol, and Jalal-Abad in the Kyrgyz Republic and Turkistan and Karagandiskaya in Kazakhstan. On the other hand, there are Oblasts for which decreases between 80 and 90% are observed for all SSPs, such as Lebap (Turkmenistan), Khatlon Province (Tajikistan), Samarkand (Uzbekistan) and Batken (Kyrgyz Republic).

As previously mentioned, the flood hazard modelling for current scenario was carried out for two cases: defended, and undefended. As expected, flood risk is lower for the defended case although certain care must be taken when interpreting these results because of the uncertainties explained in the previous section regarding the assumption of existence of flood defenses. However, a comparison between the two cases at Oblast level can be made and some discussion is provided next. Regardless the case, the Oblast with the largest flood AAL is the Badakhshan Autonomous Mountainous Region in Tajikistan. The largest relative difference caused by modelling the defenses is found in Batken Oblast (Kyrgyz Republic) although for the undefended case the flood risk AAL was relatively low (0.4‰). A major flood risk reduction because of the defenses is observed in Ysyk-Kol Oblast, with a decrease of around 40% which is notable considering the large flood risk AAL for the undefended case.

Combined results (earthquake and undefended flood), show that there are Oblasts such as Jalal-Abad (in the Kyrgyz Republic), and Khatlon Province and the Cities and Districts of the Republican Subordination (in Tajikistan) where the risk caused by these two hazards is high. On the other hand, there are Oblasts where only the risk caused by one of these hazards is relevant whereas the other is very low, as in the case of Zapadno-kazachstanskaya (in Kazakhstan) where the undefended flood relative AAL is almost 6‰ and earthquake relative AAL is approximately 0.1‰, or the case of Almatinskaya Oblast (in Kazakhstan) where earthquake relative AAL is above 2‰ but undefended flood relative AAL is lower than 0.5‰. Similar results can be observed for the Sughd Province (Takikistan) and Namangan (Uzbekistan) with large and low relative AALs for earthquakes and floods, respectively, or for Karakalpakstan (Uzbekistan), Lebap (Turkmenistan) and Akmolinskaya (Kazakhstan), with large and low relative AALs for floods and earthquakes, respectively.

Regarding the comparison of earthquake risk for current and future (2080) scenarios and bearing in mind that the exposure projection has only been made for the residential sector, regardless the reviewed SSP there is a decrease of future risk, measured in terms of relative AAL and specific return period losses, for all countries. This decrease in most of the cases is around 30% and are maintained regardless the scale of the aggregation of the losses (i.e., Oblast, country, or regional level).

2.7 Task 7 - Landslide Scenario Assessment

2.7.1 Objective

The rough topography of Central Asia, encompassing high mountain chains especially at its southern and eastern borders, along with complex geological structures and active tectonics/seismicity are important landslide predisposing factors, making landslides the third most prevalent natural hazard in Central Asia, following earthquakes and floods (CAC DRMI, 2009). During the two decades spanning between 1988 and 2007, according to observed estimates, out of 177 reported disasters 13% were landslides, which caused 700 deaths. In the same period landslide-related economic losses have been as high as $150 million, including damage to infrastructures, settlings and agricultural/pasture lands, as well as displacement of the population (GFDRR, 2009; 2016). Due to their large size and impact, most of the occurring landslides have profound transboundary implications. Tajikistan and Kyrgyz Republic are the countries most impacted by landslides: in Tajikistan around 50,000 landslide were mapped, 1,200 of which threaten settlements or facilities (Thurman, 2011), while Kyrgyz Republic has been affected by 5,000 landslides, of which 3,500, at various levels of activity, are located in the southern portion of the country (the Fergana Valley) (Pusch, 2004). Only in the Kyrgyz Republic, up to 2017, 784 landslides and 1658 among mudflows and flash floods caused 352 victims (Kalmetieva et al., 2009; Havenith et al., 2015a, b; 2017). Almaty province in Kazakhstan, Tashkent, Samarkand, Surkhandarya, Kashkadarya Provinces of Uzbekistan are also exposed to landslides (World Bank, 2006). For these reasons a regional scale landslide scenario assessment was performed based on an integrated geo-statistical methodological approach (World Bank, 2022g). The proposed approach represents an innovation in terms of resolution (from 30 to 90 m), of extension of the analyzed area and of different analyzed landslide effects (e.g., river damming potential) with respect to previous regional landslide susceptibility and hazard zonation models applied in Central Asia (e.g., Nadim et al., 2006; Havenith et al., 2015b; Stanley and Kirschbaum, 2017; Pittore et al., 2018). For each studied country the landslide susceptibility distribution in the area covered by elements at risk, such as roads, railways, and buildings, was assessed using the data gathered by the Consortium. The river damming susceptibility was also analyzed with a new tool developed in a GIS environment (Tacconi Stefanelli et al., 2020).

2.7.2 Data

As a part of the proposed multi-hazard approach, within this project the most detailed landslide inventories covering both national and transboundary territories in Central Asia were collected, thanks to the availability of new global data, the academic network of the Consortium, and the contribution and resources from the local partners (scientists and practitioners) involved in the current project (Behling et al., 2014, 2016, 2020; Havenith et al., 2015a; Juliev et al., 2017; Kirshbaum et al., 2015; Strom and Abdrakhmatov, 2018; Pittore et al., 2018; Niyazov R.A. 2020). The susceptibility model was fed with independent variables, namely twenty "basic parameters" selected in the central Asian countries, based both on the available data and on those most widely adopted in the literature (Catani et al., 2013). Many of these data are DEM-derived products (e.g., elevation, aspect, slope, slope curvature, flow accumulation, etc.). It must be considered that the resolution of the susceptibility maps depends on the resolution of the input data. Therefore, it was decided to adopt pixels corresponding to the MERIT DEM resolution.

In addition, the DEM itself was used as a reference map, so that the other parameters were processed to have a perfect overlapping (in this way the resulting landslide susceptibility maps was also perfectly overlapped). The variables, such as lithology and land use, were rasterized with this resolution by choosing the most frequent value in a reference window. In addition to the twenty "basic parameters", in this study it was decided to use some innovative parameters, related to the propensity of the territory to be affected by precipitation. These parameters were obtained from the ERA5 database. These data, spanning from 1981 to 2020 and having an hourly resolution (which were summed to daily resolution for this work), provided a robust data set for the analyses. Regarding the river damming susceptibility, besides the landslide inventories the data used for the procedure were a Digital Elevation Model (with the higher resolution freely available from the NASA's SRTM project with 30 m resolution), and the river network database provided by the RED Consortium partners.

2.7.3 Methodology

2.7.3.1 Landslide susceptibility

Landslide susceptibility models identify those areas where landslides can occur, based on their geological, morphological, and climatic characteristics. To generate the landslide susceptibility map in this work, the Random Forest model (RF) was used. The RF model is a nonparametric and multivariate machine learning technique proposed by Breiman (2001), and first adopted in landslide susceptibility analysis by Brenning (2005). This model has been already developed and tested by the Consortium in a variety of applications at different scales and in different geological-geomorphological and geographic settings (Catani et al., 2005, 2013; Trigila et al., 2013; Casagli and Catani, 2020). Among the advantages of using the RF algorithm, there is the possibility of using numerical and categorical variables at the same time, without assumption on the statistical distribution of their values.

2.7.3.1.1 Model optimization and training

In the RF model the collected landslide inventories are considered as the dependent variables, while as independent variables the abovementioned basic and innovative parameters were fed to the model. Once all the data were prepared and organized, the algorithm to create the landslide susceptibility maps was developed. As a consequence, the variables were sampled pixel by pixel, after which from the total of the sampled points, all the points within a landslide and a same amount of randomly chosen non-landslide points were extracted. This database was divided into two parts, 70% of the data (calibration dataset) was used for the training phase, and the remaining 30% (validation dataset) for the testing phase. Each one of these datasets was created to be equally composed by pixel within a known landslide and pixel outside any known landslide. All these data were then used to train and test the created algorithm to obtain the best predictor tree of the landslide susceptibility of the whole area. RF also automatically performs a validation by building a Receiver Operating Characteristic Curve (ROC Curve) and calculates the relative Area Under the Curve (AUC): this can range from 0.5 (completely random predictions) to 1.0 (maximum quality of prediction). The quality of the susceptibility model has been also evaluated using a confusion matrix: a table where true classes of the pixels are compared with the predicted classes, to verify how many pixels are correctly (True Negative or True Positive) or wrongly (False Positive or False Negative) classified.

2.7.3.2 Landslide susceptibility and assets at risk

The susceptibility map of the study area was intersected with the assets at risk, consisting of roads-railways, buildings and population. This database was obtained by the activities of Task 4. The aim of this activity was to define the landslide susceptibility distribution in the area covered by assets at risk through a simple overlapping of the abovementioned databases and susceptibility map.

2.7.3.3 River damming susceptibility

A semi-automated GIS-based mapping methodology, based on a statistical correlation of morphometric parameters described by the Morphological Obstruction Index (MOI) (Tacconi Stefanelli et al., 2020), was adopted to spatially assess the likelihood of a river obstruction by landslide damming for two main mechanisms: the reactivation of existing landslides and the formation of new landslides. Concerning the damming susceptibility caused by new landslides along all the river network in the study area, two different maps were produced using the Non formation and Formation volumes values. The former provides the volumes of landslides that surely create an obstruction, while the latter the yields volumes below which obstructions certainly do not form. The magnitude of the damming susceptibility has been classified in five categories according to landslide volumes classes. The five volumes intervals describing damming susceptibility were decided according to general value distribution of landslides volumes and using an expert judgement.

2.7.4 Results

2.7.4.1 Landslide susceptibility

In the map presented in Figure 22, the susceptibility values, ranging from 0 to 1, were classified into five classes (Table 24) according to the Natural Breaks Method of Jenks, widely adopted in the literature. Here the corresponding extension and percentage of the study area are also reported, showing that the most frequent susceptibility class for the whole study area is the null class (=85%; landslides do not occur in flat areas), followed by low-medium classes (see also Figure 20). Only the 2.3% of the central Asian territory is represented by areas with high-to-very-high landslide susceptibility (Table 24).

Table 24. Landslide susceptibility class intervals, corresponding area, and percentage with respect to CA

Susceptibility class	Landslide spatial probability interval	Corresponding area (km^2)	Corresponding percentage of CA (%)
Null	0 - 0.05	2,890,811.5	88,5
Low	0.05 - 0.31	156,615	4.8
Medium	0.31 - 0.48	144,868.3	4.4
High	0.48 - 0.78	72,450.7	2.2
Very High	0.78 - 1	2,151	0.1

As we can see in the ranking of the susceptibility parameters reported in Figure 21, land use, lithology, elevation, the distance from roads and from earthquake hypocenters play a crucial role in landslide susceptibility, since these are the five most influencing factors. Rainfall parameters are also important in the obtained landslide susceptibility, in particular the 1-day rainfall value shows the highest importance among the rainfall parameters. Also, the PGA at the slope location is a relevant factor, while the DEM-derived parameters such as Topographic Wetness Index and slope curvature are the less important. The AUC value of the models is 0.935 (where 0 is bad predictor, 1 represents a perfect predictor), indicating their very good quality. Such high AUC values can indicate the presence of overfitting issues, but this hypothesis can be discarded, since the random variable did not show any significant contribution to landslide susceptibility (Figure 21).

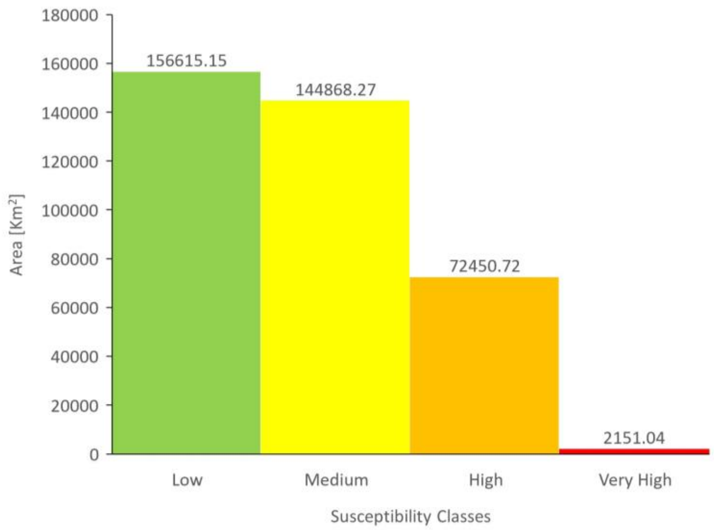


Figure 20. Frequency histogram of susceptibility classes for Central Asia; on each bar the corresponding area is reported in km² ("Null class" was not included to emphasize other classes).

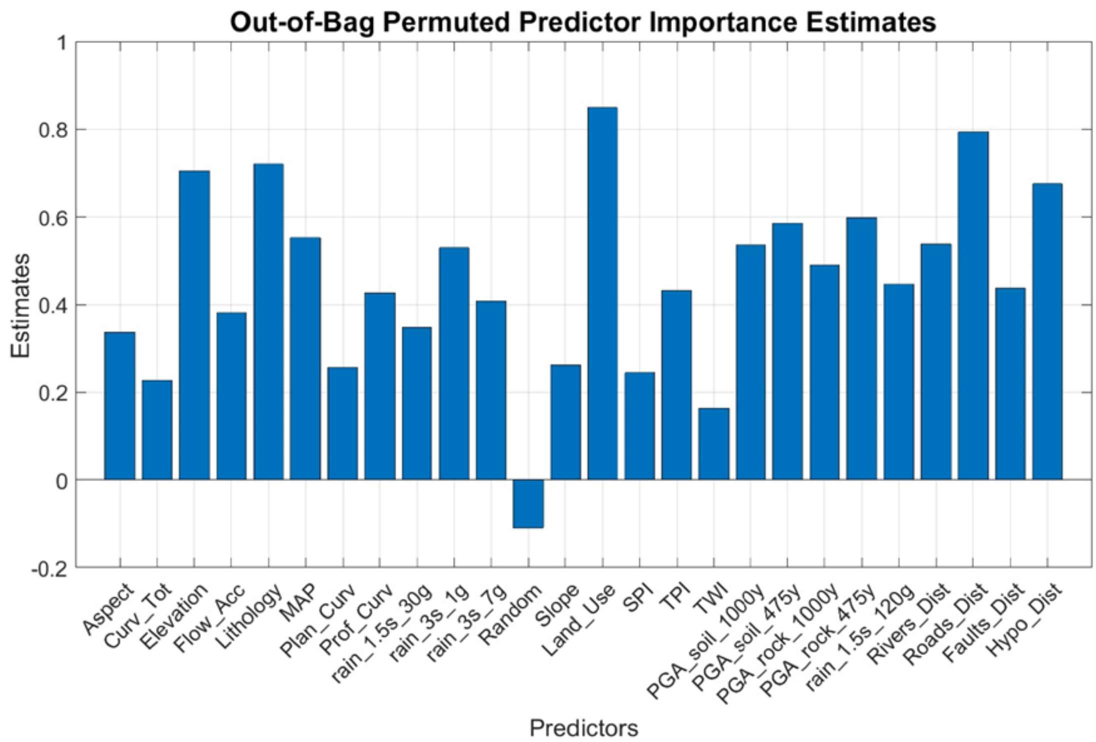


Figure 21. Variable importance in landslide susceptibility for the area where the model was trained.

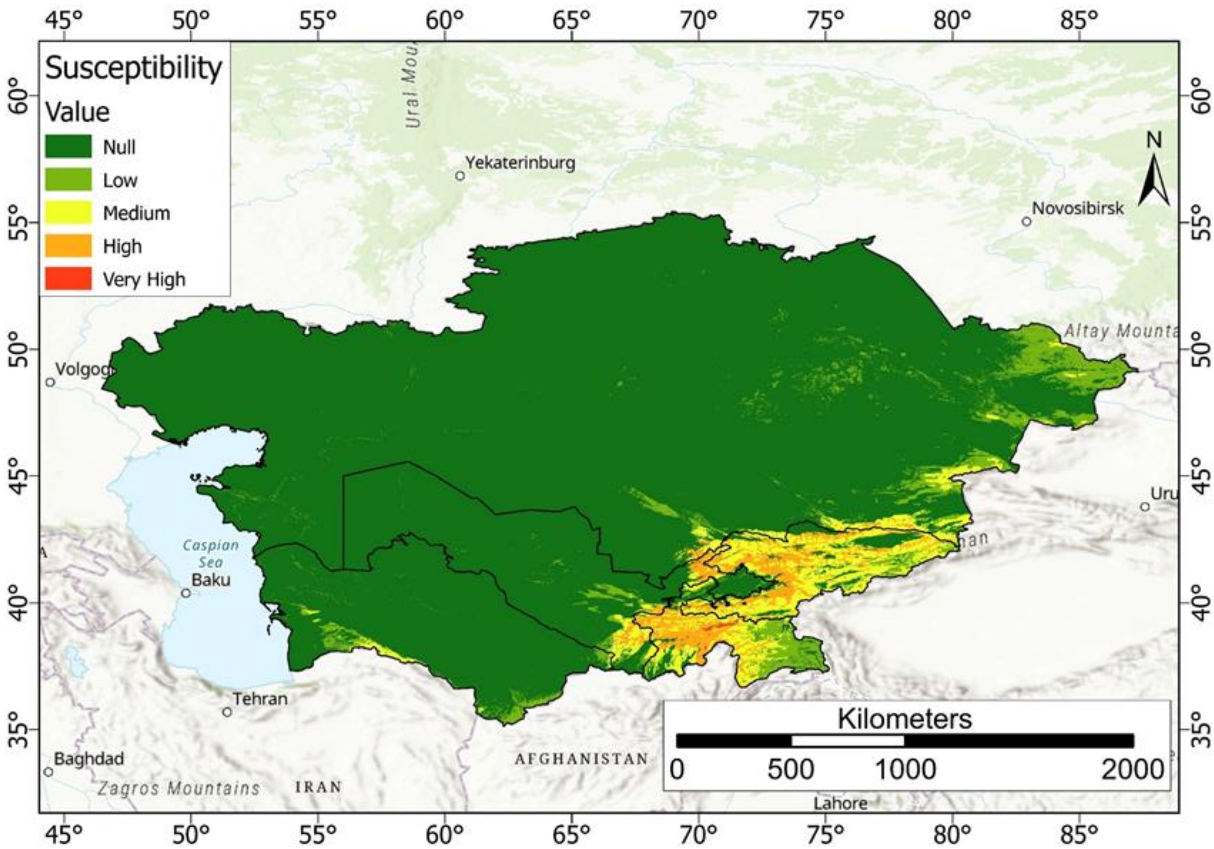


Figure 22. Landslide susceptibility map of the whole Central Asia

The outcomes regarding buildings and population prone to landslide hazard are represented in the pie charts in Figure 23. For roads and railways, 1-km long lines (named "transects") were considered in the analysis and divided in the corresponding landslide susceptibility classes. Statistical analysis for roads and railways was also performed considering the major classes: primary, secondary, tertiary, trunk, and motorway for roads; high-speed and conventional for railways (Figure 24).

