Task 4 – Exposure development

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

16 November 2022

RED – Risk Engineering + Development – Pavia, Italy

Revision History

Version	Date	State	Initials	Changes
r1d1	25/10/2021	Draft	OGS: CS	
r1d2	29/10/2021	Draft	RED: PB; OGS: SP	General review, copyediting
r1	12/11/2021	Approved	OGS: CS, SP; RED: PB	Changes based on reviewers' comments
r2d1	26/11/2021	Draft	OGS: CS	Changes based on reviewers' comments
r2	20/12/2021	Approved	OGS: CS, SP; RED: PB	Changes based on reviewers' Comments
r3	09/02/2022	Draft	OGS: CS, SP; RED: PB	Changes based on reviewers' Comments
r4d1	03/03/2022	Draft	OGS: CS, SP; RED: PB	Changes based on reviewers' comments
r4	18/03/2022	Approved	OGS: CS RED: GC, PC	Changes based on reviewers' comments
r5		Approved	RED: GC, PC	Review of a few typos
r6	17/10/2022	Approved	OGS: CS; RED: GC, PC	Changes carried out during the calibration process, as part of the activities of Task 6
	16/11/2022	Approved	WB	

Technical Assignment number 1266456

RED Risk Engineering + Development

Executive Summary

The European Union, in collaboration with the World Bank and the GFDRR, has started a programme for "Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia" (SFRARR). The World Bank has commissioned the project "Regionally consistent risk assessment for earthquakes and floods and selective landslide scenario analysis for strengthening financial resilience and accelerating risk reduction in Central Asia" to an international consortium constituted by the leading partner (Risk, Engineering and Development, Pavia, Italy), other 4 partners from outside Central Asia and a wide range of locally-based research and engineering partners from each of the 5 Central Asia countries (Kazakhstan, Kyrgyz Republic, Tajikistan, Uzbekistan and Turkmenistan).

The project has three main objectives: quantifying regional disaster risks, increasing risk awareness and financial resilience at regional and local scale. Both these objectives rely on exposure assessment and mapping, which is of paramount importance in order to produce reliable risk estimates. The exposure analysis allows the identification of the main exposed assets and their spatial location. In addition, it allows the assessment of the reconstruction costs for each asset. In the past, strong effort was devoted to disaster risk reduction in Central Asia and pointed out the need for regionally-consistent exposure datasets. However, at the moment the available exposure information is scattered across different datasets, most of them created at national scale.

This project aims at contributing to fill this gap and at producing the first exposure dataset for Central Asia. The adopted approach combines the most recent datasets and technologies, which allowed the development of high-resolution datasets (e.g., the Facebook high-resolution population grid, https://data.humdata.org/organization/facebook) and local-scale official data (e.g., population census). All collected data were harmonized in order to produce a regionally-consistent exposure database for Central Asia. The exposure database developed during the project includes multiple datasets for the different exposed asset types:

- population
- residential buildings
- non-residential buildings (schools, healthcare facilities, industrial and commercial buildings)
- croplands
- transportation system (roads, railways and bridges)
- airports and airstrips
- mines
- supply infrastructure

This report describes the methodologies adopted for developing the exposure layers and summarizes the outcomes of the exposure development. The report includes the following topics, described in separate sections:

- Introduction and context for the exposure development (Section 1)

- Description of the methodologies used for the exposure assessment and the results obtained for each exposed asset type (Section 2)
- Validation of the exposure database (Section 3)
- Limitations of the approach, data gaps and reliability of results (Section 4)
- Capacity building activities (Section 5)
- Discussion of the results and conclusions (Section 6)

The exposure database developed during this project can be used at regional scale, national scale or sub-national scale (e.g., at O*blast* scale). The appendix provides additional information on the data collected during the project, the link between exposure and vulnerability and the general guidelines for using and modifying the exposure dataset.

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1 Introduction

The Central Asian region covers 4 million square km and is constituted by five countries over two time zones. It comprises different climatic zones, socio-economic systems and heterogeneous land use patterns. The region has undergone a strong development in recent years, and saw a strong population growth (ESCAP, 2019). In addition, almost 50% of the population is concentrated in a few major cities while rural areas have a very low density. Central Asia is undergoing a strong development of energy and transportation infrastructures, both due to national development plans and international initiatives devoted to the construction of new railways and energy pipelines (mostly oil and gas). However, central Asia is also subjected to multiple hazardous phenomena including earthquakes, floods and landslides which can cause strong social and economic impacts on the population and the national economies.

Evidence of this impact is given by past hazardous events in the region, which underline the importance of increasing risk-related knowledge and, subsequently, preparedness. The knowledge on the location, number and type of exposed assets (i.e., the exposure assessment) is a paramount component of this process. Past projects have focused on assessing exposure related to specific risks in selected countries (e.g., World Bank, 2017 for seismic risk in Kyrgyz Republic). The first regional-scale seismic exposure dataset was developed by Pittore et al. (2020) and is focused on residential buildings and their occupancy. However, the database does not include other typologies of exposed assets such as non-residential buildings and transportation and supply infrastructure. The experience accumulated in past projects provides a solid starting point for the development of regional-scale exposure assessment. However, despite the strong effort devoted to disaster risk reduction in the region, at the moment, no regional exposure assessment study exists that collects all the exposed assets into a regionally-consistent dataset. In addition, the exposure of Central Asia comprises a wide number and type of assets located in different national contexts.

This work consists in the first attempt to assemble a regionally consistent database for Central Asia and makes a strong effort to include most exposed assets in the region. The development of such a database is funded on a balance between global-scale datasets and national-scale data that allow grasping the differences and peculiarities of the 5 countries. There are nonetheless several challenges associated with the definition of a regionally-consistent exposure database, the main ones being the differences in the characteristics of exposed assets in the region and the inhomogeneous data availability. Moreover, exposure databases require regular updates in order to be used for disaster risk assessment and for decision making. New data are continuously becoming available due to new technologies such as high-resolution remote sensing earth observations and new projects and studies targeting different exposed asset typologies. The database developed in this project has been structured and documented with the aim of being easily updated once new information becomes available. There are a number of projects that are currently being deployed with the aim of collecting information on education facilities (e.g., ERIK project, 2018) and of enhancing the current infrastructure, such as water supply (World Bank ongoing projects P162637 and P162263). All these efforts can in the future contribute to enhancing the exposure database which, far from being a static layer, requires regular updates.

This document describes the methodology adopted to develop the exposure layers for Central Asia and provides the reader with an overview of the results in the form of maps and tables of aggregated values on specific administrative regions. The outcomes of the exposure assessment provide a starting point for risk assessment in the region and allow identifying priorities for future actions devoted to disaster risk reduction. The outcomes will be shared with National governments in order to support risk reduction actions in the region.

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 local experts in the use of open tools and resources (see Table 1 for the complete list of involved scientific institutions from each partner country).

Table 1. List of partner countries of the consortium and associated scientific institutions

Country	Main Scientific Institution	Local Representatives and support team
Kazakhstan	IS - Institute of Seismology under MoES of RoK	Dr. Natalya Silacheva Dr. Satbek Sarzahov Dr. Baurzhan Adilkhan Dr. Zhanar Raimbekova
Kyrgyz Republic	ISNASKR - Institute of Seismology of Kyrgyz Republic	Prof. Kanatbek Abdrakhmatov Dr. Anna Berezina Dr. Ruslan Umaraliev Prof. Ulugbek Begaliev
Tajikistan	IWPHE - Institute of Water Problems, Hydropower Engineering and Ecology	Prof. Zainalobudin Kobuliev Dr. Mustafo Savarov Dr. Javhar Aminov Dr. Iftikhor Kalandarbekov
Turkmenistan	Various individual consultants	Dr. Japar Karaev Dr. Vladimir Belikov
Uzbekistan	ISASUz - Institute of Seismology Uzbekistan TSTU - Tashkent State Transport University	Prof. Vakhitkhan Ismailov Dr. Zukhritdin Ergashev

2 Exposure development

2.1 Approach

This section summarizes the methodology adopted for developing a regionally-consistent exposure database for Central Asia. Exposure development activities were organized in three phases: data collection, exposure development and validation. This assignment is performed at regional scale, but exposure assessment relies on multiple datasets collected at different spatial resolution (global, regional, national, sub-national and local). As a general strategy, global/regional layers were used as a starting point, and allowed to achieve a good spatial coverage. Secondly, national and/or local scale information was included in order to enhance the database with country-specific information. This method relies on the assumption that local-scale data provided by local partners are in general more reliable than regional and global scale layers. Global and regional-scale database have a large coverage, but often with lower spatial resolution. National data, in their turn, are usually collected by national institutions with higher spatial resolution and therefore have a higher reliability. In absence of data or information on specific assets, we used the available data for countries with similar features (e.g., same geopolitical context).