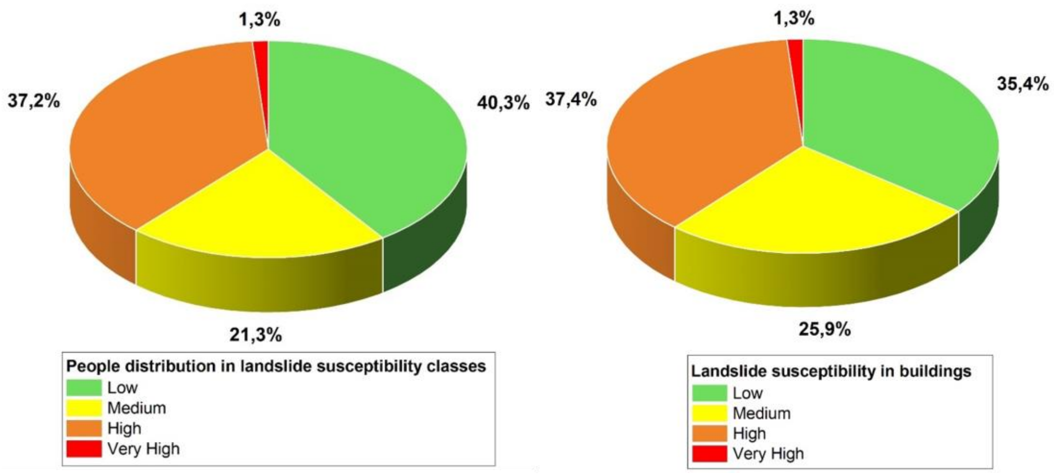


Figure 23. Pie chart of population (left) and building (right) distributions in landslide susceptibility classes.

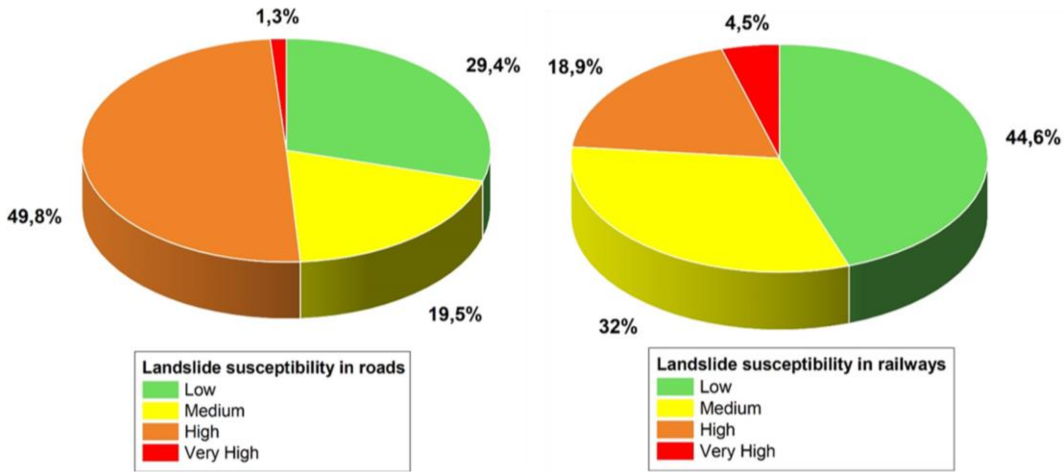


Figure 24. Pie chart of percentages of roads (left) and railway segments (right) in the different landslide susceptibility classes.

2.7.4.2 River damming susceptibility

The assessment of Damming Susceptibility on the available landslide inventory is shown in the map of Figure 25. This severely affects the deep narrow valleys in the area most mountainous sectors. In the class distribution shown in Figure 26 the most frequent class is the Very Low, with 81% of the whole database, followed by the Moderate with 9% and the remaining percentage divided among the Very High (7%), Low (2%) and High (1%) classes. This distribution is quite coherent with the landslide volumes frequency distribution, since it is reasonable to associate landslides having very low volume (83%) with those classified with very low susceptibility (81%, Figure 26).

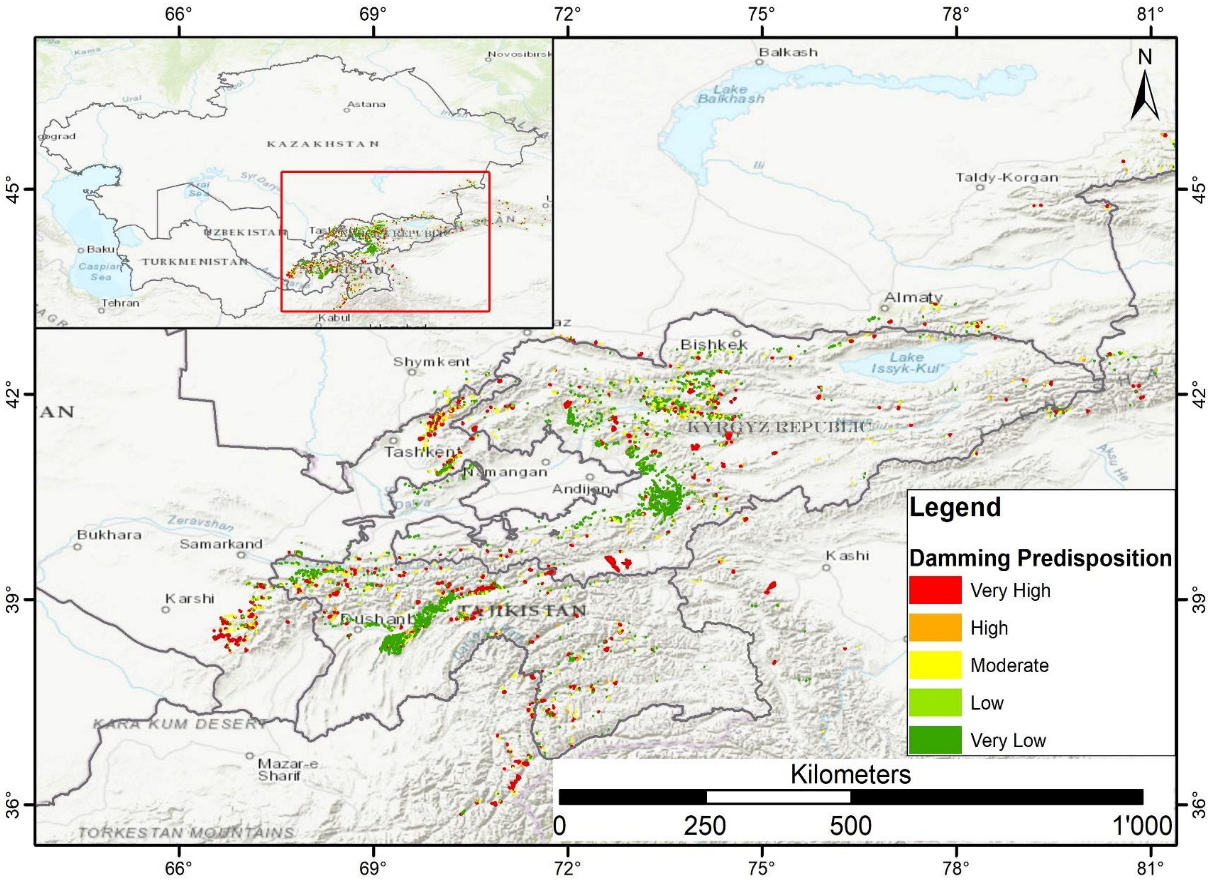


Figure 25. Map of Damming Predisposition by reactivation of landslides in Central Asia.

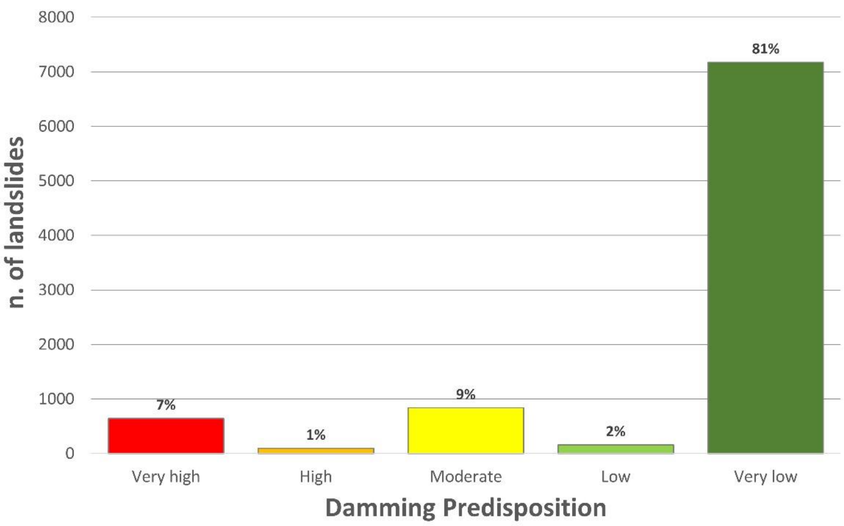


Figure 26. Classes distribution of the damming predisposition for landslides reactivation.

The landslides classified with the higher values of susceptibility (Moderate, High, and Very High with a total of 17%) instead do not only include landslides with higher volumes (more than 100 million m^3 representing 4% of the total). This implies that also even smaller landslides can potentially block narrow river stretches. Detailed slope scale landslide hazard assessment should be performed in correspondence of the high number of landslides (644 cases) that are classified with Very High damming predisposition (in particular those located nearby urban areas).

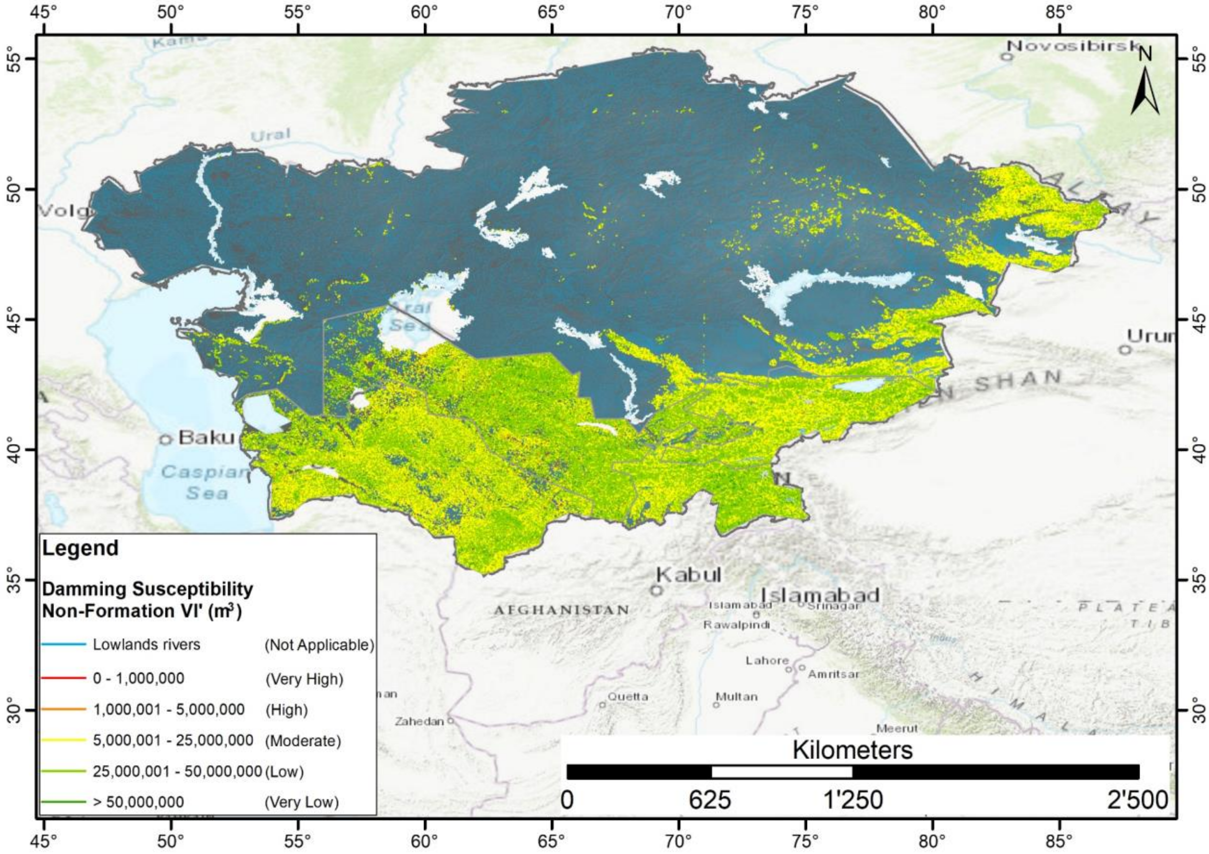


Figure 27. Damming susceptibility map of Non-Formation of river stretches by new landslides in the region.

In the map of damming susceptibility of the river network related to the "Non formation", reported in Figure 27, the Moderate and Low classes are the most frequent, with 4.4% and 5.8% respectively (river stretches where it is not applicable are not taken into account, as reported in Figure 28). Regarding the map of damming susceptibility of the river network related to Formation values, (Figure 29), the most frequent classes (without considering the river stretches where it is not applicable) are the two lowest ones, Low and Very Low, with 4.4% and 6% respectively, as described in Figure 28. This implies that the minimum landslide volume necessary to have the river valley dammed, with a confidence of 99%, has values bigger than 25 million m^3.

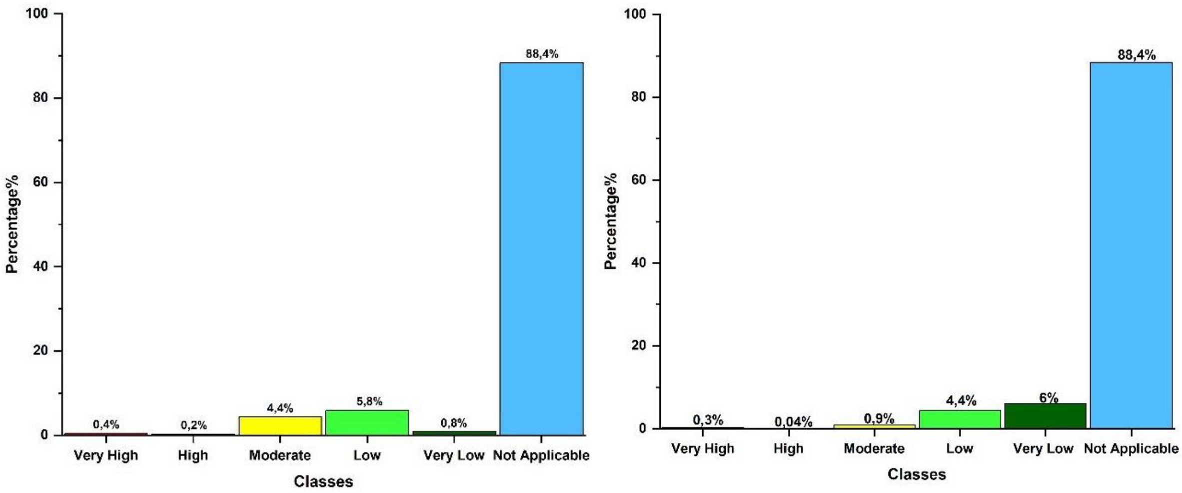


Figure 28. Distribution of the damming susceptibility in the study area by new landslides related to Non formation (left) and Formation (right) boundary values.

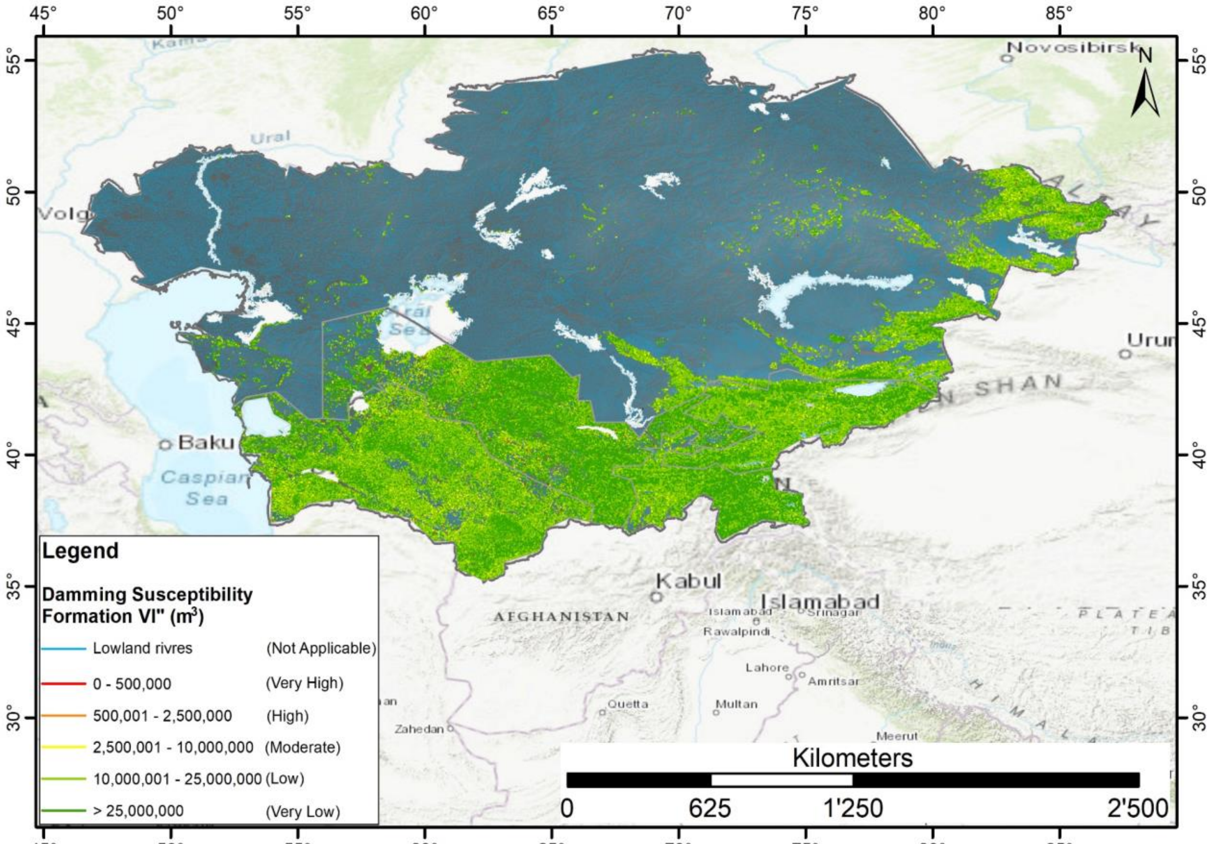


Figure 29. Damming Susceptibility Map of Formation of river stretches by new landslides in the region.

3 Task 8 - Capacity Building

The main activity of Task 8 (World Bank, 2022h) consisted in the organization of a series of eight capacity building workshops devoted to the different risk components, namely five country-based workshops on exposure assessment and three regional thematic workshops on hazard, vulnerability and risk modelling. This activity was carried out in close collaboration with local experts and representatives from all five countries of the region. The workshops provided participants an opportunity to learn about international best practice and latest methodologies related to natural risks assessment.

Due to the continued Covid19 emergency, all workshops were held in online mode; this restriction eventually turned out to be an advantage, as it allowed for a much broader participation, which largely exceeded expectations, especially for the regional thematic workshops. Participation was pretty active and variegate, involving not only individuals from academy and research institutes, but also a significant number of representatives from Ministries, professionals, young experts and students, as detailed in the following. The feedback from participants, received through anonymous evaluation forms and via email, was especially positive and encouraging, indicating that the topics covered by the workshops were relevant to their current work and that participants are likely to use the presented tools and data in their activities. A summary description of the capacity building workshops, including attendance and feedback from participants, is provided hereinafter; full descriptions and participation reports can be found in the Annexes.

3.1 Objective

Building capacity of local experts, institutions, and research groups with a role in DRM and emergency planning in Central Asia countries was one of the key objectives to be achieved throughout the project. The project, in fact, had the main intent of harmonizing risk assessment at the regional scale of Central Asia, including available input data and methods, based on efforts and results from earlier studies and projects. In this framework the capacity building workshops provided an excellent occasion to discuss and demonstrate the value of the methods that were applied within the project for large-scale risk assessment, and to show how they complement and advance what was previously done in the region. The involvement of local scientific experts (including project partners, RSTC members and invited speakers) was essential in recognizing and supplying relevant information from methodologies previously applied in each country, as well as to discuss the possibilities offered by the newly proposed procedures and to validate their products. To increase the impact of the capacity building activities and to cascade the training, local universities, research institutes and associations have been involved, so as to reach younger professionals and experts.

Special attention in the capacity building activities was devoted to the exposure component. Specifically, five country-based workshops have been organized to provide training on methods in exposure data collection, and on combination of ground data with remote sensing data. These workshops allowed sharing knowledge with local experts and provided an opportunity for emergence and inclusion of a greater amount of locally collected information into the analysis. During the workshops participants were involved in hands-on exercises and trained with the goal to enable them to autonomously develop and update the exposure layers in future. The training programs, including the detailed agenda of each of the eight workshops, were outlined with the fundamental support from the World Bank. The active discussions about the organization and content of the lectures, tutorials, and presentations by local expert speakers, as well as the use of capacity building practices recommended by World Bank, substantially contributed to the success of the training.

In summary, the objective of the capacity building activities, realized through a series of eight workshops, was to enhance the understanding of the overall approach and methodologies applied for the risk assessment, and their potential applications by key local experts and stakeholders. This was especially relevant for the workshops on exposure mapping, where participants (young professionals in particular) had the opportunity to interact with international and local experts and get timely explanation on novel data methodologies applied in the process of risk assessment.

3.2 Structure and content of capacity building workshops

To achieve capacity building and training of local experts in DRM in Central Asia region, a series of workshops was planned. Besides the Inception and Final Workshops organized by the World Bank, the following eight Workshops were held (see Table 25 for details):

- **Five Country-based Workshops on Exposure assessment,** one workshop in each of the involved countries: Kazakhstan, Kyrgyz Republic, Tajikistan, Uzbekistan and Turkmenistan. These workshops, which account for the country-specific needs and data availability, had a significant practical training component, involving analysis of selected test cases and hands-on software tutorials. Each workshop included a final panel discussion, focused on challenges and possibilities offered by the proposed methodologies towards building a comprehensive exposure database in the respective countries.
- **Three regional Thematic Workshops on the different components of risk assessment,** namely**:** Hazard modeling**;** Vulnerability modeling and Risk assessment. These methodological workshops introduced participants to the international best practice and the latest methodologies and tools implemented in the framework of the Project. The program also included selected contributions from qualified local and national experts, providing state-of-the-art description of existing data and applications in their respective countries. Each workshop comprised focused discussions in order to identify the main issues and challenges encountered by the participants; the workshops on Vulnerability and Risk modeling, in particular, had two panel discussions, one manly focused on available data and their harmonization, and another on implementation of the proposed methodologies.

Workshops lectures and materials, particularly hands-on exercises, were tailored on local communities of scientific and technical experts. All the partners contributed to the discussion of contents and preparation of training materials, which allowed to successfully transfer the knowledge to the participants. All workshops allocated space for questions and interaction with the participants, in order to collect the feedback of the local communities. The contribution of local partners and World Bank representatives revealed essential, in order to effectively identify and involve local communities of experts. The World Bank also assisted in partial organizational support, particularly in sharing contact information and soliciting participation of representatives from Ministries and Agencies (both at national and urban scale). For this purpose, before each workshop, two dedicated meetings were organised with the World Bank, to discuss the details of the capacity building workshops, including dates, methods and participants list.

In view of the restrictions imposed by the Covid19 emergency, **online organization of the workshops** turned out to be a necessary and valid alternative to in-person workshops. Due to the virtual organization of the activities, the workshops had a longer duration, namely 4 days, half-day only, instead of 2 full days originally planned for in-person workshops. In this way participants were allowed sufficient time to practice independently and interact with lecturers about data (especially during Exposure workshops); this organization also allowed to better deal with the technical difficulties that were faced by some of the participants (e.g., connection problems). The program of all workshops, except for the Turkmenistan country-based workshop, was organized according to a similar structure: specifically, the activities were scheduled over 4 days (from Tuesday to Friday), in the afternoon only (approximately from 14:00 to 18:00 pm, local time), which turned out the most convenient time especially for participants from Ministries and Agencies. The workshop on Exposure assessment in Turkmenistan had a shorter duration (3 days, about 3 hours/day) and simplified agenda, with less exercises/online forms, in order to meet the specific audience and connection resources available in the Country. **The online organization mode**, in spite of the mentioned (non-critical) technical difficulties and possibly reduced interactions, had the main advantage of **significantly increasing the audience** of the workshops. In fact, instead of the 40 participants who were originally foreseen for the in-presence workshops, the number of attendees exceeded 100 individuals for the Country-based workshops and 300 individuals for the Thematic workshops.

To enhance **participation and visibility of the organized workshops**, different strategies were adopted. Besides the official invitation letters to Ministries and governmental Agencies, which were prepared in collaboration and delivered by World Bank, the Consortium sent formal invitations to a list of Research Institutes and Universities identified by Local partners in their respective countries. Dedicated **web pages** for each workshop, including full agenda and registration instructions, were published both on Eventbrite platform and on OGS institutional website. Application/registration forms were set up using Google platform; on account of technical issues encountered by some participants, also Microsoft and offline (PDF) registration forms were made available. All the web pages and application forms were set up and published in both English and Russian versions. To facilitate participation of individuals to the workshops on the different components of risk assessment, information about the Thematic Workshops was delivered to all registered participants from country-based workshops on Exposure assessment. Finally, to increase visibility of the capacity building activities, draft press releases were prepared and delivered to World Bank, and posts were published on RED and OGS social (e.g., Facebook, LinkedIn) at the time of each workshop.

Participation was open to scientific/technical experts and practitioners, including research groups, engineers, territorial planners, representative of the main institutions and facility managers from all Central Asian countries. Participation was allowed by invitation and through on-line application process; invitation, registration, and final selection of the participants was carried out in close collaboration with the World Bank. Initially the number of participants foreseen for each workshop was limited to 40 individuals for in-presence activities, and up to 60 participants, in case of fully on-line workshops. Restrictions on the number of participants to the Country-based workshops were imposed by the need to create individual accounts for hands-on exercises on exposure assessment. Such restrictions were released for the regional thematic workshops, which allowed removing limitations on the number of participants (and related selection procedure); this increased significantly the participation, which exceeded 300 individuals from Central Asian countries.

Participation in the capacity building workshops of young professionals and students was promoted advertising the workshop among professors and students from relevant university courses, with the assistance of Local Partners. Professors and thesis supervisors were allowed to submit applications for selected students, and in the final selection of participants (carried out, when necessary, in collaboration with World Bank) priority was given to young professionals and best students.

All workshops were delivered in English and/or Russian, with simultaneous translation between the two **languages**. The associated training materials specifically developed for the Workshops (e.g., presentation slides, lecture notes, forms for hands-on exercises) were also released in Russian and English; the training materials were made available for download to the participants by the end of each Workshop. In addition, existing on-line courses and materials, including those previously developed by the World Bank (https://olc.worldbank.org/content/understanding-risk - also available in both Russian and English language), were suggested to participants to get the basic general background information, and were especially recommended to young professionals and researchers before attending the Workshops. Besides sharing the workshop materials, the lecturers from the Consortium remained available in the aftermath of the training activity, in order to answer questions related to the workshop content and provide support with exercises.

Certificates of attendance were issued to participants who attended at least three out of four days of the Workshop. Following World Bank indications, participation was checked twice per day (before and after the break). Attendance information was obtained by manual listing and automatic report of individuals connected to the Zoom session, as well as by information provided in the chat and via email (especially for participants attending in groups and/or using institutional login). It was observed that, while a portion of registered/nominated participants did not participate in the Workshops, a significant number of additional non-registered participants attended them; we argue that some of the registered participants were replaced by colleagues, who actually attended the Workshops, or joined in groups. Details about the participants' attendance and statistics, including full list of individuals participating day by day, were provided in the Participation reports delivered to World Bank after the end of each Workshop.

At the end of each Workshop, participants were requested to compile an anonymous questionnaire to gather suggestions for potential improvements. The feedback received via the **Evaluation form** was extremely positive for all workshops, and the received comments and suggestions, which were shared and discussed with World Bank, provided useful indications that were considered when planning the next activities. The evaluation forms included a section devoted to tutorials and hands-on exercises, which also allowed us assessing how many participants were able to follow and carry out practical exercises, and to get some feedback on the comprehension level of the training activities.

Summary participation reports were delivered to World Bank, to provide an overview of the participation in the Country based and Thematic Workshops, and including:

- Some general statistics about the participants (e.g., gender, language, specific skills), obtained based on information from Application/Registration forms, as well as a summary of attendance information collected during the Workshop;

- The checklist (Excel and PDF files) with information about daily participation, and identification of participants who received the Attendance Certificate;
- A daily list of all individuals attending the workshop (connected to the Zoom meeting, individually or in groups), including participants from World Bank, Consortium and Local Partners;
- The responses to the Evaluation Form (anonymous online form) that was compiled by the Participants, with their feedback on the Workshop activities, including their comments and suggestions.

An overview of the workshops content is provided in the next section and the workshops time schedule, venue and organizers, are summarized in Table 25. A summary discussion of the attendance and output of each capacity building activity is provided in the following.

Table 25. Workshops time schedule

TASK 8 Capacity Building WORKSHOPS LIST		ORGANIZER	TIME	LOCATION	TOPIC	DIRECTORS
T8.2 W1	Project inception	World Bank	January 2021	Online	Inception Workshop	
T8.4.1 TW3	Exposure mapping	Team OGS/RED	11-14 May 2021	Almaty Kazakhstan (Online)	Towards a regionally-consistent exposure database for Central Asia: characterizing buildings, crops and infrastructure in Kazakhstan	Chiara Scaini Ettore Fagà
T8.4.2 TW4	Exposure mapping	Team RED/ERN	15-18 June 2021	Biškek Kyrgyzstan (Online)	Towards a regionally-consistent exposure database for Central Asia: characterizing buildings, infrastructure and croplands in Kyrgyz Republic	Gabriele Coccia Ulises Cazares
T8.4.3 TW5	Exposure mapping	Team OGS/RED	27-30 July 2021	Dushanbe Tajikistan (Online)	Towards a regionally-consistent exposure database for Central Asia: characterizing buildings, infrastructure and croplands in Tajikistan	Chiara Scaini Paola Ceresa
T8.4.4 TW6	Exposure mapping	Team OGS/RED	19-22 October2021	Tashkent Uzbekistan (Online)	Towards a regionally-consistent exposure database for Central Asia: characterizing buildings, infrastructure and croplands in Uzbekistan	Chiara Scaini Paola Ceresa
T8.4.5 TW7	Exposure mapping	Team OGS/RED	1 - 3 December 2021	Ashgabat Turkmenistan (Online)	Towards a regionally-consistent exposure database for Central Asia: characterizing buildings, infrastructure and croplands in Turkmenistan	Chiara Scaini Paola Ceresa
T8.3 TW2	Hazard Modelling	Team OGS/RED	15-18 January 2022	Almaty Kazakhstan (Online)	Challenges of Multi-Peril Hazard Modelilng at Regional Scale: Assessing Earthquake, Flood and Landslide Hazard in Central Asia	Valerio Poggi Gabriele Coccia William Frodella
T8.5 TW8	Vulnerability Analysis	Team RED/OGS	22-25 February 2022	Almaty Kazakhstan (Onlline)	Vulnerability modelling for disaster risk assessment at the regional scale: an application in Central Asia	Ettore Fagà Gianbattista Bussi
T8.6 TW9	Risk Modelling	Team RED/ERN	26-29 July 2022	Almaty Kazakhstan (Online)	Risk modelling for earthquake and flood disaster mitigation in Central Asia	Paolo Bazzurro Mario Ordaz
T8.7 W10	Final project workshop	World Bank	October 2022	Almaty Kazakhstan	Final Workshop	

3.3 Country-based Workshops on Exposure Mapping

3.3.1 Country-based workshops description

Five country-based workshops focused on exposure assessment were organized in each of the involved target Countries, namely Kazakhstan, Kyrgyz Republic, Tajikistan, Uzbekistan and Turkmenistan, according to the schedule provided in Table 25. The workshops aimed to provide the basis towards the development of a regionally consistent exposure database for Central Asia, by means of the characterization of buildings, infrastructure and croplands in the different Countries, taking into account the local needs and available data.

All five workshops shared a similar structure, with significant time allocated to tutorials and hands-on exercises, as well as with the involvement of Local Expert Speakers, who presented their experience in exposure assessment for different perils in the specific Country. A final panel discussion closed each workshop, focused on the advantages and possible challenges in the application of the methodologies and data presented during the Workshop, towards the development of an up-to-date database of assets for risks assessment in the Country. The detailed description with agenda of the workshops is provided in Annex 1.

The theoretical and methodological framework for developing a regional-scale exposure datasets were introduced and **the exposure data available for each specific Country** were presented to put the basis for the hands-on activities, for which a sample set of already-collected data sources was provided. Participants were trained by tutors, who guided them using provided tools, as well as to prepare the necessary input data for exposure analysis. Case studies were selected amongst the national data available from past project on exposure assessment considering residential buildings, transportation system and critical infrastructures.

The exercises were focused on exposure fundamental topics, including:

- Guidelines for collecting and managing exposure data, including key attributes required for risk assessment (e.g., construction type and commercial value)
- Access to software and familiarization with basic tools
- Access to online resources
- Replication of the exposure assessment methodology
- Preparation of the necessary input files for the subsequent risk analysis starting from sample data
- Validation of the current datasets based on additional data (e.g., aerial images).

Hands-on exercises were carried out by making use of a set of specifically developed online forms (on Google platform), tailored for exposure data collection in the respective Countries. The use of anonymous online forms allowed carrying out the exercises in real-time mode: after the preliminary explanation, the necessary time was left to participants to fill in the forms, and results could be immediately checked and discussed by the tutors, thus allowing for a quite interactive training. After the completion of the exercises, a specific time was allocated to question and answer and/or review of the results, in order to interact with the participants, receive feedback and estimate the impact of the training.

These workshops, especially the tutorials and practical exercises, were tailored on participants' scientific and technical expertise. Along with the application forms, in fact, participants were requested to compile a questionnaire, which allowed identifying target groups (e.g., students, experts) and their interests and skills. A message with preliminary technical information, necessary

to carry out the hands-on exercises, including credentials to access the used software (i.e., Lizmap) and to links to ad-hoc materials/video tutorials, was delivered to registered participants a few days before the workshop, in order to allow them setting up and testing their computers for the exercises. Additional training materials (e.g., papers and manuals) were provided upon request.
One of the objectives of these country-based workshops was to provide the opportunity to gather missing information and to validate the exposure data layers with local participants, within their respective countries. Methodological and data harmonization was promoted as much as possible between the involved Countries, particularly during panel discussions and with the support by Mr. Jyrgalbek Ukashev (Center for Emergency Situations and DRR), who evidenced the importance of trans-boundary risk assessment. The project, in fact, aimed at large-scale risks assessment, which relies on regional scale data sets (e.g., remote sensing images of assets for exposure analysis) that must be complemented and validated with local data, which are highly reliable but often available only for limited areas. Expert knowledge also plays a crucial role in order to grasp the characteristics of the assets (e.g., building typologies) and generalize them to a wider territory. Accordingly, cross-checking and validation of large-scale remote sensing data versus national and local data and expert knowledge was one of the relevant activities carried out in the framework of the Exposure workshops. During the hands-on session participants had the possibility to get a deeper insight on both typologies of data, and to appreciate the value of remote sensing data. This eventually may provide the basis for future development of a specialized community of local experts, receptive and capable to exploit the different technologies.

3.3.2 Country-based workshops participation reports

The Country-based workshops on Exposure assessment were the first five Capacity Building activities carried out in the framework of the project. As they were addressed only to participants from the specific Country, the potential audience was naturally limited, compared to the thematic workshops; nevertheless, the number of registered participants (both applying online or nominated by Ministries) almost always exceeded the expected number of participants (originally limited to 40 individuals in presence, and 60 online). Following World Bank indications, participation was checked twice per day (before and after the break), including both registered individuals, as well as additional non-registered participants. It was observed that, while a portion of registered participants did not participate in the Workshops, a significant number of additional non-registered participants attended them; also several participants joined in groups, using their institutional account. Only participants who attended at least 3 days out of 4 days of the Workshop were entitled to receive the Attendance Certificate.

Figure 30 provides a synoptic view of the attendance for the different Exposure Workshops. It is possible to observe that participation increased progressively in the consecutive workshops, except for Turkmenistan (due to the significant technical connection difficulties). Participation was quite stable throughout the four-days of the Workshops, and more than half of the attendees received the certificate (i.e., participated for at least 3 days).

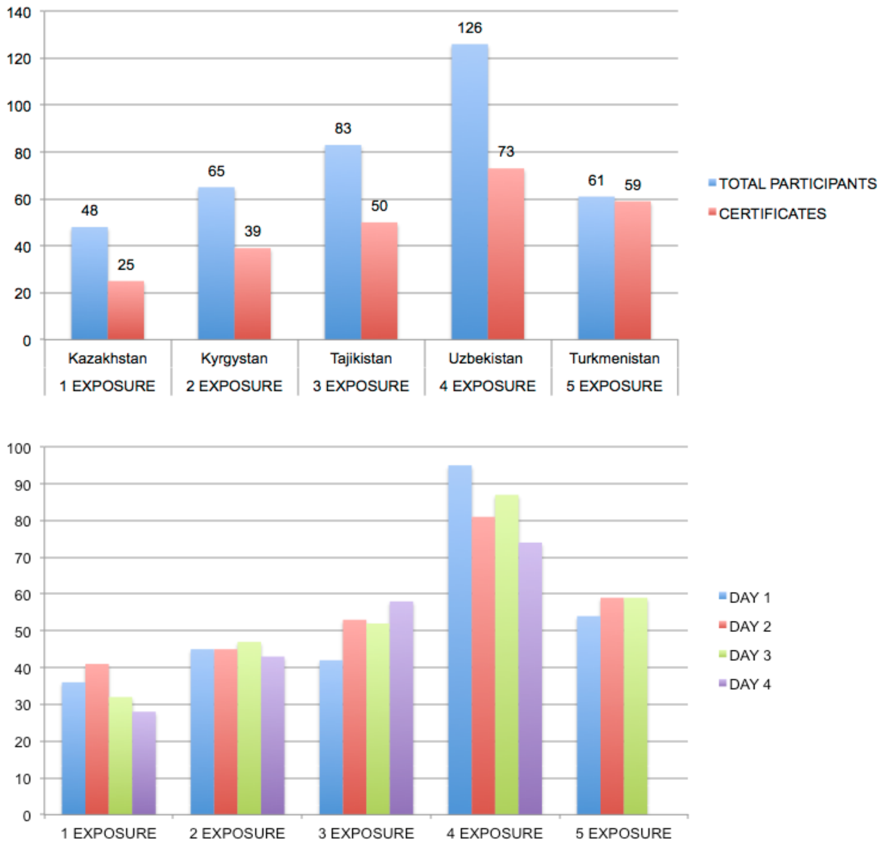


Figure 30. Number of participants in each of the five Country-based workshops on Exposure assessment: 1-Kazhakstan; 2-Kyrgyz Republic; 3-Tajikistan; 4-Uzbekistan; 5- Turkmenistan). Top panel: total number and number of participants with certificate. Bottom panel: daily participation in each workshop.