Exposure datasets are, by definition, spatial datasets, that is, digital maps where the exposure information is associated to spatial coordinates. In fact, the location of exposed assets (e.g., where different building types are located within a country) is required in order to perform the risk assessment. In absence of information on the asset location (e.g., address, coordinates), a common method to infer the buildings' or facilities' location is to distribute them spatially based on proxies such as population or land use maps. This operation, also called 'spatial disaggregation', and other spatial operations of the kind (e.g., merging of databases, intersection of different maps) were performed using the QGIS open-source program (https://www.qgis.org/en/site/).

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 (e.g., location, type, material, age), in particular those relevant to quantify their vulnerability against the perils considered in the current project. Taxonomies are defined based on the Ged4ALL taxonomy system (http://riskdatalibrary.org/resources), a common exposure data schema aimed at supporting the sharing of global and regional scale information for risk assessment purposes.

Information about the characteristics of residential building types is often available at national scale in the form of statistics on the percentage of building types in each country. Additional information is sometimes available at local scale (e.g., spatial distribution of such typologies in a city or a region). For other exposed assets such as non-residential buildings, information on the building types is only available at regional or national scale and is not associated with a spatial distribution. In this case, the characteristics of exposed assets (e.g., buildings' material) rely on national statistics. In absence of additional, local-scale information, a general building typology is defined and associated to an unknown material ('UNK' in the Ged4all system). This "material" has additional information based on the available statistics. For example, if the hospital building stock is constituted by 50% Reinforced concrete frames and 50% Precast concrete buildings, the construction material can be either one or the other. A specific vulnerability curve can be defined as a combination of the two vulnerability curves for reinforced concrete frames and precast concrete buildings, weighted according to the percentages specified in the description. This approach allows grasping the complexity behind the definition of building typologies and accounting for it in the risk assessment.

The methods adopted in this project allowed us to combine the available exposure data at different spatial resolution (global, regional, national and sub-national) and produced under several past projects based on cutting-edge technologies. In particular, remote sensing data are very important in order to derive exposure datasets that allow covering large areas, but also allow to assess the location and specific characteristics of selected sites. These data were combined with local-scale information provided by local partners in each of the 5 Central Asia countries that enabled us to grasp the differences among the national contexts. The collected information was then homogenized in order to provide regionally-consistent aggregated results for the entire Central Asia region.

2.2 Data collection

The exposure development relies on the collection of two main types of data: global and regional-scale datasets (mostly available online) and specific country-based data (gathered by local partners). Global and regional-scale data were collected by the consortium also following the suggestions of the Regional Scientific-Technical Council (RSTC) and the World Bank. Country-based data were gathered with the help of local partners of the consortium. The data collection was performed completely online, with periodic meetings with the partners. For each country, local partners provided the names of the persons responsible for the exposure development task. One initial meeting was performed in order to explain the exposure development process and the data needed to all countries' representatives. Then, one country-specific meeting was held together with the team leaders of vulnerability and risk assessment tasks. A second specific meeting was organized when needed in order to discuss the data availability and use. The local partners coordinated the data collection and provided data both from national ministries (e.g., census data) and from past projects carried out in their country. The communication with local partners and representatives in each country was very frequent, including email interchange, also due to the organization of the exposure development workshops. In particular, four out of five country-based workshops took place before the end of the exposure development phase (TW3-6). Details on the workshops are included in Section 5. These meetings, aimed at preparing the training material for the workshops, also accommodated discussions on the data collection and processing. These discussions were very useful in order to perform the exposure assessment.

The collected information includes population and households census, information on the residential and non-residential building typologies, road and railways and other infrastructure assets, including reconstruction costs. Appendix 1 summarizes the global, regional and national-scale data collected during the project. Many data were provided by local partners and/or discussed with them during the data collection phase. The report mentions the data used for the exposure development of each asset type. During the data collection, the consortium experienced two main challenges: the amount and variety of data required and the availability of spatial data in digital form. The exposure development required, in fact, a large amount and variety of data types, hosted by various partners and institutions. In addition, it was often difficult to retrieve digital data such as shapefiles, which would have facilitated the exposure development process. Data on population, demographics and total number of residential and non-residential buildings (e.g., schools, hospitals) were mostly available from official sources. However, they were often aggregated at national or sub-national (Oblasts) scale, and not associated with spatial information. Retrieving spatial data on infrastructure was particularly challenging. These difficulties were partially overcome thanks to the availability of global datasets such as OpenStreetMap which have a reasonably good coverage in Central Asia. Other global datasets used in the assignment provided the location of main hospitals, schools, dams, and industrial sites. Aggregated values were nonetheless validated by comparison with national data, when possible.

2.3 Exposure development

This section describes the methodology adopted for the exposure assessment. A specific methodology was defined for each exposed asset type based on the available data and in the context of a regional-scale assessment. The section includes the methodology adopted for estimating the reconstruction costs for each asset type. In this project, we consider two types of costs: structural and content costs. Structural costs are those associated to the reconstruction of the building at the current construction costs. Other costs such as those related to business interruption are not considered in this project. The limitations of the exposure development methodology are discussed in Section 4.

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. This section includes the main results of the exposure assessment, such as maps and tables of aggregated values for countries and administrative units extracted from the developed exposure dataset.

2.3.1 Population

In this project, we developed a population dataset at 100m resolution that includes specific demographic attributes (age, gender) for the whole Central Asia. This dataset was based on data from several data sources, used as a starting point for the development of the exposure layers. In particular, the consortium used the Facebook high-resolution dataset (https://data.humdata.org/organization/facebook), which provides population, gender and age information at approximately 20 m in Central Asia. The Facebook population data, retrieved for 2020, was distinguished into three age classes: younger than 5 years old, older than 60 years old or the intermediate age class. The population layers were assembled as follows:

- First, the total population in the Facebook dataset was compared with the Worldpop dataset (https://www.worldpop.org/), that provides total population (but no information on age and gender fractions) for 2020. The comparison was performed after aggregating the Facebook data at the resolution of the WorldPop layer (100 m) and showed a good agreement. This operation was performed directly on the spatial layers using the QGIS open-source program.
- Second, population, age and gender data in the Facebook dataset was compared with national census data collected by local partners. Local partners retrieved the available population data from national sources, including population data by age and gender in each country and sub-national administrative units (Oblasts). The collected data were extracted from the latest available population census or equivalent data source (2021 for Uzbekistan, 2020 for Kazakhstan and Kyrgyz Republic, 2019 for Turkmenistan, and 2018 for Tajikistan).
- Finally, for each Oblast, the Facebook base layer was corrected according to the recent national-scale data. This is done under the assumption that recent national census data is more

reliable than global datasets. The difference was greater than 20% in 7 Oblasts of the 4 considered countries (Table 2). In all regions, the 100-m population grid was corrected proportionally to the estimated difference with the national census data. The correction was performed also for a number of cities in Kyrgyz Republic, Kazakhstan and Turkmenistan, for which data were available (included in Table 2). Gender and age percentages were also corrected based on the national data collected after 2019, when available from country-based data. The exception of the elder fraction (greater than 60 years old) was maintained from the Facebook population dataset because the data at national scale was only available for different age thresholds (e.g., 70 for Kyrgyz Republic and Uzbekistan, 63 for Kazakhstan).

Table 2. Population in each Oblast of Kazakhstan, Kyrgyz Republic, Uzbekistan and Turkmenistan according to the Facebook layer and the national census. Percentage differences exceed the 20% in 7 Oblasts (bold values).

Country	Oblast	Total population Facebook	Total population local data	Percentage difference
Kazakhstan	Akmola	1,004,785	736,735	**27%**
	Aktobe	853,512	881651	-3%
	Almaty	1,938,716	2,055,724	-6%
	Atyrau	535,726	645,280	-20%
	East Kazakhstan	1,381,766	1,369,597	1%
	Jambyl	1,090,763	1,130,099	-4%
	Karagandy	1,365,888	1,376,882	-1%
	Kostanay	848,801	868,549	-2%
	Kyzylorda	770,273	803,531	-4%
	Mangystau	655,953	698,796	-7%
	North Kazakhstan	551,654	548,755	1%
	Pavlodar	740,589	752,169	-2%
	Turkestan	1,972,120	2,016,037	-2%
	West Kazakhstan	614,935	656,844	-7%

Uzbekistan	Andijan	3,022,734	3,188,000	-5%
	Bukhara	1,873,042	1,947,000	-4%
	Fergana	3,528,294	3,820,000	-8%
	Jizzakh	1,173,257	1,411,000	-20%
	Karakalpakstan	1,663,991	1,924,000	-16%
	Kashkadarya	3,057,743	3,335,000	-9%
	Khorezm	1,823,217	1,893,000	-4%
	Namangan	2,657,004	2,867,000	-8%
	Navoi	1,331,673	1,014,000	**24%**
	Samarkand	3,281,422	3,947,000	-20%
	Sirdarya	845,751	861,000	-2%
	Surkhandarya	2,467,273	2,681,000	-9%
	Tashkent	3,944,791	2,994,000	**24%**
Kyrgyz Republic	Batken	438,572	537,365	**-23%**
	Chu	839,552	959,884	-14%
	Jalal-Abad	1,228,239	1,238,750	-1%
	Naryn	285,465	289,621	-1%
	Osh	1,231,589	1,368,054	-11%
	Talas	280,266	267,360	5%
	Issyk-Kul	455,706	496,050	-9%
Turkmenistan	Ahal	868,623	968,600	-12%
	Lebap	1,126,468	1,371,100	**-22%**

	Balkan	474,586	569,100	-20%
	Dashoguz	1,161,253	1,409,400	**-21%**
	Mary	1,251,297	1,519,000	**-21%**

Figure 1 shows a detail of the population exposure dataset provided by the high-resolution Facebook dataset and the grid developed at 100m resolution in this project (bottom) showing that it matches successfully the building's distribution in the aerial image (top).