A statistical overview of the general characteristics of registered participants, both general features (e.g., gender, age, occupation) and specific features relevant to the Workshops (e.g., knowledge of GIS, engineering experience, type of data used) is provided in the following. The collection of participation reports for the individual Country-based workshops, with statistics obtained for the different countries, are provided in Annex 2.

The statistics of participants' **gender** (Figure 31a) shows that, even if participation of female was significant, there was a prevalence of male individuals, which could be observed in almost all countries, except Turkmenistan; the unbalance was especially evident in Uzbekistan. Most participants had an **age** below 40 years; while participation was prevalently in the age range 30-40 years in Kazakhstan, Uzbekistan and Turkmenistan, younger individuals with age 20-30 years prevailed in Tajikistan and Kyrgyz Republic (Figure 31b).

The participation of **students** was quite comparable in the different countries, although the proportion of students was rather low in Turkmenistan (Figure 32a). The knowledge of **English language** turned out to be comparatively high in Kazakhstan, and low in Turkmenistan. In all countries most of the participants understand English, at least in written form; still, a quite significant portion (about 20-30%) of the participants declared that they do not understand English (Figure 32b).

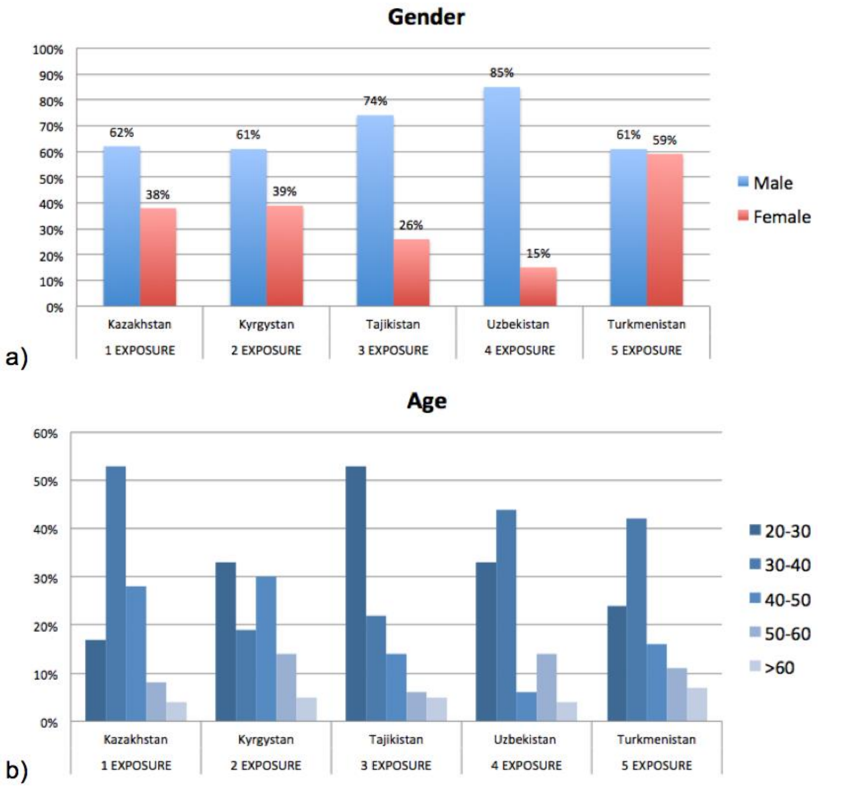


Figure 31. Distribution of participants versus: a) Gender and b) Age for each of the five Country-based workshops on Exposure assessment.

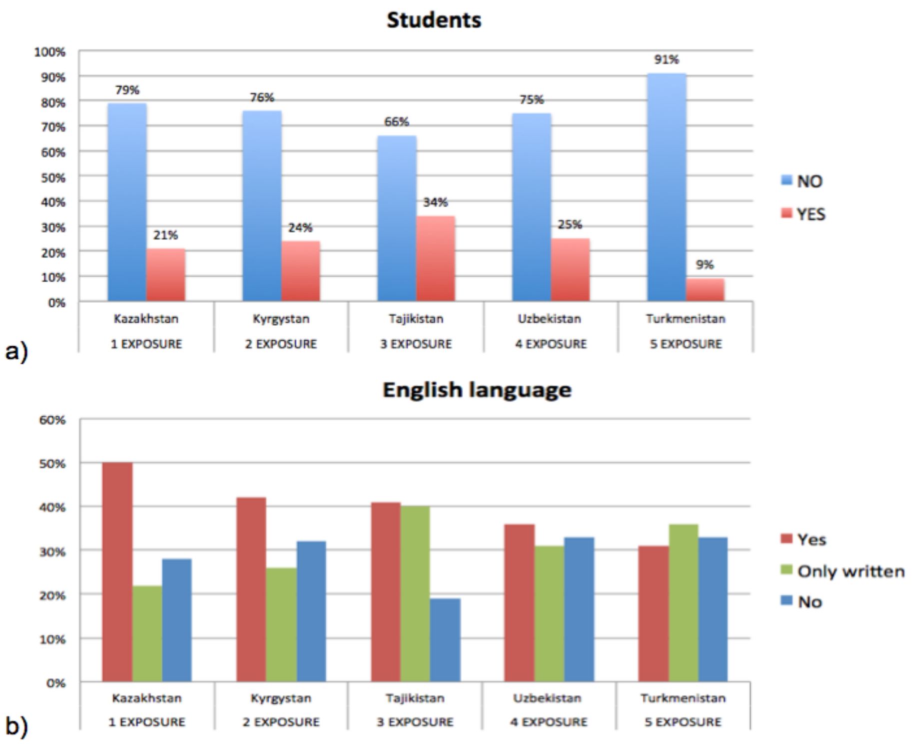


Figure 32. a) Percentage of students and b) knowledge of English language for the participants of the five Country-based workshops on Exposure assessment.

In all country-based workshops most participants were from Academy and Research institutes; involvement of professionals was also remarkable (about 15-20%) in most of the countries. In Kazakhstan, Turkmenistan there was a significant participation of representatives from Ministries (Figure 33a). The analysis of the type of data used by participants, revealed quite a heterogeneous situation in the different countries, with the majority of participants declaring use of different sets of data (i.e., Other data). Similarly, to Uzbekistan, most of the participants in Turkmenistan were familiar with Building stock and Infrastructure data, whereas in Tajikistan and Kyrgyz Republic they were more familiar with Land use and Croplands data (Figure 33b).

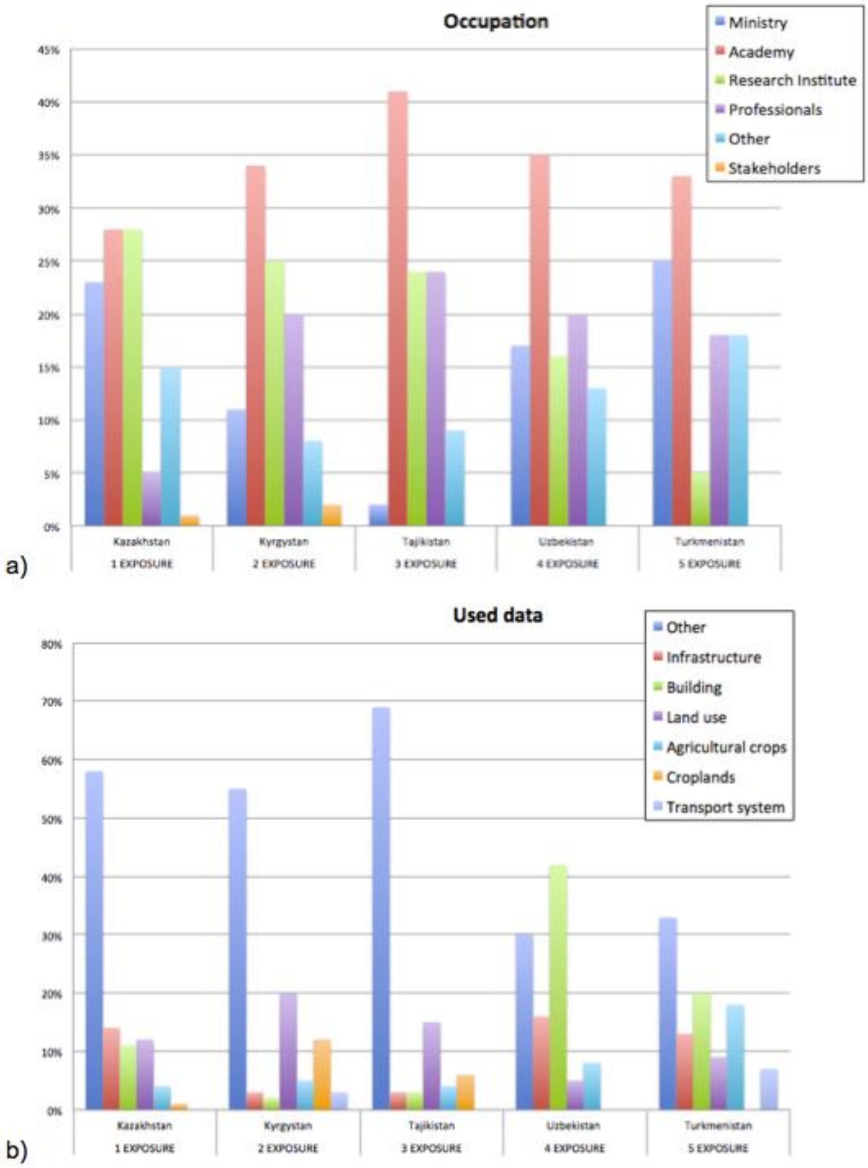


Figure 33. Participants a) occupation and b) used data in the five Country-based workshops on Exposure assessment.

The **engineering expertise** declared by participants (i.e., knowledge of buildings and infrastructure typologies and their features) was fairly good, ranging from intermediate to high, with about 70% of individuals with expertise equal or above the average level (Figure 34b). A rather different situation was observed in Kazakhstan, where there the percentage of involved professionals was much (Figure 33a). The declared **knowledge of GIS** (Geographic Information System), instead, tended to be intermediate or low (Figure 34a); the declared expertise with GIS also turned out lower in Kazakhstan, compared to the other countries.

The experience in collecting and handling national-scale ground base data, such as population or agricultural census data, is fairly good; in almost all countries the majority of participants declared an experience equal or better than average (Figure 35a). The situation with remote sensing data is quite similar, though with a larger percentage of individuals declaring no expertise with such data (Figure 35b).

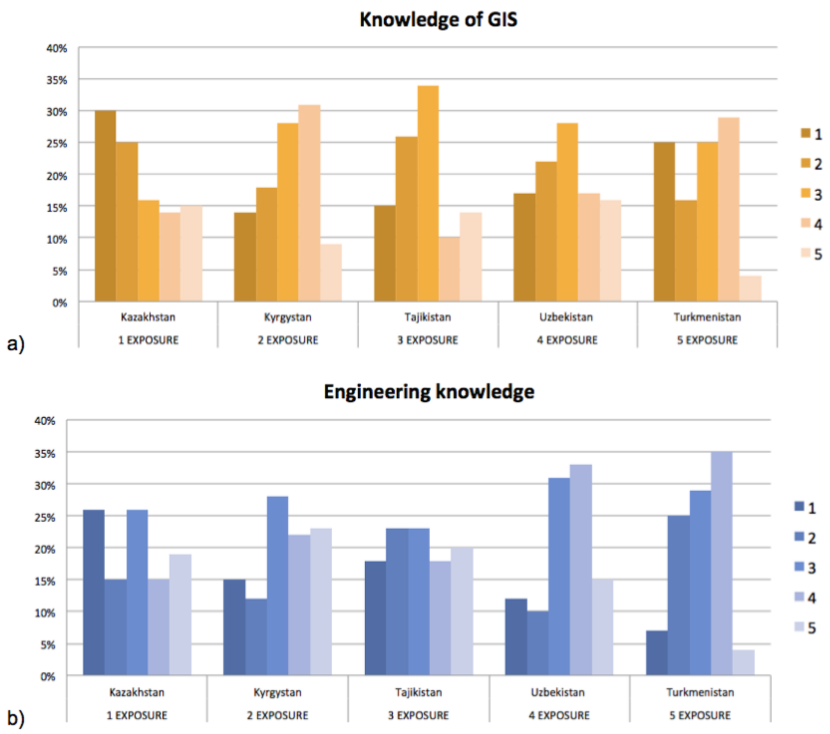


Figure 34. a) GIS knowledge (1=Never used 5=Expert user) and b) Engineering knowledge (1=No experience 5=Major experience) declared by the participants of the five Country-based workshops on Exposure assessment.

Figure 35. Experience in collecting and handling: a) national-scale ground base data (1=No experience 5=Major experience) and b) remote sensing data (1=No experience 5=Major experience) declared by the participants of the five Country-based workshops on Exposure assessment.

3.4 Thematic workshops

The Thematic Workshops on Hazard, Vulnerability and Risk assessment in Central Asia aimed at providing participants an overview of the most recent methodologies used in the project to produce regionally consistent risk estimates, building on earlier projects and resources available in the region.

The structure and duration of the Thematic workshops was similar to that of Country-based Exposure workshops (four days, half-day only); however, a larger number of presentations by Local Experts was allowed, in order to provide an overview of past experience with different perils in the five countries of Central Asia. Moreover, two panel discussions, involving Directors and Expert Speakers, were organized in the framework of the Vulnerability and Risk workshops, to discuss the newly presented methodologies and their implementation in view of the current regulations in Central Asian countries. A session on Disaster Risk Financing (DRF) was also organized by World Bank experts in the framework of the workshop on Risk assessment, to create a bridge towards future practical actions for risk mitigation in Central Asia. A summary description of the content of each Thematic Workshop and of related participation is provided in the next sections; the full description with agenda is provided in Annex 1.

3.4.1 Thematic workshop on Hazard Modelling

Title: *"Challenges of Multi-Peril Hazard Modelling at Regional Scale: Assessing Earthquake, Flood and Landslide Hazard in Central Asia"*

Description: Hazard is one of the components of risk assessment and usually represented by the intensity and frequency of the hazardous events (e.g., earthquake, floods, landslides) that might affect a certain region. Hazard assessment aims at estimating the characteristics of such future events through the analysis of historical data and the development of mathematical models to complement the limited information given by direct observations. Hazard assessment techniques are different for each peril and for the different spatial scales of application, which are set depending on the objective of the analysis.
This workshop covered the different methodologies for regional-scale seismic, flood and landslide hazard assessment, underlining the importance of merging information from global and local datasets, results from past existing studies and newly developed techniques. Large-scale risk assessment, in fact, relies on the use of regional scale models and data sets (e.g., earthquake catalogues for seismic analysis, river flow, precipitation and temperature records for flood hazard, landslide inventories for landslide analysis) that must be complemented and validated with local data, which are conversely often available only for limited areas.

Practical examples were provided to illustrate the methodology for earthquake, flood and landslides hazard assessment, with a focus on the hazard models developed within the SFRARR project. The exercises were focused on the following fundamental topics:

- Guidelines for collecting and managing regional hazard data, including input required to hazard modeling and data potentially suitable for validation;
- Access to software and familiarization with basic processing tools;
- Access to online resources;
- Preparation of the necessary input files for the subsequent hazard modeling starting from sample data;
- Visualization and interpretation of hazard calculation output;
- Validation of the current datasets based on additional data;

A brief panel discussion, involving Directors and Local Speakers, closed each day of the Workshop, providing an opportunity to discuss the presented methodologies towards up-to-date hazards assessment for seismic, flood and landslide risk mitigation in Central Asia.

3.4.2 Thematic Workshop on Vulnerability Analysis

Title: *"Vulnerability modelling for disaster risk assessment at the regional scale: an application in Central Asia"*
Description: Reliable risk assessment depends on the adequate quantification of vulnerability, which estimates how prone assets are to suffer certain levels of damage in case of natural disasters. Vulnerability can be assessed through the analysis of historical damage/loss data or, alternatively, the development of analytical models to complement the limited information given by direct observations. Vulnerability assessment techniques are different for each peril and exposed asset type, and for the different spatial scales of application.
This workshop provided an overview on the methodologies available for regional-scale earthquake and flood vulnerability assessment. Practical examples were provided to guide the audience through the development and application of regional scale vulnerability models, with a focus on models developed within the project in Central Asia. The lectures covered the following theoretical and methodological topics:

- Methodologies for the development of regional earthquake vulnerability models;

- Methodologies for the development of regional flood vulnerability models;
- Development of seismic vulnerability curves for Central Asia: methodology and results;
- Development of flood vulnerability curves for Central Asia: methodology and results;
- Component-based flood vulnerability of residential buildings: a step-by-step overview of the INSYDE methodology;
- Methodologies to derive earthquake vulnerability models: practical applications;
- Use of the vulnerability curves to compute losses caused by a seismic event and a flood event.

3.4.3 Thematic Workshop on Risk Modelling

Title: *"Risk modelling for earthquake and flood disaster mitigation in Central Asia"*
Description: The Thematic Workshop on Risk modelling in Central Asia aimed at providing participants an overview of the methodologies applied in the project to produce regionally consistent risk estimates. The workshop benefited, in particular, from the main findings, data and results gathered at each country's level during Exposure workshops. Moreover, it built on theoretical background provided during Hazard and Vulnerability workshops, in order to provide a general view of the most important aspects of risk assessment from the regional point of view of Central Asia.
Participants were demonstrated the approach followed for risk assessment and loss estimation and got familiar with several risk metrics. Examples of loss calculation and risk model calibration/validation were provided, as well as recommendations on how to use loss estimates in the framework of Disaster Risk Management strategies. The lectures and tutorials covered the following general topics:

- Review of the components of risk assessment (hazard, exposure and vulnerability);
- What is Probabilistic Risk Assessment?
- Probabilistic and deterministic scenarios;
- Common outputs of risk modelling (metrics and meaning);
- Examples of risk results;
- Applications of probabilistic risk assessment;
- General overview of the CAPRA platform;
- Sections and components of the CAPRA platform;
- Outputs and results;
- Hands-on session on deterministic risk assessment;
- Hands-on session on probabilistic risk assessment.

The workshop included a session on Disaster Risk Financing (organised by World Bank) and ended up with a Round Table with the participants, where suggestions about how to introduce the project results in the countries standard practices, accounting for local regulations and procedure, could be discussed.

3.4.4 Thematic workshops participation reports

The Thematic workshops on Hazard, Vulnerability and Risk assessment were the last three Capacity Building activities carried out in the framework of the project. As they were addressed participants from all five Central Asian countries, the potential audience was much broader, compared to the country-based workshops. Moreover, the activities carried out during the hands-on exercises did not impose any limit to the number of participants (e.g., number of specific software accounts), therefore it was not necessary to limit a priori the number of participants. As a result, the actual number of individuals attending the workshops, including those registered online or nominated by Ministries, was several times larger than the originally expected number of participants, and it exceeded 300 attendees in the last workshop. Following World Bank indications, participation was checked twice per day (before and after the break), including both registered individuals, as well as additional non-registered participants. As for the country-based workshops, a significant number of non-registered participants attended the workshops; several participants also joined in groups, using their institutional account, which further complicated checking attendance. Anyway, only participants who attended at least 3 days out of 4 total days of the Workshop were entitled to receive the Attendance Certificate.

Figure 36 and Figure 37 provide a synoptic view of the attendance for the three Thematic Workshops. It is possible to observe that participation was remarkable for all events, with a maximum attendance in the last workshop on Risk assessment (Figure 36a). Participation was pretty stable throughout the four-days of the Workshops: in all cases more than half of the attendees were entitled to get the certificate (i.e., participated for at least 3 days). Variability was larger during the Risk workshop; as a result, the number of issued certificates was comparable to that of earlier Thematic workshops, in spite of the larger number of participants. Figure 37 shows that large part of the individuals attending the workshops was from Uzbekistan, followed by Kazakhstan; in both these countries, besides the received online applications, there was also a significant number of nominated participants from Ministries and Agencies. In Turkmenistan the majority of participants were nominated ones, with a limited number of online applications.

A statistical overview of the general characteristics of registered participants, both general features (e.g., country, gender, age, occupation) and specific features relevant to the Workshops (e.g., knowledge of GIS, engineering experience) is provided below. The collection of participation reports for each of the Thematic workshops is provided in Annex 2.

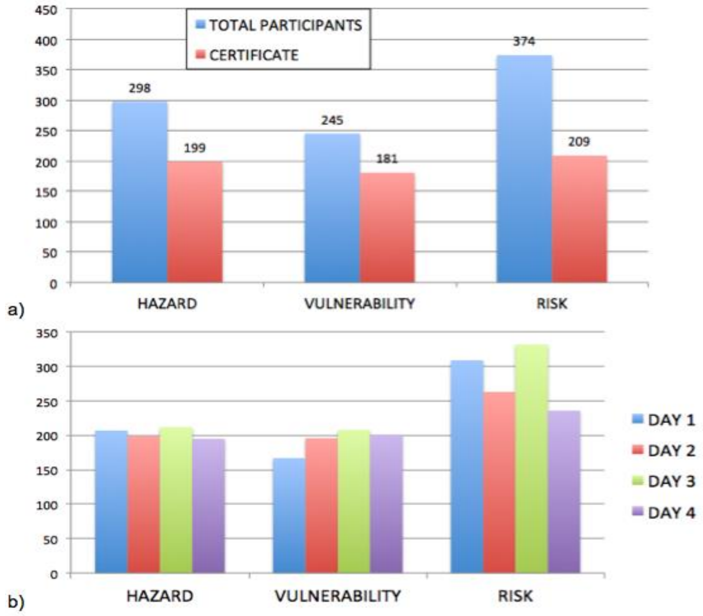


Figure 36. Number of participants in each of the three Thematic workshops on Hazard, Vulnerability and Risk assessment: a) total number and number of participants with certificate; b) daily participation in each workshop.

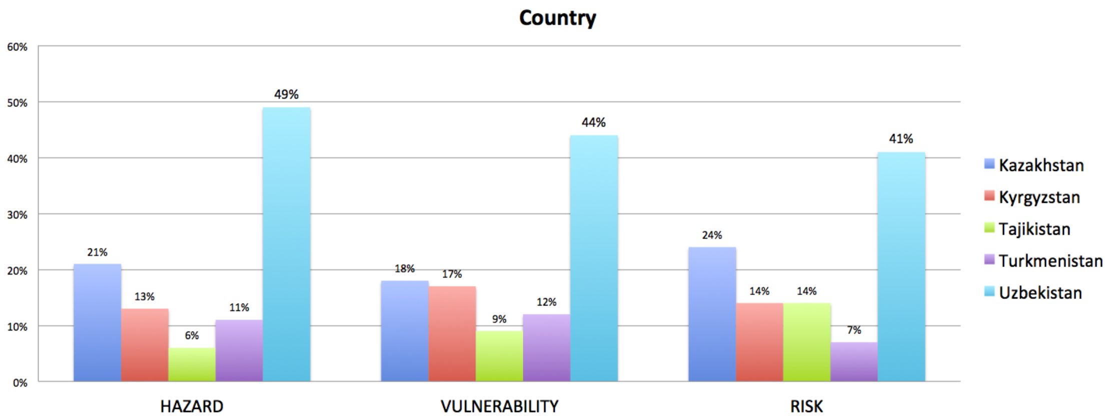


Figure 37. Distribution vs. Country of participants attending the Thematic workshops.

The situation with participants' **gender** (Figure 38a) was very similar for all workshops: even if participation of female individuals was significant (35% on average), there was a prevalence of male individuals. The majority of participants had an **age** below 40 years; while participation was prevalently in the age range 30-40 years for the three workshops, a larger percentage of senior participants was observed in the Risk workshop (Figure 38b). The knowledge of **English language** was very similar for all workshops: about 40% of the participants understand English (both spoken and written), about 35% only in written form, while about 25% of the participants declared that they do not understand English at all.

The participation of **students** was rather different in the three workshops (Figure 39a); the proportion of students was very high in the Hazard workshop, possibly due to the larger involvement of participants from Academy and Research institutes, while it was quite low in the Risk workshop, where the participation of representatives from Ministries and Professionals was prevalent. Involvement of Professionals and Ministries was remarkable in Vulnerability and Risk workshops (Figure 39b).

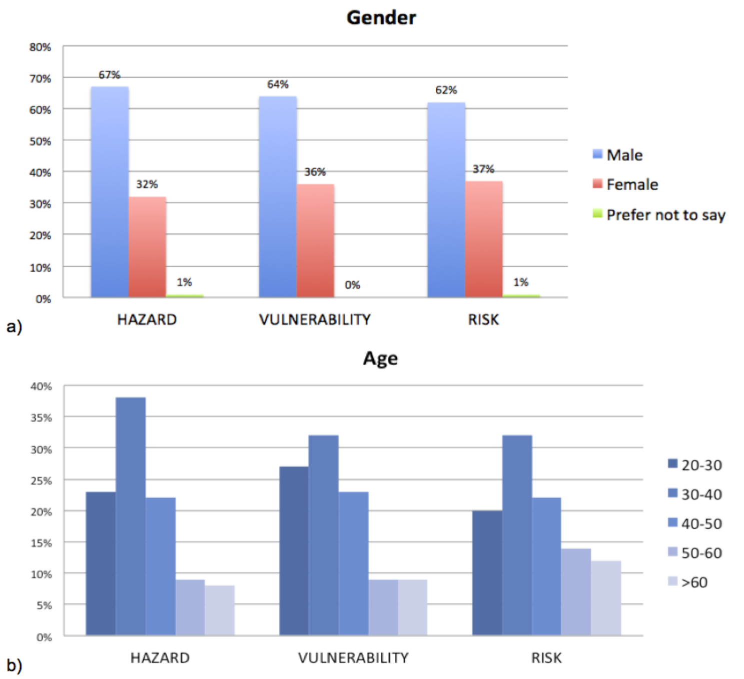


Figure 38. Distribution of participants versus: a) Gender and b) Age for each of the three Thematic workshops.

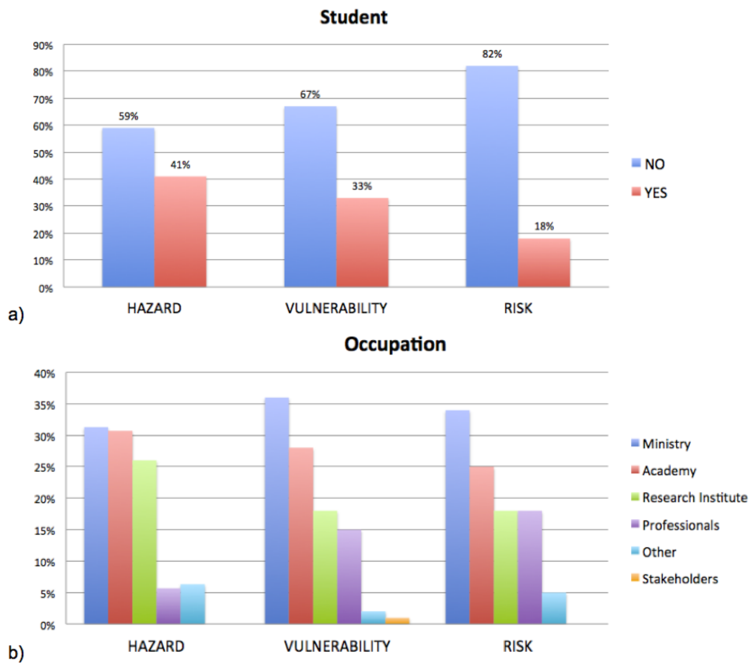


Figure 39. Percentage of students (a) and occupation (b) of the participants for each of the Thematic workshops.

The **risk type** with which participants were most familiar was Earthquake risk, eventually combined with Floods; several participants declared expertise with different kind of risks (see Annex 2 for further details).

The **knowledge of GIS** (Geographic Information System) declared by participants was mostly an intermediate one, with a moderate prevalence of individuals with expertise equal or above the average level (Figure 40a). The **engineering expertise** (i.e., knowledge of buildings and infrastructure typologies and their features) is more heterogeneous, with a non-negligible part of individuals declaring no engineering knowledge in Hazard and Vulnerability workshops (Figure 40b). The experience in collecting and handling national-scale ground base data is good, as in all workshops the majority of participants had an experience above or equal than average (Figure 41a). The situation with remote sensing data, instead, displays a larger percentage of individuals declaring no expertise with such data, especially in Hazard and Risk workshops (Figure 41b).

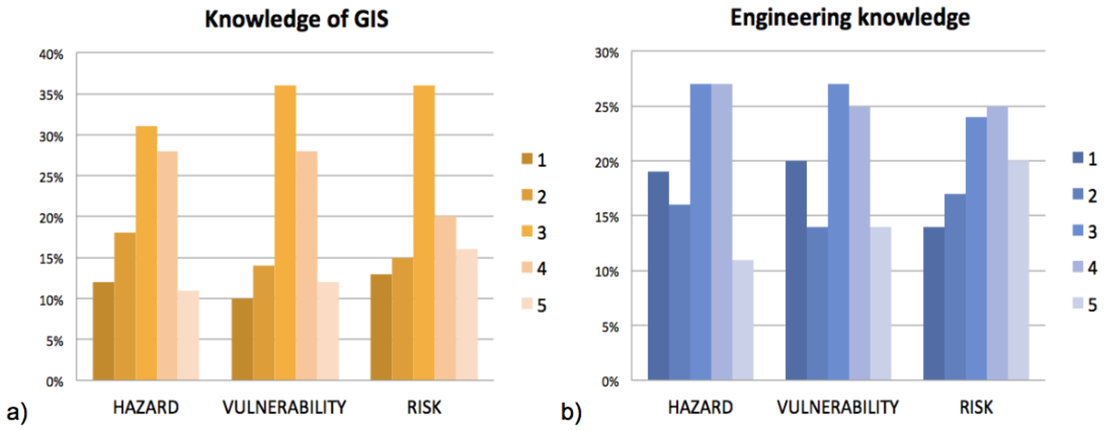


Figure 40. a) GIS knowledge (1=Never used 5=Expert user) and b) Engineering knowledge (1=No experience 5=Major experience) declared by the participants of the Thematic workshops.

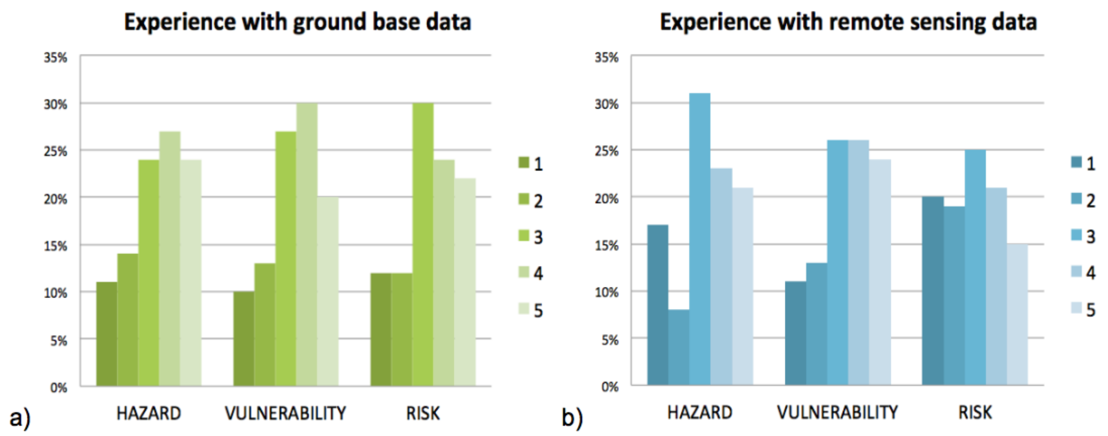


Figure 41. Experience in collecting and handling: a) national-scale ground base data (1=No experience 5=Major experience) and b) remote sensing data (1=No experience 5=Major experience) declared by the participants of the Thematic workshops.

3.5 Feedback from participants: the evaluation forms

At the end of each capacity building workshop, the participants were requested to compile an anonymous questionnaire, so as to assess the effectiveness of the training and to gather suggestions on how to improve the future training. The feedback from participants, received through the anonymous **evaluation forms** and via email, was especially positive and encouraging, indicating that the topics covered by the workshops were relevant to their current work and that participants are likely to use the presented tools and data in their future activities. The evaluation forms also included a section devoted to tutorials and hands-on exercises, which allowed assessing how many participants were able to follow and carry out practical exercises (duly taking into account the possible technical difficulties with connection and used platforms), and to get some feedback on the comprehension level of the training activities.

The questionnaire was set up on Google Forms and was composed by three sections. The first two sections included a set of 18 close-ended questions (where respondents had to choose from a set of pre-defined responses), aimed at assessing the quality and organization of the lectures and of the practical exercises, respectively. The last section aimed at collecting suggestions and comments about the workshop from the participants, in the form of free text. A fairly large number of participants provided their response: on average, feedback was received from about 45% of the attendees, with a maximum of 135 filled forms collected for the Risk workshop. All the received comments were shared and discussed with World Bank, providing useful indications that were considered when planning the next activities. A summary description of the feedback from participants of the Country-based and Thematic workshops, is provided in the following; the full set of collected responses and comments can be found in Annex 3.

3.5.1 Organization and relevance of the lectures

The first section of the questionnaire was devoted to the quality and organization of the lectures, and consisted of the following set of closed-ended questions, with an answer in the range from 1 to 5 (1=Poor, 5=Very good):

- 1.1 How useful do you think the workshop was?
- 1.2 How was the topic of the workshop covered?
- 1.3 What was your impression on the content of the workshop?
- 1.4 How was the workshop structured?
- 1.5 Was the workshop pitched at the right level?
- 1.6 How was the lecture material prepared?
- 1.7 Which part of the workshop activities would you expand?
- 1.8 Which part of the workshop activities would you reduce?
- 1.9 How relevant was the workshop to your current work/research activity?
- 1.10 How likely will you use the presented methods and tools in your work/research activity?
- 1.11 How likely will you use the presented data sources in your current activity?
- 1.12 How likely would you attend an advanced workshop on similar topics?

Examples of the received feedback are provided hereinafter.

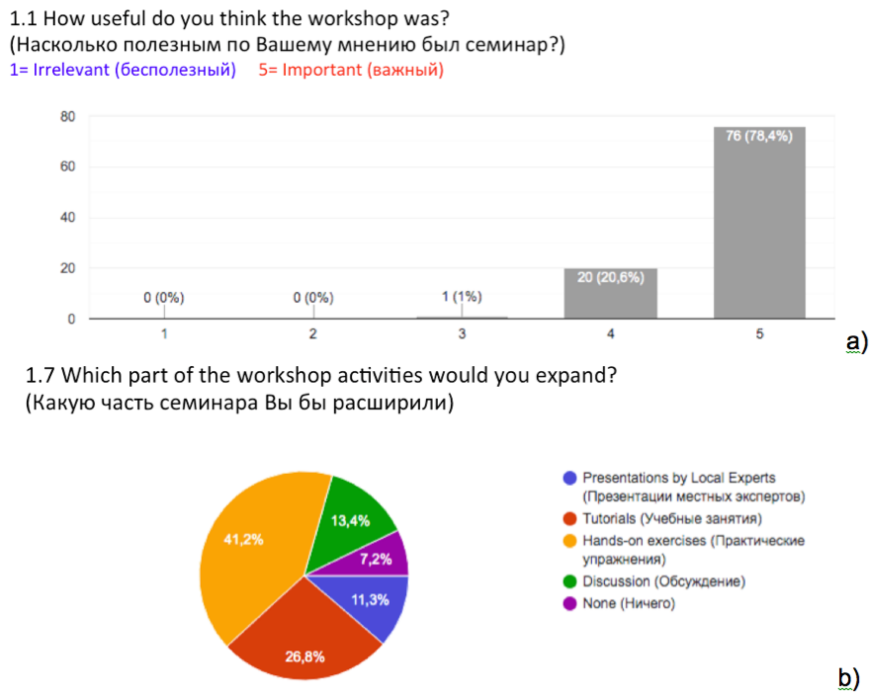


Figure 42. Examples of feedback provided by participants to: a) question 1.1 and b) question 1.7 of the Hazard workshop.

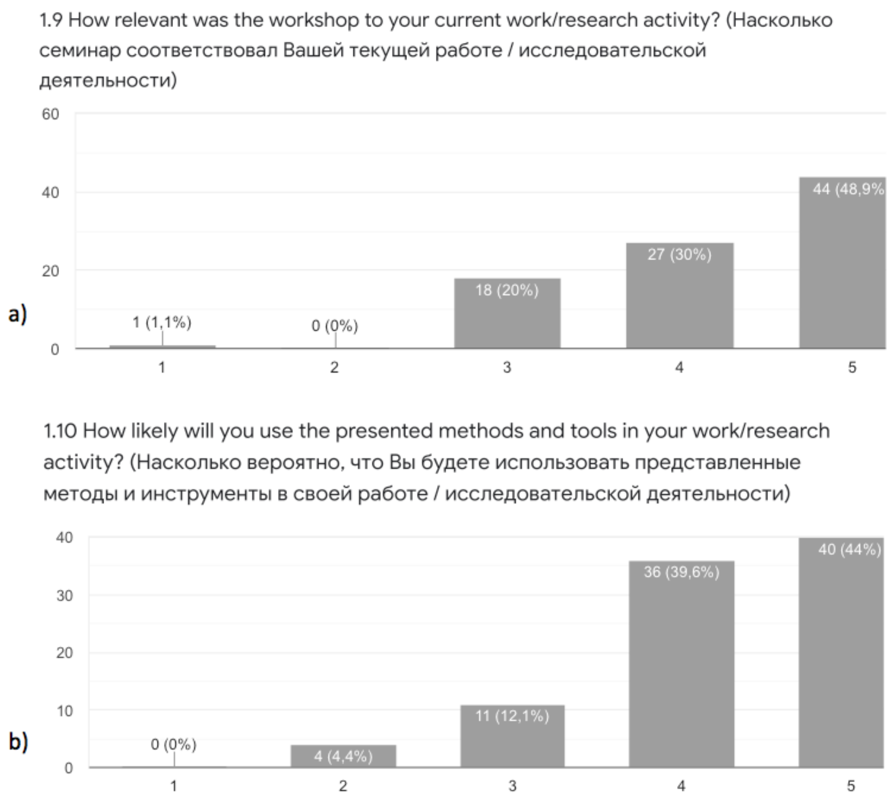


Figure 43. Examples of feedback provided by participants to: a) question 1.9 and b) question 1.10 of the Vulnerability workshop.