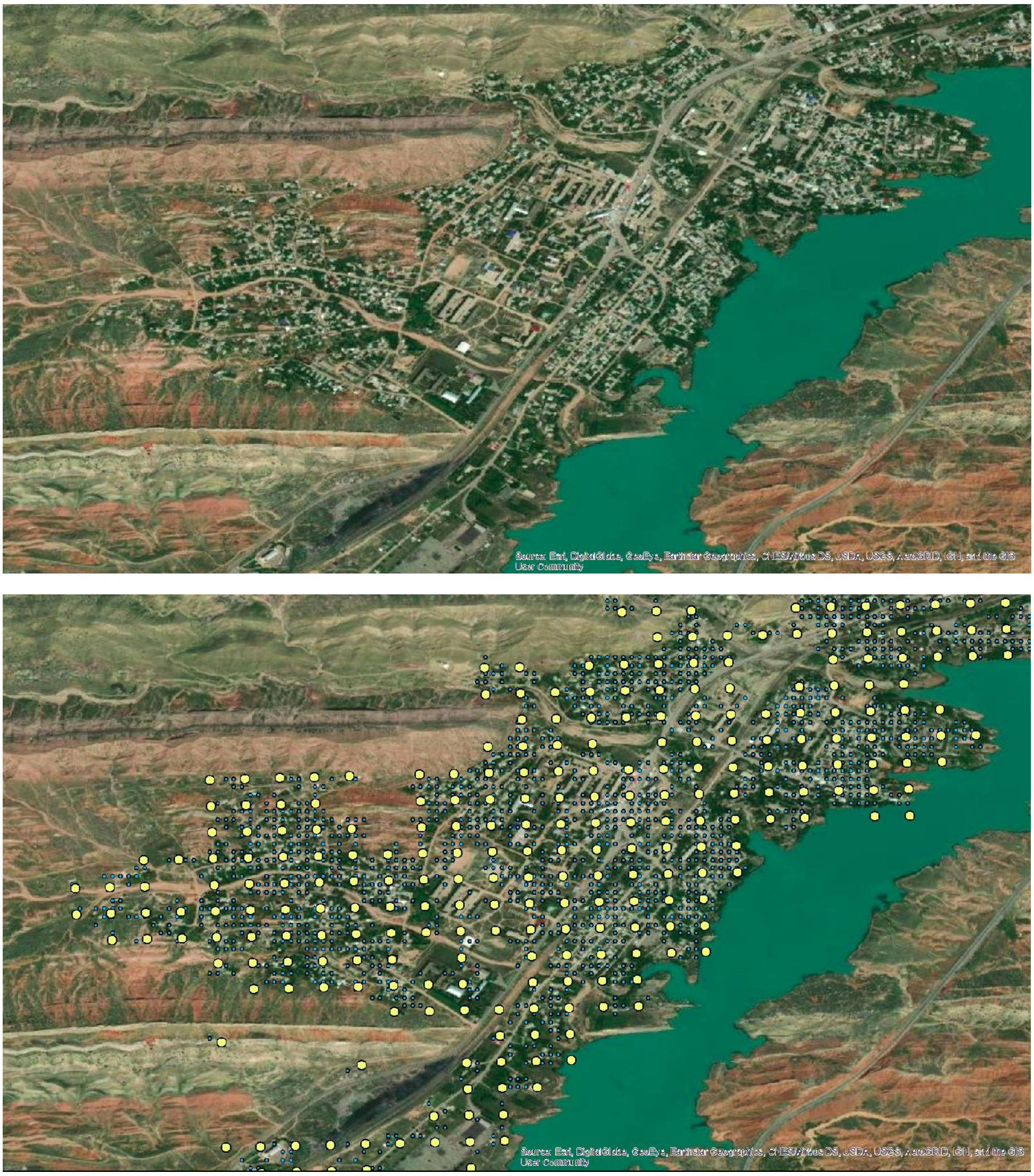

Figure 1. Distribution of the buildings based on an aerial image in a village in Jalal-Abad Oblast, Kyrgyz Republic (top), (bottom) population grid at 20m (Facebook) and 100m resolution (blue and yellow dots respectively).

Table 3 shows the distribution of total population in the country and the fraction of men, women, elder and young people for each Oblast of the five Central Asia countries and for the entire region. These values are used for assembling the final population exposure layer.

Table 3. Total population and gender and age fractions in each Central Asia country and for the whole region.

Country	Oblast	Total	Men	Women	>60 years old	<5 years old
Kazakhstan	Akmola	1,732,686	831,689	900,996	190,595	138,614
	Aktobe	915,196	439,294	475,902	100,671	73,215
	Almaty	2,440,375	1,171,380	1,268,995	268,441	195,230
	Almaty (city)	1,437,016	689,767	747,248	158,071	112,961
	Atyrau	653,678	318,765	339,912	71,904	52,294
	East Kazakhstan	1,431,196	686,974	744,222	157,431	114,495
	Jambyl	1,166,798	560,063	606,735	128,347	93,343
	Karagandy	1,439,313	690,870	748,443	158,324	115,145
	Kostanay	907,530	435,614	471,915	99,828	72,602
	Kyzylorda	832,005	399,362	432,642	91,520	66,560
	Mangystau	711,729	341,630	370,099	78,290	56,938
	North Kazakhstan	786,807	377,667	409,140	86,548	62,944
	Pavlodar	784,726	376,668	408,057	86,319	62,778
	Shymkent (city)	1,038,152	500,439	537,713	78928	n.a.
	Turkestan	3,084,568	1,480,593	1,603,975	339,302	246,765
	West Kazakhstan	682,746	327,718	355,028	75,102	54,619

	Total	19,006,369	9,123,054	9,883,309	2,090,693	1,520,503
Kyrgyz Republic	Batken	587,701	293,850	293,850	35,262	70,524
	Biškek (City)	1,053,915	494,540	559,375	75,221	122,284
	Chu	2,143,766	1,071,883	1,071,883	128,626	257,252
	Jalal-Abad	1,323,477	661,738	661,738	79,408	158,817
	Naryn	289,351	144,675	144,675	17,361	34,722
	Osh	1,770,649	885,324	885,324	106,238	212,477
	Osh (city)	312,530	151,571	160,959	14,512	45,846
	Talas	267,364	133,683	133,683	16,041	32,083
	Issyk-Kul	488,611	244,305	244,305	29,316	58,633
	Total	6,870,919	3,435,457	3,435,457	412,252	824,508
Tajikistan	Areas of republican subordination	2,158,424	1,079,212	1,079,212	107,921	280,595
	Khatlon	3,408,656	1,704,328	1,704,328	170,432	443,125
	Sughd	2,644,018	1,322,009	1,322,009	132,200	343,722
	Dushanbe	983,911	491,955	491,955	49,195	127,908
	Gorno-Badakhshan (GBAO)	206,934	103,467	103,467	10,346	26,901
	Total	9,401,943	4,700,971	4,700,971	470,094	1,222,251
Uzbekistan	Andijan	3,078,004	1,539,002	1,539,002	153,900	400,140
	Bukhara	1,996,248	998,124	998,124	99,812	259,512
	Fergana	3,841,356	1,920,678	1,920,678	192,067	499,376
	Jizzakh	1,411,590	705,795	705,795	70,579	183,506
	Karakalpakstan	2,166,042	1,083,021	1,083,021	108,302	281,585

	Kashkadarya	3,336,649	1,668,324	1,668,324	166,832	433,764
	Khorezm	1,619,288	809,644	809,644	80,964	210,507
	Namangan	2,798,605	1,399,302	1,399,302	139,930	363,818
	Navoi	773,271	386,635	386,635	38,663	100,525
	Samarkand	4,141,357	2,070,678	2,070,678	207,067	538,376
	Sirdarya	750,147	375,073	375,073	37,507	97,519
	Surkhandarya	2,659,531	1,329765	1,329765	132,976	345,739
	Tashkent	3,496,335	1,748,167	1,748,167	174,816	454,523
	Total	34,322,170	17,161,081	17,161,081	1,716,102	4,461,877
Turkmenistan	Aşhgabat (City)	1,032,000	697,412	520,128	21,878	120,744
	Ahal	1,968,467	754,478	984,233	39,369	236,216
	Lebap	1,359,465	679,732	679,732	27,189	163,135
	Balkan	540,831	270,415	270,415	10,816	64,899
	Dashoguz	1,394,824	697,412	697,412	27,896	167,378
	Mary	1,508,957	754,478	754,478	30,179	181,074
	Total	7,772,544	3,386,270	3,386,270	153,449	812,702
Central Asia	Total	76,373,945	37,806,833	38,567,088	4,824,590	8,841,841

2.3.2 *Residential buildings*

The method adopted here for developing exposure maps of residential buildings consists of refining the exposure model of Pittore et al. (2020) by increasing its spatial resolution and by better characterizing the residential building typologies. The building typologies used in the exposure model of Pittore et al. (2020) were defined during the Earthquake Model Central Asia project (EMCA, http://www.emca-gem.org/) and will be referred to here as 'EMCA' typologies (Table 4). Each typology and sub-typology are associated to a description and a taxonomy, which can also specify if the structure is designed to be Earthquake Resistant (ERD). The taxonomies are expressed based on the GEM building taxonomy (https://taxonomy.openquake.org/). Each string in the taxonomy corresponds to a specific building feature. The taxonomy is assembled in a specific order: material, lateral-load resisting system, storey numbers and age. These typologies are also associated to several sub-typologies and a specific taxonomy compatible with the Ged4All format. The first block of the taxonomy string represents the construction material ('MUR'=masonry, 'RC'=reinforced concrete, 'W'=wood, 'S'=steel). The second block provides information on the building units ('MOC'=Cement mortar; 'MOCL' = Cement and clay mortar, 'CLBRS' = Fired clay solid bricks) or material ('CIP' = cast-in-place concrete, 'PC' = precast concrete). The lateral load-bearing system, if present, is also codified as 'LWAL' (lateral walls), 'LFM' (moment frame) or 'LDUAL' (Dual frame-wall system). Information on the ductility can also be included ('DNO'=Non-ductile; 'DUC'=ductile). Information on the floor types, if available, is also codified. The typologies identified in Central Asia can have wooden floors ('FW') or concrete floors ('FC'). The number of storeys, if available, is provided in form of value or range associated with the 'HBET:' string. Note that the EMCA-3 typology defined by Pittore et al., 2020 (precast reinforced concrete) also includes precast frames. Such building typology is specifically mentioned in Wieland et al., 2015 and in most cases has rigid walls in one direction and is thus included in the RCPC1 sub-typology.

Table 4. EMCA typologies according to Pittore et al. (2020). ERD stands for Earthquake-Resistant design according to the EMS-98 buildings classification.

EMCA typology	Sub-typology	Description	Taxonomy (Pittore et al., 2020)
EMCA1	URM1	Unreinforced masonry, wooden floors	/MUR + CLBRS + MOC/LWAL + DNO/FW
	URM2	Unreinforced masonry concrete floors	MUR+ MOCL/LWAL + DNO/FC
	CM	Confined masonry	/MCF + MOC/LWAL + DNO/FC/HBET
	RM-L	Reinforced masonry, low rise	/MR + MOC/LWAL + DNO/FC/HBET:1
	RM-M	Reinforced masonry, medium rise	/MR + MOC/LWAL + DNO/FC/HBET:3
EMCA2	RC1	RC (reinforced concrete) frame without ERD	/CR + CIP/LFM + DUC/FC/HBET
	RC2	RC (reinforced concrete) frame with moderate ERD	/CR + CIP/LDUAL + DNO/FC/HBET:7
	RC3	RC (reinforced concrete) frame with high level of ERD	/CR + CIP/LFINF + DNO/FC/HBET:3
	RC4	RC (reinforced concrete) walls without ERD	/CR + CIP/LWAL +DNO/FC/HBET:8
EMCA3	RCPC1	RC (reinforced concrete) walls with moderate level of ERD	/CR + PC/LWAL + DUC/FC/HBET
	RCPC2	RC (reinforced concrete) walls with high level of ERD	/CR + PC/LFLS + DUC/FC/HBET:5

EMCA4	ADO	Adobe	/MUR + ADO/LWAL + DNO/FW/HBET:1
EMCA5	WOOD1	Timber structure, load-bearing braced frames	/W/LWAL + DUC/FW/HBET:1
	WOOD2	Timber structure, wooden frame and mud infill	/W+ WLI/LO + DUC/FW/HBET:1
EMCA6	STEEL	Steel structure	/S/LFM +DNO/FME/HBET:1

The spatial layer produced by Pittore et al. (2020) has a variable resolution ranging from a few hundred meters in urban areas to several km in rural areas. This layer was developed specifically for earthquake damage and risk assessment purposes, for which the spatial resolution was appropriate. However, in order to perform a risk assessment for fluvial and pluvial hazard, spatial resolution needs to be increased considerably. During this project, we increased the layer spatial resolution in order to produce a residential buildings exposure layer on a constant-resolution grid. Local partners collected and provided information on the number of buildings or households by Oblast or city and, when available, the number of buildings for each structural typology. For two countries, Kazakhstan and Uzbekistan, local partners provided the information about the number of households by Oblast and load-bearing material (which were associated to EMCA structural typologies, Table 4). This information was used to update the spatial distribution of building typologies in each country of Central Asia based on national-scale data. The method for deriving the final residential buildings exposure layer has 4 main phases:

- The original polygons from Pittore et al. (2020) were classified into urban and rural areas based on the urbanized areas mask provided by the GRUMP dataset (CIESIN, 2021, Figure 2a)
- For each country and Oblast, the number of buildings in each typology (provided by local partners) was distributed into the urban and rural polygons identified in the previous step (Figure 2b). This method was applied to the countries where local data were available. Buildings were distributed based on the population in the buildings in each polygon (provided by Pittore et al., 2020). The fraction of different typologies in urban and rural areas of each Central Asia country was extracted from Wieland et al. (2015).
- For each building type, the total number of buildings was distributed among the sub-typologies (Table 4) based on the relative fraction of each sub-typology in the Pittore et al. (2020) dataset. This operation was carried out for each polygon.
- Finally, residential buildings in each polygon were distributed spatially based on the population layer developed for Central Asia at 100m resolution (see 2.3.1 for details). This allowed increasing the resolution and obtaining an equally spaced grid of 100-m resolution (Figure 2c).

Figure 2 shows examples of the exposure development main steps for Eastern Uzbekistan. Figure 2a shows the urban and rural mask provided by the GRUMP dataset. Figure 2b shows an example of how data provided by locals for each country's Oblast (e.g., Navoi province, Tajikistan) are distributed on the existing variable-resolution grid. Figure 2c shows how the data are distributed on the population grid in order to reach higher resolution. The final result of this procedure is an equally-spaced grid of 100m resolution with the number and type of buildings in each sub-typology in Table 4. Information on exposed residential buildings is therefore provided in aggregated format (i.e., a number of buildings are located on a point belonging to a constantly-spaced grid).

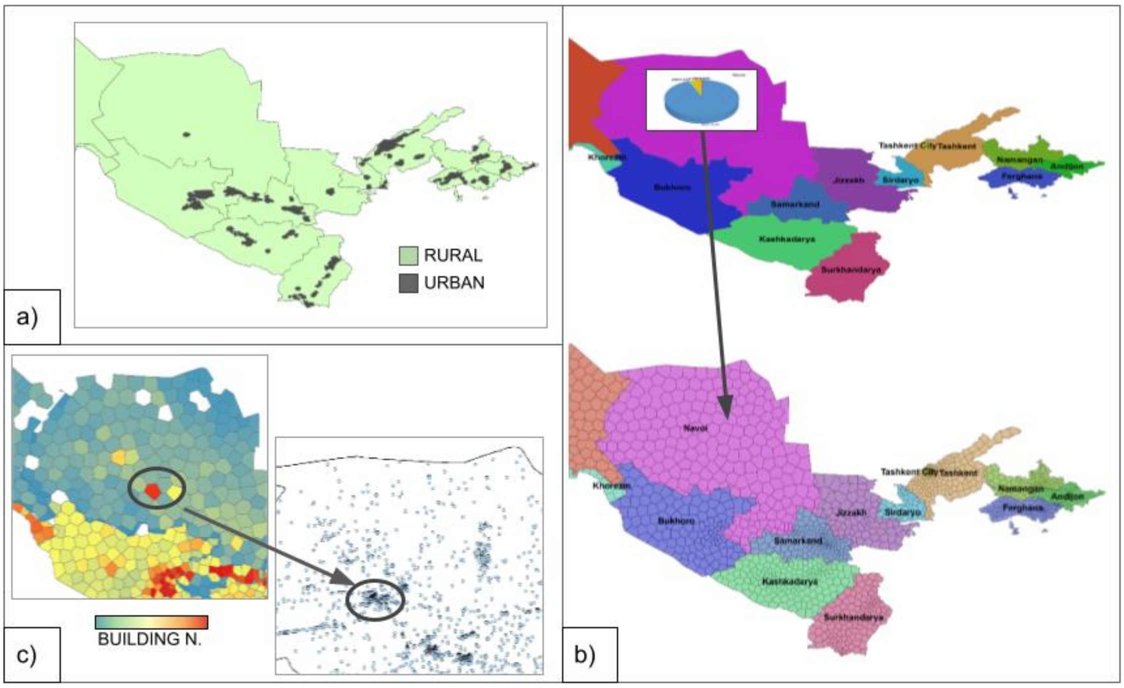

Figure 2. a) Urban and rural mask provided by the GRUMP dataset, b) example of distribution of national and sub-national scale buildings data on the variable-resolution grid (Pittore et al., 2020), c) distribution of buildings data on the high-resolution Facebook population grid.