In almost all workshops, the large majority (i.e. 80% or more) of the answers to the questions 1.1 - 1.6 were very positive, namely 4 or 5 (i.e. Good or Very good), as shown in Figure 42a. Regarding the part of the activities to be expanded (question 1.7), the most frequent one was hands-on exercises, while in general none of the activities should be reduced (1.8), as shown in Figure 42b.

The response to the questions on the relevance of the workshops to the participants' current work or research (question 1.9), as well as those on the possible future use of the presented methods and data (questions 1.10 and 1.11), evidenced the good/high relevance of the training in their future activities (see Figure 43 for an example). The interest of participants is confirmed by the responses to the question 1.12, where the large majority (more than 80%) of the participants indicated that they are likely/very likely to attend an advanced workshop on similar topics.

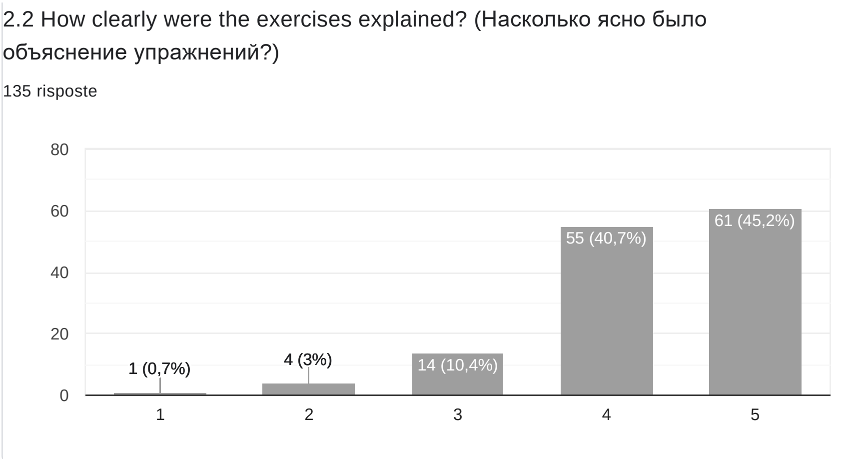
3.5.2 Practical exercises

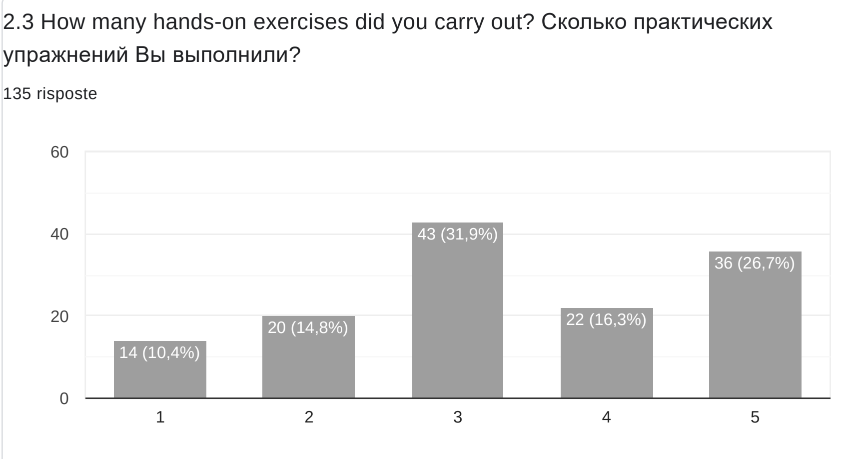
The second section of the questionnaire refers to the hands-on exercises; it consisted of the following six closed-ended questions, with allowed answers in the range from 1 to 5 (1=Poor, 5=Very good):

2.1 How was the quantity of practical exercises?
2.2 How clearly were the exercises explained?
2.3 How many hands-on exercises did you carry out?
2.4 Were the exercises simple to carry out?
2.5 Were the support and answers from the lecturers sufficient?
2.6 Have you got any technical difficulties to carry out the exercises?

An example of the received feedback for questions 2.2-2.4 is provided in Figure 44; the full set of collected responses is available in Annex 3.
Although the answers in this section displayed certain variability amongst the different workshops, still the feedback was very satisfactory. In fact, most of the participants considered the quantity of practical exercises fairly good (question 2.1) and well explained (question 2.2; e.g., Figure 44 top panel). During the workshops, particularly the Exposure ones, most of the participants were able to carry out a rather good number of hands-on exercises (see question 2.3 in Figure 44; 1 stands for no exercise done, while 5 stands for all exercises done), despite the technical difficulties with the connection and with the Google forms that were faced in some countries (question 2.6).

The attendees found the exercises moderately simple to carry out, with a score prevalently in the range from 3 to 5 (question 2.4; Figure 44 bottom panel), thanks also to the support from the lecturers, which was considered pretty good (question 2.5).





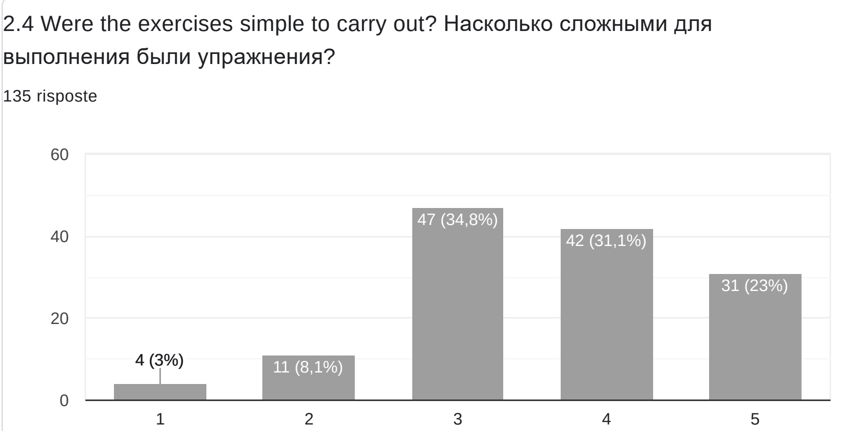


Figure 44. Examples of feedback provided by participants of the Risk workshop to the questions related to hands-on exercises, namely: 2.2 Clarity of explanations (1 = Poorly; 5 = Skilfully), 2.3 Number of exercises carried out (1 = None; 5 = All exercises) and 2.4 Difficulty (1 = Too difficult; 5 = Adequate)

3.5.3 Comments by the participants

In addition to the feedback based on closed-ended questions discussed above, several participants also provided their free comments, both through the online form and via email. The full set of comments received by participants was enclosed to the participation reports for each capacity building workshop and can be found in Annex 3. A selected sample of the most typical/frequent comments by the participants is given below.

1. Спасибо большое за информативный семинар! Спасибо за то, что делитесь своими опытом, данными и полезными ссылками!
   Thank you very much for the informative workshop! Thank you for sharing your experiences, data and useful links!
2. Семинар был своевременным и актуальным и необходимо проведение серии последующих семинаров
   The workshop was timely and relevant and there is a need for a series of follow-up workshops
3. Семинар очень хороший для нас молодых ученых. Мы многое услышали узнали от людей, которые имеют больше опыта
   The workshop was very good for us young scientists. We have learned a lot from people who have more experience
4. Регулярно проводить подобные семинары.
   Conduct such workshops regularly.
5. Было бы хорошо, чтобы семинары проводили в оффлайн режиме
   It would be good if the workshops could be held offline
6. Семинар подготовлен и проведен очень хорошо. Местные эксперты представили новые информационные материалы. Учебные и практические занятия также были подготовлены и организованы на отлично. Желаю подобные семинары были почаще
   The workshop was very well prepared and conducted. The local experts presented new information materials. The training and practical sessions were also prepared and organised to a very high standard. I wish such workshops were more frequent
7. Семинар очень интересный, поскольку тематика для нас совершенно новая. Семинар был построен качественно, лекции и практические занятия на высоком уровне.
   Безусловно, полученные сведения будут полезны большинству слушателей в их практической работе. Организаторам надо сказать спасибо за прекрасную работу.
   The workshop was very interesting, as the topic was completely new to us. The workshop was well structured; the lectures and practical exercises were of a high level. No doubt, the information gained will be useful for most of the attendees in their practical work. The organisers are to be thanked for their excellent work.
8. Спасибо огромное за семинар. С удовольствием приму приглашение снова.
   Thank you so much for the workshop. I will be happy to be invited again.
9. Большое спасибо за продуктивные занятия, за организацию таких масштабных проектов!
   Thank you very much for the productive training sessions and for organising such large-scale projects!
10. Это именно то, что надо. Побольше таких проектов, побольше таких семинаров!
    This is exactly what is needed. More projects like this, more workshops like this!
11. в начале непонятен был материал для скачивания, нужно наверно дать предварительное объяснение, что мы планируем делать на практических уроках.
    At the beginning it was not clear about the downloadable material, perhaps there should be a preliminary explanation of what we plan to do in the practical lessons.
12. При ознакомлении с новыми прикладными программами было бы хорошо высылать базовое практическое видео-руководство с небольшими примерами. Спасибо!
    It would be good to send a basic practical video tutorial with some examples when learning about new software tools. Thank you!

13. *I would like to ask about possibility to increase the number of tutorial and hands-on sessions accompanied by corresponding assessment of received results.*

The received comments highlight the relevance of the training (comment n. 10), which was considered useful for the attendees in their practical work (n. 7), especially for young scientists (n. 3). Training sessions were found productive (n. 9), as they allowed sharing experiences, data and useful links (n. 1). Though the large majority of comments were very positive, still a few of them evidenced some difficulties in carrying out practical exercises and suggested extending the allocated time (n. 13), as well as sharing manuals and video tutorials (n. 12), possibly in advance of the workshop (n. 11).

Several comments also pointed to the need for follow-up workshops (n. 2), to be organized more frequently and/or on a regular basis (comments n. 4, 6 and 8), especially practical training on tools and software. Finally, some participants would have preferred if the workshops were held in person, rather than online (n. 5); this option was discussed during the training activities organisation and was found not viable, due to the continued Covid-19 pandemic. At the same time, the online organization allowed broadening significantly the participation in the capacity building workshops and facilitated attendance from the different countries of Central Asia.

4 Risk Assessment Discussion and Recommendations of potential DRM and DRFI solutions

A) Recommendations related to Disaster Risk Management

Disaster risk management (DRM) can be understood as the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses[5]. Disaster risk management actions can be distinguished between ex-ante and ex-post. "Ex-ante" are proactive actions or interventions oriented to reduce the risk before the impact of a catastrophic event. "Ex-post" actions are those actions carried out after the impact of a catastrophic event, which are generally oriented to relief and reconstruction.

It is always desirable and recommended the implementation of actions and policies aimed at reducing risk prior to the impact of a damaging natural event ("ex-ante" actions), the first step of which is risk identification, which was carried out in detail during the development of this project. Money well spent to mitigate damage before the occurrence of events has a higher return of investment than money spent after the fact to repair the damage. The future steps for Central Asian countries are the implementation of risk reduction actions aimed at reducing the impact of future events on the population and critical infrastructure. The results of this project will be an important source of information for the implementation of disaster risk reductions actions.

The following are general recommendations regarding potential disaster risk management (DRM) interventions for the Central Asia countries:

- For earthquake risk mitigation.

Since earthquakes are unpredictable events that can occur at any time, risk reduction actions are mainly aimed at reducing the vulnerability of buildings to ground motion, as well as improving knowledge of the seismic hazard of the region. Some of the strategies that could be implemented in the future are, for example:

  - Update seismic hazard studies (for which the results of Task 2 of this project can provide valuable information). A good knowledge of the seismic hazard of the region allows updating seismic design values, as well as improving construction regulations. According to the results of Task 6, the countries with higher earthquake risk are Kyrgyz Republic and Tajikistan. For these countries it would be advisable to check whether the design ground motion levels in their national regulations are up to date and generally consistent with those computed in this project. Along the same lines, strict enforcement of the building code prescriptions during construction of new buildings and retrofitting of existing ones would be really helpful in mitigating earthquake risk.

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5 https://www.undrr.org/terminology/disaster-risk-management#:~:text=Disaster%20risk%20management%20is%20the,and%20reduction%20of%20disaster%20losses

- Identification of high hazard zones to prioritize the implementation of risk reduction actions. High hazard zones could be identified from the earthquake hazard maps presented in the results of Task 2. From those maps, the countries with higher earthquake hazard are Kyrgyz Republic and Tajikistan.
- Campaigns to retrofit critical assets and especially those with a high concentration of population, such as hospitals, bridges, public buildings and schools. This action reduces human and economic losses in the aftermath of future events, as well as ensures continuity in the functionality of these critical infrastructure in the event of an emergency.
- Campaigns to retrofit assets in sectors with higher concentration of earthquake risk. According to the results of Task 6, the sectors with higher risk are:
  - Kyrgyz Republic: commercial and residential.
  - Kazakhstan: commercial and education.
  - Tajikistan: commercial and residential.
  - Turkmenistan: commercial and education.
  - Uzbekistan: commercial and education.
- Provide fiscal incentives to encourage retrofitting of privately owned residential and commercial assets paired with inspections to ascertain the correct implementation of such measures may prove to be useful for achieving a significant penetration of vulnerability mitigation to a large number of assets;
- Based on the knowledge of high seismic hazard areas, carry out detailed evaluation of the performance of key lifelines, such as power generation, transmission and distribution systems, water distribution systems, and transportation network, which are present in those areas in case of major earthquakes. Based on the results of such detailed analyses, put in place programs that will be triggered in the immediate aftermath of an event to fix swiftly the damage that may have occurred.
- Enforce good construction practices, which reduces the vulnerability of buildings.
- Implement early warning systems and educate the population on the actions to be taken in the event of a seismic event, which helps to reduce the loss of lives.

- For flood risk mitigation.

The main flood risk reduction strategies are oriented to the control of flood zones, that is, to reduce the flood hazard (and therefore the risk). Among the strategies that could be implemented by Central Asia countries in the future are, for example:

- Identify zones of high flood hazard: the maps shown in the results of Task 3 provide valuable information on the main flood hazard zones. One action that could be implemented in a short time by the countries is to identify the main flood zones mapped in Task 3 of this project in order to prioritize the development of local studies and projects for flood control, as well as to avoid new urban development in highly exposed areas.

- Identification of high-risk zones to prioritize the implementation of risk reduction actions. According to the results of Task 6, the countries with areas of higher flood risk are Tajikistan, Turkmenistan and Kazakhstan.
- Campaigns to reduce flood risk in sectors with higher concentration of population and assets. According to the results of Task 6, the sectors with higher flood risk for the Central Asia countries are: transport and agriculture (cotton and wheat).
- Based on the knowledge of high flood hazard areas, carry out detailed evaluation of the performance of key lifelines, such as power generation, transmission and distribution systems, water distribution systems, and transportation network, which are present in those areas in case of major floods. Based on the results of such detailed analyses, put in place programs in peace time that will be triggered in the immediate aftermath of an event to fix swiftly the damage that may have occurred.
- Options of flood control measures to reduce risk can be divided into two main types: 1) grey infrastructure, 2) nature-bases solutions. Some examples are:
    - Grey infrastructure: upgrade drainage networks, rock beams, rock rip-raps, embankments, retention basins, reservoirs, canals, sand bags, among others.
    - Nature-based solutions: urban forests, terraces and slopes, river and stream renaturation, open green spaces, green corridors, urban farming, natural inland wetlands, river floodplains (World Bank, 2021).
- Flood early warning system: which relies on a system of monitoring (e.g., using rain and river gauges) as well strategies of dissemination and communication to the population. This strategy helps to reduce the loss of life, especially in the event of flash floods.

B) Recommendations related to managing the financial costs of natural catastrophes

Managing the financial costs of natural catastrophes is a complex area for any Government around the world. The sudden disruptions that natural catastrophes impose on population, economic activity and public infrastructure make disaster management policy a key function of government for countries highly exposed to them. In order to reduce the complexity of managing disasters, governments around the world have relied extensively on studies like this one, where engineering models can provide robust estimates of their impact and costs.

In particular, the loss exceedance curves produced in these studies have allowed to determine the price of transferring part of these financial costs to the financial markets, such as the ones for government debt or the international (re)insurance, or even measuring the financial benefits and costs of using particular debt or insurance instruments versus reserving public funds aside and keeping them ready to be deployed if a major sudden catastrophe occurs.

Using the information given by the loss exceedance probability curves (or PML) constructed for the countries covered in this report, and applying public information on the terms of contingent debt and catastrophe reinsurance, it is possible to derive a preliminary set of recommendations oriented to guide policy makers in their disaster management policy formulation.

Policymakers in charge of Disaster Risk Financing and Insurance (DRFI) would do well to use the Loss Exceedance Curves as the main tools in policy design. In this section we show one way to manipulate the curves presented in previous sections in order to design a DRM public policy. We show that it is possible to:

i. Measure the effectiveness of the DRFI policy through time (e.g., 5 or 10 years);
ii. Identify the components of an effective Strategy (i.e., the combination of instruments to be used through time and the portion of the risk portion of the Loss Exceedance Curve that is transferred to the capital markets (as contingent debt), to the reinsurance markets (as an insurance policy), or inter-temporally into the future (retained as a self-insurance or reserve fund)). This approach is commonly known as "risk-layering" and it allows policymakers to select the most appropriate disaster risk financing instrument available for each one of the risk segments as represented in the loss exceedance curve.
iii. Estimate the costs and benefits of each component of the strategy and the strategy as a whole.

The results of the work presented in this document can be used to identify potential financing alternatives. We can also identify a set of initial financing strategies that could be considered beneficial in terms of their economic costs and benefits. In other words, we illustrate how policymakers may gain resiliency by being financially prepared to face uncertain catastrophes, in a way that their choices can be based on socially desirable parameters such that the benefits of contracting debt and/or catastrophe insurance outweigh their costs or figuring out if setting aside a publicly funded reserve makes sense. By choosing the right financial instrument, or combination of instruments, financial policymakers can effectively reduce the economic risk borne by the Government from earthquakes and floods.

The methodology that follows is described in non-technical terms and complements each Country Summary (World Bank, 2022i) as support for the particular recommendations made there. In Section 4.1 we describe the methodology used in general terms, in Section 4.2 we summarize the DRFI recommendations for all countries based on such methodology, and in Section 4.3 we provide recommendations for implementing the methodology.

4.1 Modelling financial policy from the Loss Exceedance Curves

4.1.1 Step 1: Generating Risk Reduction Scenarios.

We use each country's earthquake and flood loss exceedance curves to generate over 200,000 random economic losses over any given 5-year period. We do this to illustrate how policymakers may take into account a reasonable period of responsibility under which resilience is sought to be maintained. Economic losses as read directly from the resulting dataset are understood to be "Gross Losses" and can be generated for periods of different lengths, like annual or 5 years in our case. If we run the same random analysis, but now including the resulting economic loss after taking into account the costs and benefits of each of the three financial instruments (contingent debt, catastrophe insurance and a public reserve fund), we can derive a set of "Net Losses". If the benefits from a particular financial instrument or a combination of instruments exceed their costs, it is expected that the Net Losses retained by the country or Government will be smaller than the original Gross Losses. In that sense, "Costs" are understood as any expense that the Government has to pay that are related to the financial instrument acquired. "Benefits" are understood as the portion of "Gross Losses" that the entity acting as counterpart to the financial instrument, or the reserve fund itself in its own case, absorbs effectively as part of the risk transfer agreement. Since costs and benefits are generated throughout the policy planning period (and beyond in the case of debt), we use a discount rate to bring all future flows to present USD values.