The exposure layer developed in this project maintains the residential buildings classification proposed by Pittore et al., based on the EMCA building typologies (Table 4). Overall, the regional residential building layer from Pittore et al. (2020) is mostly constituted by EMCA4 and EMCA1 buildings (58 and 33%, respectively) (Figure 3). However, we enhance the definition of these building typologies with additional information based on the collected national-scale data. As stated earlier, the underlying assumption is that local partners provided reliable data at sub-national scale, which is needed for enhancing the existing residential buildings exposure model.

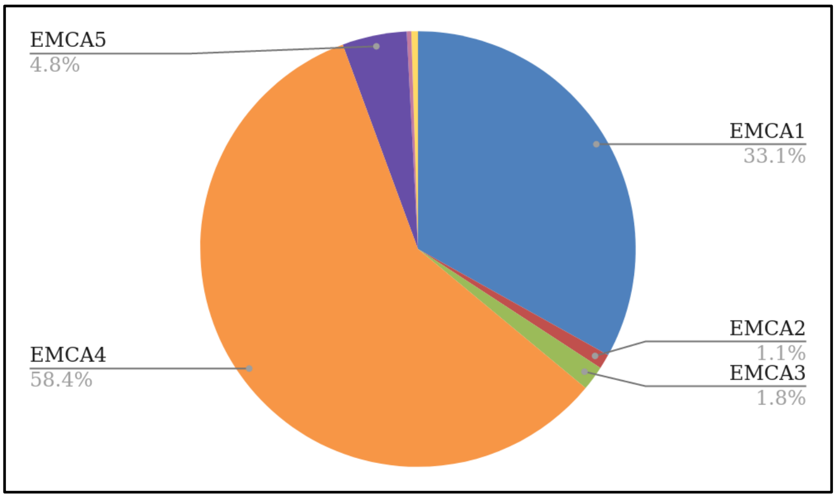

Figure 3. Building typology fractions in Central Asia according to Pittore et al. (2020).

For example, the building typologies in the exposure dataset of Pittore et al. (2020) are not associated with the year of construction. The typologies were enriched with age information based on the characteristics extracted from past projects and from local partners' data. As for the storey number, similarly for the age of construction, a value was associated to each building typology based on the information provided with the EMCA macro typologies (see Wieland et al., 2015 for details) and on the data collected from past projects and/or provided by local partners. The average floor area for each sub-typology was originally extracted from the dataset provided by Pittore et al. (2020). Finally, to reduce the uncertainty that might still exist in the derived parameters it is good practice to adjust them based on comparisons between observed losses and modelled losses (either in probabilistic terms, e.g., exceedance probability curves, or on an event basis). More details regarding this calibration are presented in the Task 6 Report (Earthquake and flood risk assessment). During this calibration phase, average floor areas were adjusted based on local-scale data combined with expert judgement. In particular, the average floor area of load-bearing masonry, reinforced concrete frames and wood buildings were decreased. The decrease factor was defined for each sub-typology included in Table 4 and varies between a factor of 2 and 10. During the course of this project, local partners also provided pictures for each building typology. Figure 4 shows examples of residential building images provided by local partners of Kyrgyz Republic and Tajikistan (left and right column) for typical precast panel buildings (a, b) and adobe buildings (c, d). These images contributed to the characterization of the building types and were used for setting up the capacity building activities and, in particular, the training material.

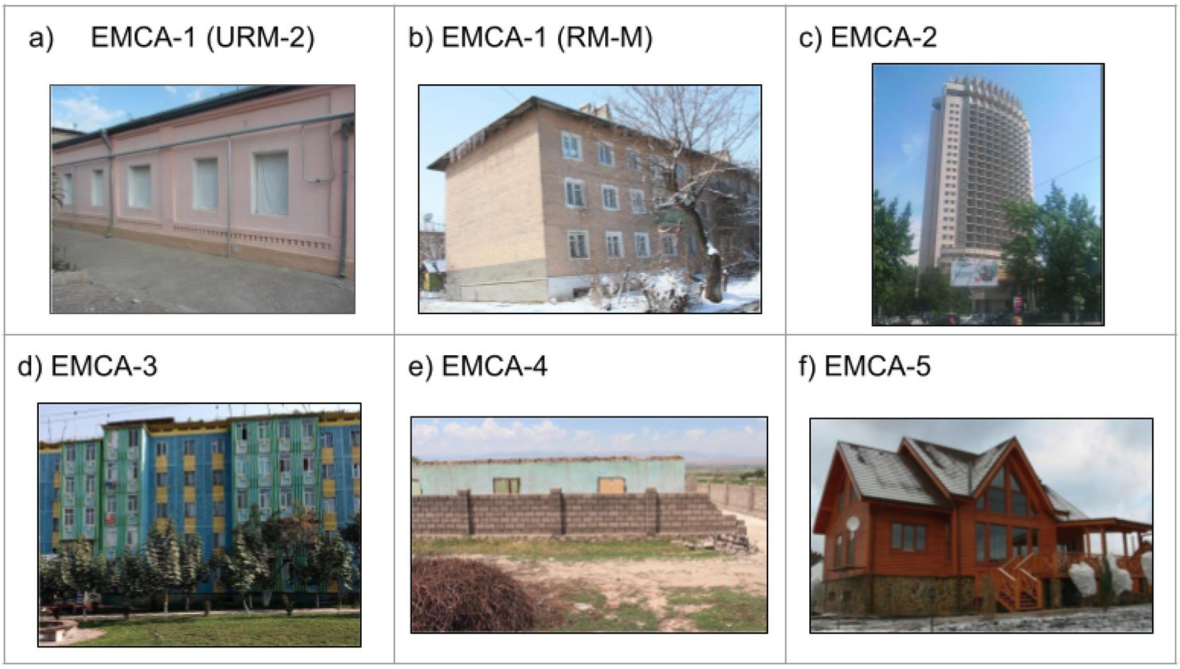

Figure 4. Examples of residential building images provided by local partners for selected EMCA typologies. In particular, two types of EMCA1 are shown (URM-2 and RM-M). typical precast panel buildings (a, b) and adobe buildings (c, d), which correspond to the EMCA3 and EMCA4 typologies, respectively.

Table 5 shows the characteristics of each building typology defined in this project based on the abovementioned considerations, including the construction year and storey number ranges and the average floor area, number of households and occupancy. Information about the presence of the basement is not explicitly considered in the exposure database. However, it is relevant for the characterization of flood vulnerability, and therefore the reader is referred to the specific report "Task 5b - Flood Vulnerability" for more information. The taxonomies defined in Table 5 are therefore used in the exposure datasets and replace the original ones (Table 4).

Table 5. EMCA typologies according to Pittore et al. (2020) and additional information collected in this project. The final column shows the updated taxonomies developed for residential building typologies.

EMCA typology	Sub-typology	Age	Storeys	Floor area (m²)	House-holds	Average occupancy	Taxonomy
EMCA1	URM1	1930-1960	2-4	250	1	3.8	/MUR + CLBRS + MOC/LWAL + DNO/FW + HBET:2,4 + YBET/1930,1960
	URM2		1-2	150			MUR+ MOCL/LWAL + DNO/FC + HBET:1,2 + YBET/1930,1960
	CM	1960-2001	1-5	2000	12	76	/MCF + MOC/LWAL + DNO/FC/HBET:1,5 + YBET/1960,2001
	RM-L		1-2	250		5.2	/MR + MOC/LWAL + DNO/FC/HBET:1,1 + YBET:1960,2001
	RM-M		3-4	2000		104	/MR + MOC/LWAL + DNO/FC/HBET:3,4 + YBET:1960,2001
EMCA2	RC1	1957-2006	3-7	1500	45	152	/CR + CIP/LFM + DUC/FC/HBET:3,7 + YBET:1957,2006
	RC2	1957-2021	4-9	2000			/CR + CIP/LDUAL + DNO/FC/HBET:4,9 + YBET:1957,2021
	RC3	1957-2021	2-5	1500			/CR + CIP/LFINF + DNO/FC/HBET:2,5 + YBET:1957,2021
	RC4	1957-2006	4-16	5000		190	/CR + CIP/LWAL +DNO/FC/HBET:4,16 + YBET:1957,2006
EMCA3	RCPC1	1956-1980	1-16	5000	70	152	/CR + PC/LWAL + DUC/FC/HBET:1,16 + YBET:1956,1980
	RCPC2	1980-2021	3-12				/CR + PC/LFLS + DUC/FC/HBET:3,12 + YBET:1980,2021
EMCA4	ADO	n.a.	1	100	1	5.2	/MUR + ADO/LWAL + DNO/FW/HBET:1
EMCA5	WOOD1	to present	1-2	150	1	3.8	/W/LWAL + DUC/FW/HBET:1,2 + YPRE:2021
	WOOD2	<1980	1-2				/W+ WLI/LO + DUC/FW/HBET:1
EMCA6	STEEL	n.a.	1	2000	1	3.8	/S/LFM +DNO/FME/HBET:1

Reconstruction costs of residential buildings:

Past research projects provided an estimate of reconstruction costs for residential building typologies (Pittore et al., 2020) and other assets (Project 'Measuring Seismic Risk in Kyrgyz Republic', World Bank project P149630). Here, we updated the information with reconstruction costs retrieved by local partners for each country. Costs provided by local partners were compared with each country's GDP 2020 per capita, and across the different countries. In order to reduce discrepancies between country-specific costs, and to provide a regionally-consistent dataset of reconstruction costs, we made the following assumptions:

- Given the wide range of reconstruction cost values collected for EMCA1, we distinguished two sub-typologies: the lower range was associated with the URM, and the upper range with RM or CM.
- For the other EMCA typologies, if a range of values was provided, we took as reference the average value.
- We converted the cost per unit of volume provided by Turkmenistan partners in cost per unit area assuming 3-meter inter-storey height
- In absence of other data, i.e., for adobe and steel typologies, we used the costs estimated by Pittore et al. (2020)

Based on these considerations, the EMCA2/EMCA1 costs ratio ranges between 2.3 and 3, with the exception of Turkmenistan, where the ratio is much lower. The typology for which there are larger discrepancies across countries is the EMCA5 (wood), likely because of the different availability and cost of the material. This is very evident in particular for Turkmenistan, where wood buildings are the most expensive. The final exposure layers contain, for each asset type, the average reconstruction cost for each country, converted from local currency to USD (Table 6). The residential buildings content cost can be estimated based on the procedure described in the HAZUS inventory technical manual (2021). The content cost is expressed as a percentage of the building structural cost, and is 50% for all residential building types.

Table 6. Reconstruction unit costs (in 2021 USD/m²) defined in this project for each EMCA residential building typology in each Central Asia country.

		Kazakhstan	Kyrgyz Republic	Tajikistan	Uzbekistan	Turkmenistan
EMCA1	Unreinforced masonry (URM)	190	175	175	175	105
	Confined or reinforced masonry (CM, RM)	300	300	300	285	150

EMCA2	Reinforced concrete frame (RC)	570	400	425	400	180
EMCA3	Reinforced concrete precast (RCPC)	425	425	425	400	180
EMCA5	Wood	330	330	177.5	300	648
EMCA4	Adobe	125	125	125	190	125
EMCA6	Steel	175	175	175	175	175

Figure 5 shows the distribution of building typologies in each country in the final database for a) Kazakhstan, b) Kyrgyz Republic, c) Tajikistan, d) Uzbekistan and e) Turkmenistan. Pie charts show the different distribution of typologies based on local data, which differ substantially from those in the EMCA layer.

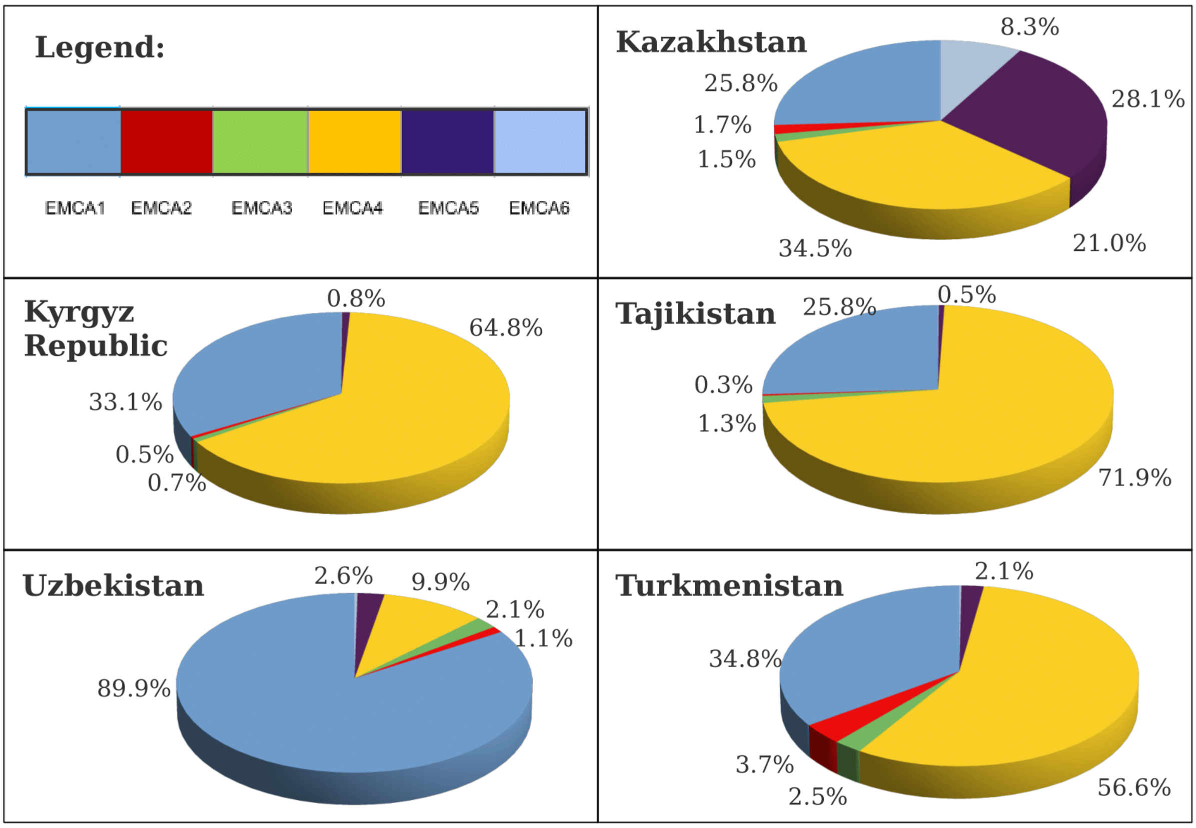

Figure 5. Distribution of residential building typologies in each country in the final database

Figure 6 shows an example of an exposure map showing the number of buildings in a specific sub-typology, the unreinforced masonry (URM-1) in Uzbekistan.

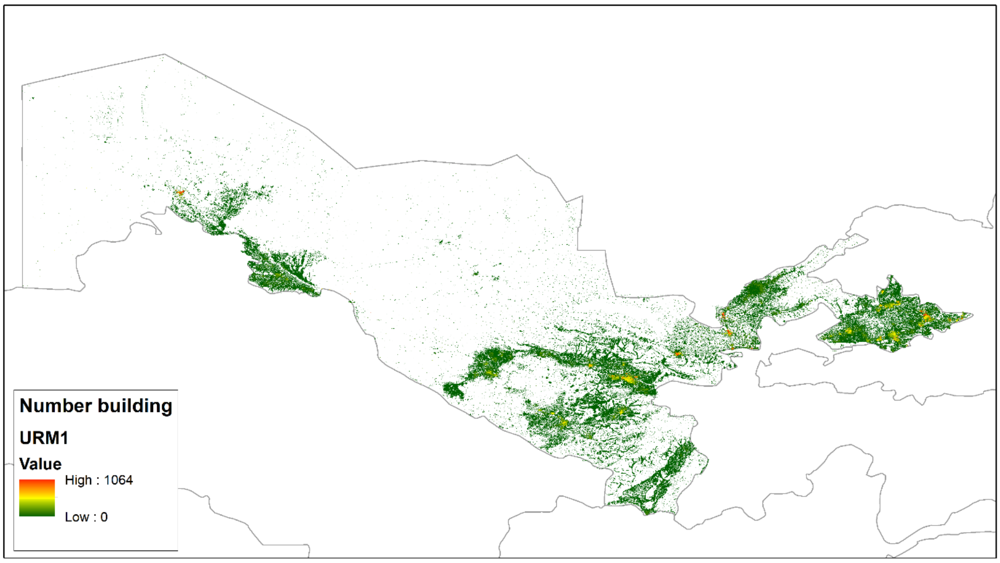

Figure 6. Example of exposure map showing the number of residential buildings in a specific sub-typology, unreinforced masonry (URM-1) in Uzbekistan.

Table 7 shows the total number of buildings in each EMCA typology, per country and the total structural cost. The total cost of residential buildings in Central Asia is approximately 4,000 billion USD.

Table 7. Total number of residential buildings in each EMCA typology, per country and the total structural cost for Central Asia (in billion USD).