4.1.2 Step 2: Financial Assumptions.

We use macroeconomic data and reasonable assumptions to determine the costs of three financial instruments: a) Contingent Debt as potentially offered by the World Bank as a mechanism to provide loans contingent to the occurrence of earthquakes and floods; b) Insurance, as a contract offered to a Sovereign Government and reinsured in the reinsurance markets; c) Reserve Fund for self-insurance.

Discount rate	This rate refers to the rate at which socially desirable projects implemented by the Government are discounted. We assume for all countries a rate of 10% because it is commonly used in many countries on our experience.
Insurance cost terms	The price of catastrophe insurance is determined by an actuarial rate and loaded for administrative costs and the cost of capital. In our model, we use the Average Annual Loss (AAL) computed from the loss exceedance curve for a particular Layer [Attachment return period, Exhaustion return period], and we loaded to account for risk deviations and cost of capital, resulting in a total Premium = AAL*(1.5 +.08)
Contingent debt terms	We assume that debt can only be disbursed once a gross loss event equal or higher than the attachment point of the layer is observed. Once disbursed, there is a capital payment grace period of 5 years, a repayment period of 15 years, a Front-end Fee, a Commitment Fee, and a Debt Interest Rate plus a country specific spread[6].

Financial instruments are understood as contracts that allow Governments to transfer a predefined portion of the Gross Losses to a third party (a multilateral or private bank or an insurance company) in exchange of a set of fees or premium. The face value of these contracts is assumed to be an amount equivalent to the risk layer (i.e., the difference between the Gross Losses at the exhaustion and attachment return periods that define the "layer" or segment of the loss exceedance curve in

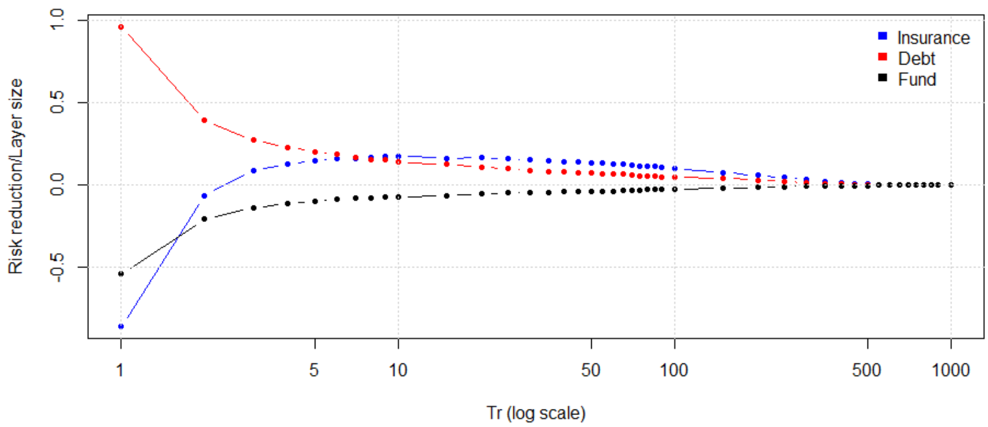
[6] These assumptions are taken from https://treasury.worldbank.org/en/about/unit/treasury/ibrd-financial-products/lending-rates-and-fees. The Secured Overnight Financing Rate (SOFR) is a broad measure of the cost of borrowing cash overnight collateralized by Treasury securities. See https://www.newyorkfed.org/markets/reference-rates/sofr

question). The public reserve fund is understood as budgetary money, equal also to the risk layer in size, set aside and maintained fully available (liquid) and ready to deploy if the natural catastrophes materialize. Since it should be ready to deploy at all times, we assume that no interest is gained from keeping it idle, and that a cost to society is incurred from setting the funds aside because there are other public programs that generate a social return (e.g., education or health expenditures). In that sense, the reserve fund bears a social discount rate.

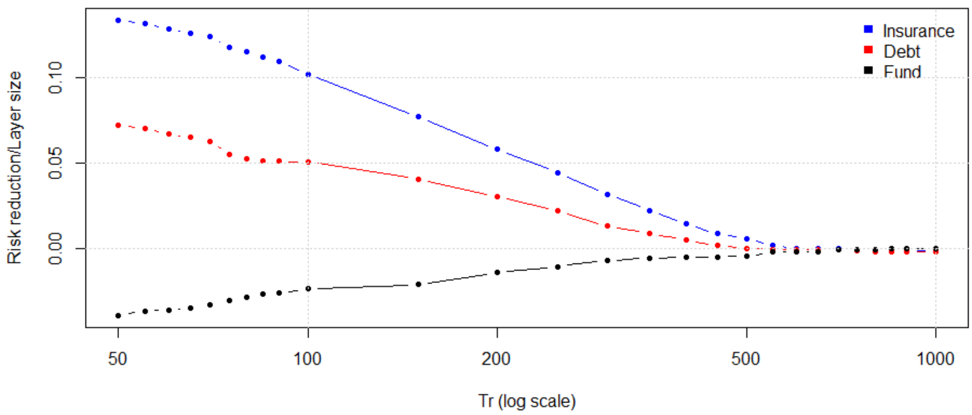
4.1.3 Step 3: Understanding risk reduction potential of each instrument.

Once financial instruments are modeled to absorb a defined portion of the Gross Loss from each curve, it is possible to explore how effective they are relative to each other along the loss exceedance curve. In each Country Summary (World Bank, 2022i) we include a figure like the one that follows, which allows policymakers measure how much risk reduction can be achieved by each instrument along the curve. For each return period in years (Tr), we define risk reduction as the difference (normalized by the marginal Layer size multiplied by the size of the period) between the Gross Loss and the Net Loss, considering an instrument that covers a marginal Layer around the Tr, for randomly generated losses within a 97.5% significance. In other words, we compute the risk reduction that can be achieved 97.5% of the time for random losses occurring within a marginal layer (small portions of the loss exceedance curve defined by the discrete points that represent it).

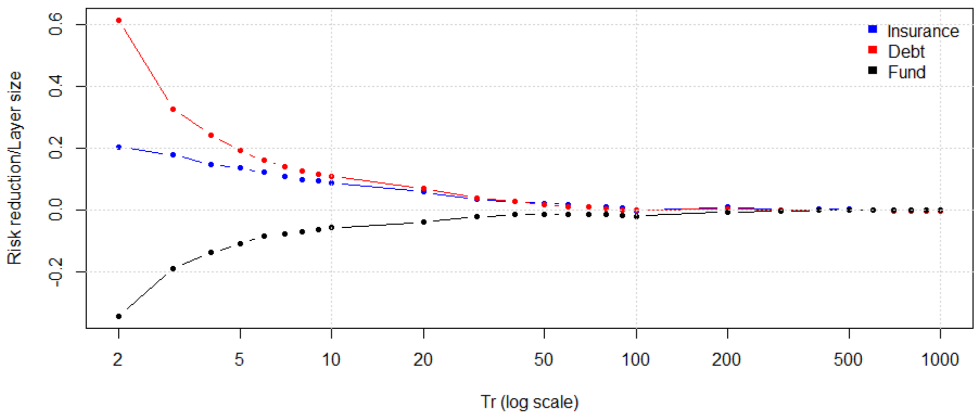
Figure 45 shows the risk reduction gained from using each financial instrument over different return periods of the curve. We normalize this reduction by the size of the Layer in order to compare instruments on a like-for-like manner and to evaluate the effectiveness of coverage for each section of the curve in the period analyzed (at a specific statistical significance level). For example, in graph a), for short return periods, we observe that debt is more efficient than the other instruments in reducing risk, going from a ratio of 96% to 20%, for Tr from 1 to 5 years, respectively. As longer return periods are analyzed, insurance becomes a more efficient tool, as expected and shown in graph b), with ratios of 13% to 8% in return periods of 50 to 150 years.



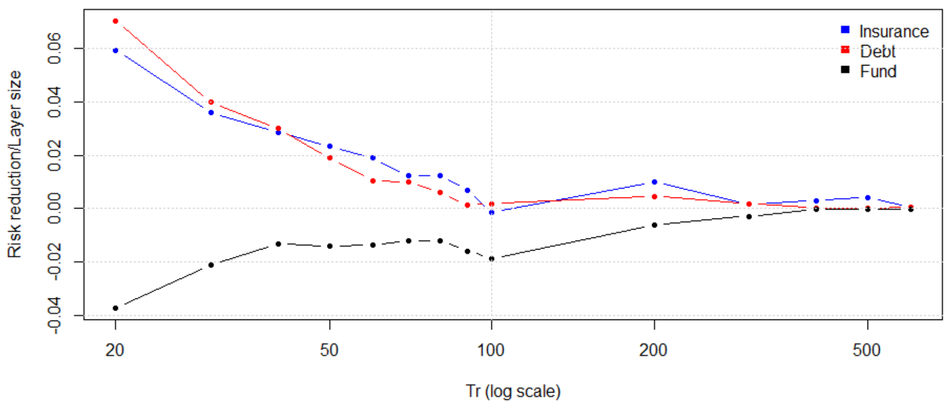
a)



b)



c)



d)

Figure 45. Earthquake and Flood risk reduction from each financial instrument. Loss reduction in a 5-year period at a 97.5% significance level of each loss return period for earthquake (a and c for complete set of return periods "Tr" of the loss exceedance curve and b and d for a segment of longer return periods "Tr", a and b for earthquake, c and d for flood)

4.1.4 Step 4: Selecting the relevant risk layers to protect against.

Policymakers can now have a sense of the relative effectiveness of each financial instrument, and they can turn their attention to defining the segments of the loss exceedance curve that represent the loss levels more critical to them, such that their impact on society and the economy is so large, that government intervention is absolutely necessary.

To illustrate this point, we include in each Country Summary (World Bank, 2022i) a figure that defines the potential set of layers in terms of their attachment and exhaustion return periods within the loss exceedance curve. The set of layers are defined as shown in Table 26.

The selection of the Layers was made considering the following criteria:

- The attachment return period of the first Layer reflects the upper limit of the Government's retention, typically related to higher frequency but lower severity events. Attempting to transfer the risk of these lower of loss amounts would cause the cost of the financial instruments to be very high.
- Above the retention level, a layered approach was constructed based on the analyses of the previous section, where we propose each layer's attachment/exhaustion corresponding to those return periods where we observed a change in the more effective financial instrument in terms of risk reduction[7].
- To allow for consistent comparison between the different countries, we proceeded to select layers around the same attachment/exhaustion return periods.
- These results are shown in each Country Summary (World Bank, 2022i).

Table 26. Earthquake and Flood gross loss segments and most effective instruments. Layer selection and analysis[8]

	Return Period (Tr) in years			
	Earthquake		Flood	
	Attachment	Exhaustion	Attachment	Exhaustion
Layer 1	50	150	2	20
Layer 2	150	500	20	200
Layer 3	500	1000	200	600

Following the loss simulation method described in step 1 above, we can have a sense which instrument works better under a particular significance level for absorbing part of the losses from each layer. We compute the benefit (portion of risk transferred) and costs (financial expenses to service each instrument) through the time period under study of 5 years, discount the cash flows and then determine which of the financial instruments, if any, has the largest risk reduction

[7] using as criteria both the expected value and the 97.5% level of significance.

[8] For flood, we stopped at the exhaustion of 600 years in the return period of flood because it was the highest return period in the loss exceedance curve provided that allowed to achieve a reduction in risk (a lower Net Loss than the Gross Loss).

(difference between Gross Losses and Net Losses). The results are obtained by choosing, for each Layer in Table 26, the optimal instrument (with the greatest risk reduction or None if it is negative for all three of them) and then calculating the impact of the consolidated strategy on Gross Losses.

4.2 Summary of potential DRFI Strategy recommendations

Table 27 and Table 28 collect country specific recommendations from the Country Summaries (World Bank, 2022i) and allow regional analyst to compare the results obtained from applying our method to all countries for both earthquake and flood risks. We only consolidate results for the three layers as defined for each peril in the Country Summaries. The results are obtained by choosing, for each Layer in Table 26, the optimal instrument (with the greatest risk reduction or None if it is negative for all three of them) and then calculating the impact of the consolidated strategy on Gross Losses.

Table 27. Earthquake risk management total benefits and costs in million USD

	Earthquake Layer 1, 2 & 3 – Attachment 50, Exhaustion 1000				
	Kazakhstan	Kyrgyz Republic	Tajikistan	Turkmenistan	Uzbekistan
Strategy (Layer 1+ Layer 2 + Layer 3)	Insurance + Insurance + None	Insurance+ Insurance+ None	Insurance+ Insurance+ None	Insurance+ Insurance+ None	Insurance+ Insurance+ None
A. Gross loss [MUSD]	$5,996.60	$2,369.60	$2,729.69	$545.66	$16,303.02
B. Net loss [MUSD]	$4,270.78	$1,880.29	$2,253.65	$404.02	$12,351.26
A – B [MUSD]	$1,725.82	$489.31	$476.04	$141.64	$3,951.77
Risk reduction (%)	28.8%	20.6%	17.4%	26.0%	24.2%
Total Benefit [MUSD]	$2,004.52	$580.99	$571.10	$165.57	$4,644.75
Total Cost [MUSD]	$278.70	$91.68	$95.06	$23.93	$692.98
Total Cost as % GDP	0.15%	1.1%	1.09%	0.05%	1.0%

Table 28. Flood risk management total benefits and costs in million USD

	Flood Layer 1, 2 & 3, Attachment 2, Exhaustion 600				
	Kazakhstan	Kyrgyz Republic	Tajikistan	Turkmenistan	Uzbekistan
Strategy (Layer 1+ Layer 2 + Layer 3)	Debt+ Insurance+ Insurance	Debt+ Insurance+ Insurance	Debt+ Insurance+ Insurance	Debt+ Insurance+ Insurance	Debt+ Insurance+ Insurance
A. Gross loss [MUSD]	$9,558.39	$797.32	$1,487.19	$1,148.17	$5,307.89
B. Net loss [MUSD]	$9,136.02	$751.01	$1,401.17	$1,011.51	$4,992.03
A – B [MUSD]	$422.37	$46.31	$86.02	$136.66	$315.85
Risk reduction (%)	4.4%	5.8%	5.8%	11.9%	6.0%
Total Benefit [MUSD]	$980.09	$101.71	$192.24	$284.11	$747.96
Total Cost [MUSD]	$557.72	$55.40	$106.22	$147.45	$432.11
Total Cost as % GDP	0.29%	0.6%	1.21%	0.3%	0.6%

Table 27 and Table 28 above show that the cost of natural disaster risk reduction varies significantly within the Central Asia countries. Whereas Kazakhstan can achieve a 28.8% risk reduction at a cost equivalent to 0.1% of GDP for earthquakes. Tajikistan can only achieve a 17.4% reduction at a cost of 1.1% of GDP. In general, potential risk reductions for earthquake are larger in percentage terms and less costly.

4.3 Recommendations for implementing the methodology on a regional scope

From a technical perspective, regional analysis of natural catastrophes for DRFI purposes would need further development of loss exceedance curves that adjust for correlation for the same peril affecting all countries within the region. It is possible that the same earthquake or flood affects more than one country, which would challenge the simple aggregation of loss exceedance curves that implicitly treat each curve as independent.

Producing correlated loss exceedance curves would allow for the exploration of risk pooling, a regional strategy that has been successfully implemented in other parts of the world.

5 Recommendations for Future Risk Assessment and Data Development

While the objectives of this project were fulfilled, a series of recommendations can greatly contribute the to the successfully developing of new projects in this region under the framework of SFRARR project.

As mentioned before in Section 2 of this report, the risk assessment of each peril was only possible by homogenizing multiples sources. This information varying in scale (local to global) as well as in the nature of the source, that is public and non-public. Therefore, new projects can greatly benefit from access to standardized information. To do so, it is recommended that the World Bank and stakeholders together fund and create a platform where all local institutions can load and open data to the public. This platform is not only of great interested to the successful development of the SFRARR project and future projects alike but also to local research institutions in their respective country. Similarly, another platform should be created where all the data and models concerning the risk assessment for the region can be easily accessible to stakeholders (governments and research institutions). This common platform will allow access to the most recent models as well as a channel for future updates and allow country members visualize the risks take conjunctive action towards mitigating those risks.

The workshops to build the capacity in the region woke great interest within the participants. Expanding these to include relevant topics such as the risk assessment normative in third countries, would create a point of comparison and support to the introduction of new normative in the same or similar topics in this region. Moreover, expanding the workshops beyond the current presentation format towards a more active involvement of selected participants with partners of the consortium, would enhance the program as well as the learning curve of the participants.

Finally, but not of minor importance, it is recommended that local partners and local stakeholders would advertise the project results and present the technical approaches used within the project framework and presented during the several workshops. It is advised that national programs will leverage also on these results and these methodologies to disseminate not only the traditional approach to risk assessment, mainly applied to local specificities for engineering design of structural defenses, but also the emerging large-scale approaches that are increasingly used to support and define DRM and DFI solutions to increase resilience and reduce the risk of natural hazards. Such solutions are taken at political level, but they need to be supported by technical opinion of local experts, who will need to become familiar with these risk assessment approaches to make robust and informed recommendations.

References

Abdullabekov, K.N., Artikov, T.U., Ibragimov, R.S., Ziyaudinov, F.F., 2012. Seismic hazard of Uzbekistan territory., in: Geosciences in Uzbekistan. GP ’93NIIMR,’94 Tashkent, pp. 195–202.

Ahmad N., Crowley H., Pinho R. (2011) Analytical fragility functions for reinforced concrete and masonry buildings and buildings aggregates of Euro-Mediterranean regions – UPAV methodology.

Aquastat, 2013. Geo-referenced database of dams [https://www.fao.org/aquastat/en/databases/dams, accessed 20/10/2021].

Atkinson, G.M., Boore, D.M., 2006. Earthquake Ground-Motion Prediction Equations for Eastern North America. Bull. Seismol. Soc. Am. 96, 2181–2205. https://doi.org/10.1785/0120050245

Bachmanov, D.M., Kozhurin, A.I., Trifonov, V.G., 2017. The active faults of Eurasia database. Geodyn. Tectonophys. 8, 711–736.

Behling, R., Roessner, S., 2020. Multi-temporal landslide inventory for a study area in Southern Kyrgyzstan derived from RapidEye satellite time series data (2009 – 2013) [WWW Document]. V. 1.0. GFZ Data Serv. https://doi.org/https://doi.org/10.5880/GFZ.1.4.2020.001

Behling, R., Roessner, S., Golovko, D., Kleinschmit, B., 2016. Derivation of long-term spatiotemporal landslide activity—A multi-sensor time series approach. Remote Sens. Environ. 186, 88–104.

Behling, R., Roessner, S., Kaufmann, H., Kleinschmit, B., 2014. Automated spatiotemporal landslide mapping over large areas using rapideye time series data. Remote Sens. 6, 8026–8055.