Country	Residential buildings	EMCA1	EMCA2	EMCA3	EMCA4	EMCA5	EMCA6	Structural cost (Billion USD)
Kazakhstan	2,378,980	614,196	41,031	35,243	821,613	669,169	197,693	1,030
Kyrgyz Republic	592,637	196,419	2,647	4,216	384,169	4,702	467	106
Tajikistan	844,336	218,439	2,226	10,939	607,539	4,582	599	147
Uzbekistan	5,708,009	4,790,954	64,795	122,579	567,415	145,899	16,330	2,255
Turkmenistan	280,358	97,760	10,357	6,989	158,785	5,887	567	53
Central Asia	9,804,432	5,917,768	121,056	179,966	2,539,521	830,239	215,656	3,590

Figure 7 shows the structural cost of each building typology in each country (a) Kazakhstan, b) Kyrgyz Republic, c) Tajikistan, d) Uzbekistan and e) Turkmenistan). Pie charts show the different distribution of structural costs for each building typology, expressed in percentage of the total structural cost in each country. It is worth noting that the greatest contribution to the total costs comes from EMCA1 (Masonry) followed by EMCA3 (Precast reinforced concrete) in all countries.

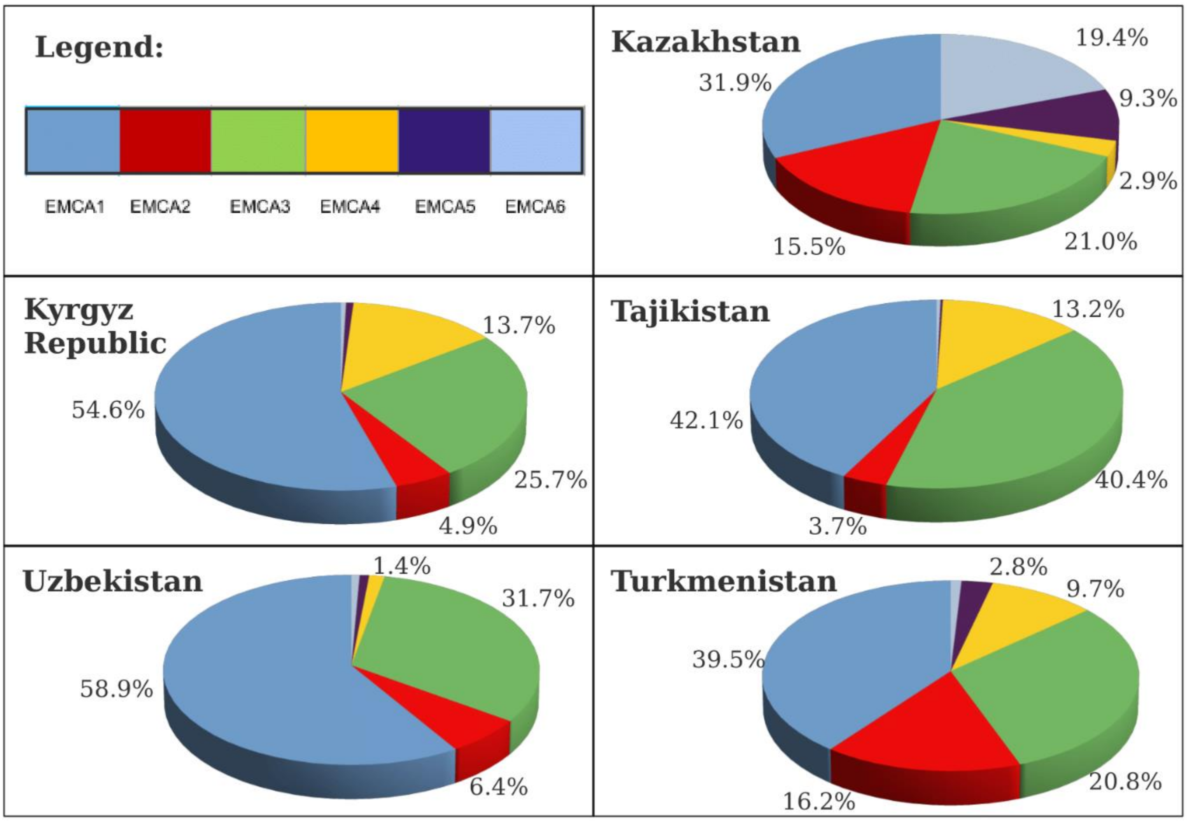

Figure 7. Residential Building Stock: Structural cost of each building typology in each country.

2.3.3 Non-residential buildings

Non-residential buildings include industrial and commercial buildings, schools and healthcare facilities. This section describes the typologies defined for each non-residential building type.

Industrial buildings:

Industrial buildings are associated to industries that produce a finished, usable product (e.g., manufacturing) or are involved in the construction-related activities. No prior information was available on the number of industrial buildings in Central Asia. Thus, we computed the number of industrial buildings in each country based on national employment statistics extracted from the World Bank data portal. More specifically, we consulted the World Bank portal[1] to retrieve data on the total labor force and percentage of employees in the industrial sector. In absence of country-based or regional-based information, the average number of employees per building was inferred from the SERA non-residential buildings' exposure layers (Crowley et al., 2020) for the available Post-soviet EU countries: Estonia, Latvia, Lithuania, Moldova. for Belarus, Ukraine and Russia

[1] https://data.worldbank.org/indicator/SL.TLF.TOTL.IN, https://data.worldbank.org/indicator/SL.IND.EMPL.ZS

were not available. The number of industrial buildings was then estimated by dividing the employed force by the average buildings' occupancy. The location of industrial buildings was inferred based on the industrial building areas included in the OSM database. Areas devoted to mining and other primary sector activities, available from the global mines dataset (Baker, 2010), were removed from the OSM polygons. In order to account for the industrial built-up area only, we assumed that half of the industrial area is accommodating buildings. Based on the estimated number of buildings and the identified area (Table 8), buildings were distributed on the industrial areas identified by OSM, in a number proportional to the polygons' area. The distribution was made so that there is at least one industrial building for each industrial area.

Table 8. Number of industrial buildings and total industrial area estimated for each Central Asia country.

Country	Number industrial buildings	Total industrial area (km²)
Kazakhstan	65,838	661
Kyrgyz Republic	21,793	58
Tajikistan	13,309	63
Uzbekistan	118,704	292
Turkmenistan	33,727	118

Local partners provided images of typical industrial buildings in Kazakhstan, Kyrgyz Republic, Tajikistan and Uzbekistan. However, no information was available on the types and distribution of industrial buildings types. Given the lack of specific data for industrial buildings in Central Asia, we assumed that industrial buildings in Central Asia are similar to the post-soviet ones in European countries. In absence of specific information on industrial building typologies, statistics were thus extracted from SERA non-residential buildings' exposure layers (Crowley et al., 2020) for the available Post-soviet EU countries. The typologies in the SERA dataset were associated with the EMCA typologies (Table 4). Figure 8 shows the relative fraction of EMCA typologies in the industrial building stock of post-soviet countries.

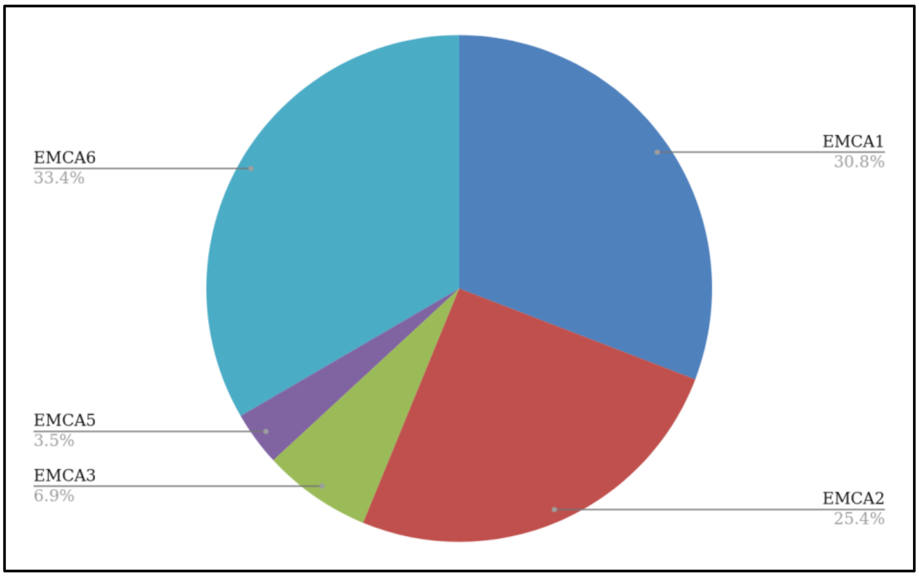

Figure 8. Percentage of industrial buildings belonging to each EMCA typology in the post-soviet countries, extracted from the SERA database.