Bindi, D., Parolai, S., Gómez-Capera, A., Locati, M., Kalmetyeva, Z., Mikhailova, N., 2014. Locations and magnitudes of earthquakes in Central Asia from seismic intensity data. J. Seismol. 18, 1–21. https://doi.org/10.1007/s10950-013-9392-1

Breiman, L., 2001. Random Forests. Mach. Learn. 45, 5–32. https://doi.org/https://doi.org/10.1023/A:1010933404324

Brenning, A., 2005. Spatial prediction models for landslide hazards: review, comparison and evaluation. Nat. Hazards Earth Syst. Sci. 5, 853–862. https://doi.org/10.5194/nhess-5-853-2005

Byers, L., Friedrich, J., Hennig, R., Kressig, A., Li, X., Malaguzzi Valeri, L., McCormick, C., 2021. A Global Database of Power Plant [WWW Document]. World Resour. Inst. URL https://github.com/wri/global-power-plant-database/blob/master/output_database/global_power_plant_database.csv (accessed 10.20.21).

CAC DRMI, 2009. Risk assessment for Central Asia and Caucasus: desk study review.

Campbell, K.W., Bozorgnia, Y., 2014. NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV, and 5% Damped Linear Acceleration Response Spectra. Earthq. Spectra 30, 1087–1115. https://doi.org/10.1193/062913EQS175M

Casagli, N., Catani, F., 2020. Sviluppo della conoscenza e supporto tecnico scientifico per la valutazione degli scenari di pericolosità idrogeologica e vulcanica.

Catani, F., Casagli, N., Ermini, L., Righini, G., Menduni, G., 2005. Landslide hazard and risk mapping at catchment scale in the Arno River basin. Landslides 2, 329–342.

Catani, F., Lagomarsino, D., Segoni, S., Tofani, V., 2013. Landslide susceptibility estimation by random forests technique: sensitivity and scaling issues. Nat. Hazards Earth Syst. Sci. 13, 2815.

CAWA, 2019. WUEMOCA: Informed Decision-Making in Land and Water Resources Management.

Chiou, B.S.-J., Youngs, R.R., 2014. Update of the Chiou and Youngs NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra. Earthq. Spectra 30, 1117–1153. https://doi.org/10.1193/072813EQS219M

Ciarapica, L., Todini, E., 2002. TOPKAPI: a model for the representation of the rainfall-runoff process at different scales. Hydrol. Process. 16, 207–229. https://doi.org/10.1002/hyp.342

Cornell, C.A., 1968. Engineering seismic risk analysis. Bull. Seismol. Soc. Am. 58, 1583–1606.

Cotton, F., Scherbaum, F., Bommer, J.J., Bungum, H., 2006. Criteria for Selecting and Adjusting Ground-Motion Models for Specific Target Regions: Application to Central Europe and Rock Sites. J. Seismol. 10, 137–156. https://doi.org/10.1007/s10950-005-9006-7

Dottori, F., Figueiredo, R., Martina, M.L.V., Molinari, D., Scorzini, A.R., 2016. INSYDE: a synthetic, probabilistic flood damage model based on explicit cost analysis. Nat. Hazards Earth Syst. Sci. 16, 2577–2591. https://doi.org/10.5194/nhess-16-2577-2016

Dottori, F., Todini, E., 2011. Developments of a flood inundation model based on the cellular automata approach: Testing different methods to improve model performance. Phys. Chem. Earth, Parts A/B/C 36, 266–280. https://doi.org/10.1016/j.pce.2011.02.004.

FEMA, 2003. HAZUS-MH Technical Manual. Washington, DC, U.S.A.

Field, E.H., Jordan, T.H., Cornell, C.A., 2003. OpenSHA: A Developing Community-modeling Environment for Seismic Hazard Analysis. Seismol. Res. Lett. 74, 406–419. https://doi.org/10.1785/gssrl.74.4.406

GFDRR (Global Facility for Disaster Reduction and Recovery), 2009. Disaster Risk Management Notes for Priority Countries 2009-2015. Eur. Asia 48–49.

GFDRR (Global Facility for Disaster Reduction and Recovery), 2016. Europe and Central Asia-Country Risk Profiles for Floods and Earthquakes. 144 pg.

Giardini, D., Basham, P., Berry, M., 1999. The Global Seismic Hazard Assessment Program, 1992/1999, Annali di Geofisica. Wiley Online Library.

Global Library of School Infrastructure, 2014. GLOSI. https://gpss.worldbank.org/en/glosi/about-glosi.

Havenith, H.B.B., Umaraliev, R., Schlögel, R., Torgoev, I., Ruslan, U., Schlogel, R., Torgoev, I., 2017. Past and potential future socioeconomic impacts of environmental hazards in Kyrgyzstan. Kyrg. Repub. Polit. Econ. Soc. Issues; Olivier, A.P., Ed.; Nov. Sci. Publ. Inc. Hauppauge, NY, USA; pp. 63–113.

Havenith, H.B., Strom, A., Torgoev, I., Torgoev, A., Lamair, L., Ischuk, A., Abdrakhmatov, K., 2015a. Tien Shan geohazards database: Earthquakes and landslides. Geomorphology 249, 16–31.

Havenith, H.B., Torgoev, A., Schlögel, R., Braun, A., Torgoev, I., Ischuk, A., 2015b. Tien Shan geohazards database: Landslide susceptibility analysis. Geomorphology 249, 32–43.

Huizinga, J., de Moel, H., Szewczyk, W., 2017. Global flood depth-damage functions: Methodology and the database with guidelines. No. JRC105688. Joint Research Centre.

Ischuk, A., Bjerrum, L.W., Kamchybekov, M., Abdrakhmatov, K., Lindholm, C., 2018. Probabilistic Seismic Hazard Assessment for the Area of Kyrgyzstan, Tajikistan, and Eastern Uzbekistan, Central Asia. Bull. Seismol. Soc. Am. 108, 130–144. https://doi.org/10.1785/0120160330

Juliev, M., Pulatov, A., Hubl, J., 2017. Natural hazards in mountain regions of Uzbekistan: A review of mass movement processes in Tashkent province. Int. J. Sci. Eng. Res. 8, 1102–1108. https://doi.org/10.14299/ijser.2017.02.013

Kalmetieva, Z.A., Mikolaichuk, A. V, Moldobekov, B.D., Meleshko, A. V, Janaev, M.M., Zubovich, A. V, 2009. Atlas of earthquakes in Kyrgyzstan.

Kappos, A.J., Panagopoulos, G., Panagiotopoulos, C., Penelis, G., 2006. A hybrid method for the vulnerability assessment of R/C and URM buildings. Bulletin of Earthquake Engineering 4:391-413 doi:10.1007/s10518-006-9023-0

Karantoni, T., Lyrantzaki, F., Tsionis, G., Fardi, M.N., 2011. Analytical Fragility Functions for Masonry Buildings and Building Aggregates – UPAT methodology.

Kirschbaum, D., Stanley, T., and Zhou, Y., 2015. Spatial and temporal analysis of a global landslide catalog. Geomorphology, 249, 4-15.

Kreibich, H., Piroth, K., Seifert, I., Maiwald, H., Kunert, U., Schwarz, J., Merz, B., Thieken, A.H., 2009. Is flow velocity a significant parameter in flood damage modelling? Nat. Hazards Earth Syst. Sci. 9, 1679–1692. https://doi.org/10.5194/nhess-9-1679-2009

Kostov, M. et al. 2004. Application to Sofia. Report RISK-UE WP13.

Lehner, B., Liermann, C.R., Revenga, C., Vörösmarty, C., Fekete, B., Crouzet, P., Döll, P., Endejan, M., Frenken, K., 2011. Global Reservoir and Dam (GRanD) database. Tech. Doc.

McGuire, R., 2004. Seismic Hazard and Risk Analysis. Engineering monographs on earthquake criteria, sturctural design, and strong motion records. Earthquake Engineering Research Infrastructure (EERI).

Milanesi, L., Pilotti, M., Bacchi, B., 2016. Using web-based observations to identify thresholds of a person's stability in a flow. Water Resour. Res. 52, 7793–7805. https://doi.org/10.1002/2016WR019182

Muñoz-Sabater, J., Dutra, E., Agustí-Panareda, A., Albergel, C., Arduini, G., Balsamo, G., Boussetta, S., Choulga, M., Harrigan, S., Hersbach, H., Martens, B., Miralles, D., Piles, M., Rodríguez-Fernández, N., Zsoter, E., Buontempo, C., Thépaut, J.-N., 2021. ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. Earth Syst. Sci. Data Discuss. https://doi.org/10.5194/essd-2021-82

Nachtergaele, F., Velthuizen, H. van, Verelst, L., Batjes, N., Dijkshoorn, K., Engelen, V. van, Fischer, G., Jones, A., Montanarella, L., Petri, M., Prieler, S., Shi, X., Teixeira, E., Wiberg, D., 2012. Harmonized World Soil Database Version 1.2. Food and Agriculture Organization of the United Nations (FAO). 19th World Congr. Soil Sci. Soil Solut. a Chang. World.

Nadim, F., Kjekstad, O., Peduzzi, P., Herold, C., Jaedicke, C., 2006. Global landslide and avalanche hotspots. Landslides 3, 159–173. https://doi.org/10.1007/s10346-006-0036-1

Niyazov, R.A., 2020. Uzbekistan landslides, Uzbekistan landslide service, technical report.

Parker, G.A., Stewart, J.P., Boore, D.M., Atkinson, G.M., Hassani, B., 2022. NGA-subduction global ground motion models with regional adjustment factors. Earthq. Spectra 38, 456–493. https://doi.org/10.1177/87552930211034889

Pedde, S., Kok, K., Hölscher, K., Oberlack, C., Harrison, P.A., Leemans, R., 2019. Archetyping shared socioeconomic pathways across scales: an application to central Asia and European case studies. Ecol. Soc. 24. https://doi.org/10.5751/ES-11241-240430

Pezeshk, S., Zandieh, A., Tavakoli, B., 2011. Hybrid Empirical Ground-Motion Prediction Equations for Eastern North America Using NGA Models and Updated Seismological Parameters. Bull. Seismol. Soc. Am. 101, 1859–1870. https://doi.org/10.1785/0120100144

Pittore, Massimiliano; Ozturk, Ugur; Moldobekov, Bolot; Saponaro, A., 2018. EMCA landslide catalog Central Asia.

Pittore, M., Haas, M., Silva, V., 2020. Variable resolution probabilistic modeling of residential exposure and vulnerability for risk applications. Earthq. Spectra 36, 321–344. https://doi.org/10.1177/8755293020951582

Poggi, V., Garcia-Peláez, J., Styron, R., Pagani, M., Gee, R., 2020. A probabilistic seismic hazard model for North Africa. Bull. Earthq. Eng. 18, 2917–2951. https://doi.org/10.1007/s10518-020-00820-4

Pollner, J., Kryspin-Watson, J., Nieuwejaar, S., 2010. Disaster Risk Management and Climate Change Adaptation in Europe and Central Asia. World Bank 1–53.

Pusch, C., 2004. A comprehensive risk management framework for Europe and Central Asia. Disaster.

Reyer, C.P.., Otto, I.M., Adams, S., Albrecht, T., Baarsch, F., Cartsburg, M., Coumou, D., Eden, A., Ludi, E., Marcus, R., Mengel, M., Mosello, B., Robinson, A., Schleussner, C.-F., Serdeczny, O., Stagl, J., 2017. Climate change impacts in Central Asia and their implications for development. Reg. Environ.

Chang. 17, 1639–1650. https://doi.org/10.1007/s10113-015-0893-z

Scussolini, P., Aerts, J.C.J.H., Jongman, B., Bouwer, L.M., Winsemius, H.C., De Moel, H., Ward, P.J., 2016. FLOPROS: an evolving global database of flood protection standards. Nat. Hazards Earth Syst. Sci. https://doi.org/10.5194/nhess-16-1049-2016

SERA project, 2019. European physical vulnerability models. https://eu-risk.eucentre.it/wp-content/uploads/2019/08/SERA_D26.5_Physical_Vulnerability.pdf

Silacheva, N. V, Kulbayeva, U.K., Kravchenko, N.A., 2018. Probabilistic seismic hazard assessment of Kazakhstan and Almaty city in peak ground accelerations. Geod. Geodyn. 9, 131–141.

Stanley, T., Kirschbaum, D.B., 2017. A heuristic approach to global landslide susceptibility mapping. Nat. Hazards 87, 145–164. https://doi.org/10.1007/s11069-017-2757-y

Strom, A., Abdrakhmatov, K., 2018. Rockslides and rock avalanches of Central Asia: distribution, morphology, and internal structure. Elsevier.

Styron, R., Pagani, M., 2020. The GEM Global Active Faults Database. Earthq. Spectra 36, 160–180. https://doi.org/10.1177/8755293020944182

Sychev, V., Mueller, L., 2018. Optimising Agricultural Landscapes, in: Novel Methods and Results of Landscape Research in Europe, Central Asia and Siberia. Russian Academy of Science, Moscow.

Tacconi Stefanelli, C., Casagli, N., Catani, F., 2020. Landslide damming hazard susceptibility maps: a new GIS-based procedure for risk management. Landslides 1–14.

Tatem, A.J., 2017. WorldPop, open data for spatial demography. Sci. Data. https://doi.org/10.1038/sdata.2017.4

Teluguntla P. G., T.P.S.X.J.N.G.M.K.G.C.M.C.O.C.R.T.J.S.T.T.M.R.P.A., Yadav, K., 2015. Global Cropland Area Database (GCAD) derived from Remote Sensing in Support of Food Security in the Twenty-first Century: Current Achievements and Future Possibilities.

The Global Water System Project, 2011. Global Reservoir and Dam (GRanD) Database.

Thurman, M., 2011. Natural Disaster Risks in Central Asia: A Synthesis. UNDP BCPR.

Trigila, A., Frattini, P., Casagli, N., Catani, F., Crosta, G., Esposito, C., Spizzichino, D., 2013. Landslide susceptibility mapping at national scale: the Italian case study, in: Landslide Science and Practice. Springer, Berlin, Heidelberg, pp. 287–295.

Trouet, V., Van Oldenborgh, G.J., 2013. KNMI climate explorer: A web-based research tool for high-resolution paleoclimatology. Tree-Ring Res. https://doi.org/10.3959/1536-1098-69.1.3

UN-ESCAP Statistics Division; UN_ESCAP ICT and Disaster Risk, Reduction Division, 2015. Geospatial Information and the Data Revolution “A Quick Win” for Sustainable Development in Asia-Pacific.

UNDRR, 2019. Global Assessment Report on Disaster Risk Reduction.

Wang, P., Huang, C., Colstoun, E.C.B. de, Tilton, J.C., Tan, B., 2017. Documentation for the Global Human Built-up And Settlement Extent (HBASE) Dataset From Landsat. NASA Socioecon. Data Appl. Cent.

Wieland, M., Pittore, M., Parolai, S., 2015. A multiscale exposure model for seismic risk assessment in central Asia. Seismol. Res. Lett.

World Bank, 2006. Natural Disaster Hotspots: Case Studies. Disaster Risk Management Series No. 6.

World Bank, 2016. Measuring Seismic Risk in Kyrgyz Republic Development of Exposure Model.

World Bank, 2020. Agriculture, forestry, and fishing, value added (% of GDP). https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

World Bank, 2021. A Catalogue of Nature-based Solutions for Urban Resilience. Washington, D.C. World Bank Group.

World Bank, 2022a. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 2 - Earthquake Hazard Assessment. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022b. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 3 - Flood Hazard Assessment. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022c. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 4 - Exposure Assessment. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022d. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 5a - Earthquake Vulnerability. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022e. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 5b - Flood Vulnerability. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022f. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 6 - Earthquake and Flood Risk Assessment. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022g. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 7 - Landslide Scenario Assessment. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022h. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 8 - Capacity Building and Knowledge Transfer. Washington, D.C. World Bank Group. https://www.linktoreport.html

World Bank, 2022i. Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia. Task 9 - Country Summaries. Washington, D.C. World Bank Group. https://www.linktoreport.html

Yamazaki, D., Ikeshima, D., Sosa, J., Bates, P.D., Allen, G.H., Pavelsky, T.M., 2019. MERIT Hydro: A High-Resolution Global Hydrography Map Based on Latest Topography Dataset. Water Resour. Res. 55, 5053–5073. https://doi.org/10.1029/2019WR024873

Yu, Y., Pi, Y., Yu, X., Ta, Z., Sun, L., Disse, M., Zeng, F., Li, Y., Chen, X., Yu, R., 2019. Climate change, water resources and sustainable development in the arid and semi-arid lands of Central Asia in the past 30 years. J. Arid Land 11, 1–14. https://doi.org/10.1007/s40333-018-0073-3

Appendix A - List of acronyms

AAL: Annual Average Loss

AFEAD: Active Fault for Eurasia and Adjacent regions

ARC: African Risk Capacity

AS: Active Shallow crust

AUC: Area Under Curve

CA: Cellular Automata

CA: Central Asia

CAC DRMI: Central Asia and Caucasus Disaster Risk Management Initiative

CAPRA: Comprehensive Approach to Probabilistic Risk Assessment

CAWA: Central Asian Water

CCRIF: the Caribbean Catastrophe Risk Insurance Facility

DEM: Digital Elevation Model

DFI: Disaster Financing and Insurance

DRFI: Disaster Risk Financing and Insurance

DRM: Disaster Risk Management

DRR: Disaster Risk Reduction

DS: Deep Seismicity

EMCA: Earthquake Model of Central Asia

EP: Exceedance Probability

ERD: Earthquake-Resistant Design

ERN: Evaluación de Riesgos Naturales

EUR: Euro

FAO: Food and Agriculture Organization

FEMA: Federal Emergency Management Agency

FLOPROS: FLOod PROtection Standards

GAF-DB: Global Active Fault Database

GDP: Gross Domestic Product

GED4ALL: Global Exposure Database for all

GEM: Global Earthquake Model

GFDRR: Global Facility for Disaster Reduction and Recovery

GIS: Geographic Information System

GLOSI: Global Library of School Infrastructure

GMPE: Ground Motion Prediction Equation

GRDC: Global Runoff Data Centre

GSHAP: Global Seismic Hazard Assessment Program

HBASE: Human Built-up And Settlement Extent

IED: Industry Exposure Database

IM: Intensity Measure

IMT: Intensity Measure Type

ISO: International Organization for Standardization

KAZ: Kazakhstan

KGZ: Kyrgyz Republic

KNMI: Royal Dutch Meteorological Institute

LEC: Loss Exceedance Curve

LLP: Limited Lability Partnership (LLP)

MERIT: Multi-Error-Removed Improved-Terrain

MOI: Morphological Obstruction Index

MUSD: Millions United States Dollars

OGS: Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

PDF: Portable Document Format

PGA: Peak Ground Acceleration

PML: Probable Maximum Loss

PSHA: Probabilistic Seismic Hazard Analysis

RED: Risk Engineering + Development

RF: Random Forest

ROC: Receiver Operating Characteristic

RSTC: Regional Scientific and Technical Council

SC: Stable Crust

SERA: European Seismic Risk Assessment

SFRARR: Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia

TJK: Tajikistan

TKM: Turkmenistan

UHS: Uniform Hazard Spectra

UNDRR: United Nations Office for Disaster Risk Reduction

UNESCAP: United Nations Economic and Social Commission for Asia and the Pacific

UNESCO: United Nations Educational, Scientific and Cultural Organization

UNICEF: United Nations International Children's Emergency Fund

US: United States

USD: United States Dollar

UZB: Uzbekistan

WUEMOCA: Water Use Efficiency Monitor in Central Asia platform

YLT: Year Loss Tables