Reconstruction costs of industrial buildings:

Based on the data collected from the SERA project, we defined a broad typology for industrial buildings in Central Asia (with the taxonomy string UNK+HBET:1:2). This typology is defined as the combination of the EMCA typologies identified in the SERA database (Figure 8), weighted by their fraction. Similarly, the average area and occupancy of industrial buildings in Central Asia was estimated as the weighted combination of area and occupancy defined for each taxonomy in the SERA dataset, obtaining an area of 2013 m^2 and an occupancy of 35. The structural cost for industrial buildings was computed as the weighted average cost of the most common industrial building typologies (Figure 8) based on the structural costs retrieved for each Central Asia country (Table 9). As for the content, the percentage of content values with respect to the structural cost was extracted from the HAZUS inventory technical manual (2021). The ratio is 150% for all building types with the exception of offices, for which it is a 100% of the building cost. The content costs are then computed as the 150% of the structural cost.

Table 9. Construction unit structural and content cost (in USD/m^2) for industrial buildings, computed as previously mentioned (rounded up)

Country	Structural cost (USD/m^2)	Content cost (USD/m^2)
Kazakhstan	300	450
Kyrgyz Republic	270	400
Tajikistan	280	410
Uzbekistan	270	400
Turkmenistan	180	270

Commercial buildings:

In this project, we consider all commercial and services buildings together (so on, called 'commercial'). We distinguish them into two categories: 'wholesale and services' (usually associated with large buildings) and 'retail' (associated with medium-to-small small businesses). Since this distinction is based on buildings' size, wholesale and services include other commercial building types of large size, namely offices, hotels, trade companies and large retail buildings. The retail buildings category comprises medium-to-small retail buildings. No prior information was available on the number of commercial buildings in Central Asia. Thus, the number of services, wholesale and retail buildings was estimated based on labor market data and on the characteristics of the defined typologies, as follows:

- The total number of employees in the commercial sector was derived as a percentage of the total labor force for each country (https://data.worldbank.org/indicator/SL.SRV.EMPL.ZS).
- Total employees in each country were distinguished into commercial activities and other services based on the percentage of 'wholesale and retail' sector over the total tertiary activities in Europe. This value was estimated based on the employment statistics by occupation and economic activities, collected from the Eurostat database (https://ec.europa.eu/eurostat/databrowser/view/LFSQ_EISN2__custom_1304651/default/table?lang=en). Using the NACE tertiary sector codes, we estimated the sum of employees of the tertiary sector and calculated the percentage of OECD class G (wholesale and retail).
- We distinguished between retail and wholesale employees based on the available detailed statistics. Most country-level labor statistics provide the total employees in the 'wholesale and retail' sector but without distinguishing between the two. Based on a report provided by Eurocommerce (2017), which retrieves specific sub-sector statistics, the fraction of employees in the retail sector in 2015 in Europe was 72%, while in post-soviet countries that belong to the EU union (Estonia, Latvia, Lithuania) was 75% (Eurocommerce, 2017). For the purpose of this first-level exposure assessment, we assumed that the percentage found for post-soviet countries applies to Central Asia as well. This assumption allows producing the first regional-scale exposure assessment for commercial buildings. However, the relative importance of retail and wholesale varies across EU Member States and might vary as well across Central Asia. Hence, further analysis might be required in the future in order to achieve a higher accuracy.
- The number of commercial buildings (Table 10) was finally estimated by dividing the total services, wholesale and retail employees by the average occupancy of each typology. For wholesale/services buildings, the average occupancy was obtained from the SERA dataset for post-soviet countries while for retail buildings the occupancy was inferred from European statistics. Further information is provided in the following paragraph. Note that the typology adopted for wholesale and services buildings is the same.

Table 10. Number of retail and wholesale and services buildings estimated in each Central Asia country.

Country	Retail buildings (number)	Wholesale-services buildings (number)
Kazakhstan	842,732	5,780
Kyrgyz Republic	201,370	1,381
Tajikistan	136,256	935
Uzbekistan	1,105,492	7,582
Turkmenistan	138,110	947

As for building typologies, given the lack of specific data for commercial buildings in Central Asia, we assumed that wholesale and services industrial buildings in Central Asia are similar to the post-soviet ones in European countries (Estonia, Latvia, Lithuania, Moldova). Again, data for Belarus, Ukraine and Russia were not available. Note that the SERA dataset includes services buildings into commercial buildings (e.g., offices, hotels and trade companies), so the approach is similar. The typologies in the SERA dataset were associated with the EMCA typologies adopted in this study (Table 5). Figure 9 shows the relative presence of different EMCA building types in the European post-soviet countries based on the SERA dataset.

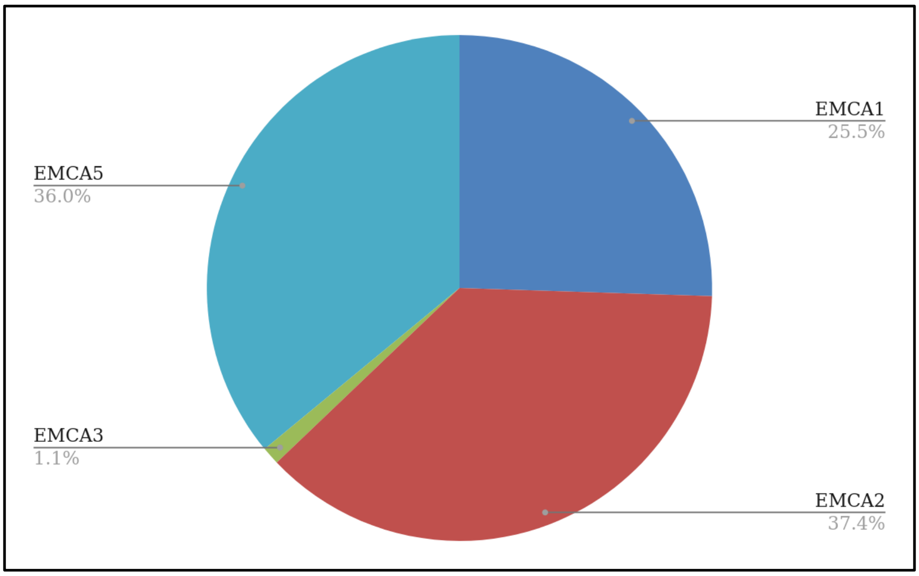

Figure 9. Percentage of commercial buildings belonging to each EMCA typology in the post-soviet countries, extracted from the SERA database.

Based on the data collected for post-soviet countries, we defined a single wholesale and services building typology for Central Asia as the combination of the EMCA typologies weighted based on their presence in the SERA database (Figure 9). The taxonomy string is UNK+HBET: 1:6.

Similarly, the average area and occupancy are calculated as the weighed combination of the area and occupancy of the typologies present in the SERA commercial buildings dataset. The obtained area is 476 m² and the occupancy is 243 people. Existing statistics estimate that wholesale employees are between 10 and 249 employees, but large wholesale firms can employ up to 700 people (OXIRM, 2014). This is consistent with the average occupancy value of 243 obtained from the SERA exposure dataset. Local partners also provided images of wholesale and services commercial buildings. Figure 10 shows examples of building images provided by local partners for typical commercial buildings in Kazakhstan, Kyrgyz Republic, Tajikistan and Uzbekistan (a to d, respectively).

Figure 10. Examples of images provided by local partners for typical commercial buildings in Kazakhstan, Kyrgyz Republic, Tajikistan and Uzbekistan (a to d, respectively).

Medium-to-small retail buildings are normally distributed along the residential areas. Assuming that retail buildings are similar to residential buildings, a single commercial retail typology was defined, in each country, as the combination of the typologies in the national residential building stock. Typologies which account for less than 5% of the residential buildings were discarded. In particular, the considered residential building typologies are EMCA1 (masonry) and EMCA4 (adobe) for Kyrgyz Republic, Tajikistan and Turkmenistan with the additional presence of EMCA5 (wood) and EMCA6 (steel) for Kazakhstan. All these typologies are low-to-mid rise and encompass a wide range of construction decades, from the '30s until today. The Ged4All taxonomy is therefore "UNK/ + HBET:1,5 + YBET:1930,2021" where UNK corresponds to the combination of the residential typologies and proportions, defined based on the country's residential exposure data (Table 11). The average retail buildings area was estimated as the weighted combination of storey/dwelling area for each building typology. In particular, the floor area was considered for single-family building typologies, while the dwelling area was used for multi-family building typologies. Results of this estimation are shown in Table 11 (values are rounded up).

Table 11. Retail building typologies defined as a weighted combination of the most common residential building typologies in each Central Asia country.

Country	Fractions	Average area (m²)
Kazakhstan	26%EMCA1, 35% EMCA4, 28% EMCA5, 9% EMCA6	350
Kyrgyz Republic	31%EMCA1, 67% EMCA4	200
Tajikistan	25% EMCA1, 72%EMCA4	200
Uzbekistan	84% EMCA1, 9% EMCA4	400
Turkmenistan	35% EMCA1, 57% EMCA4	200

As for the medium-to-small retail buildings' occupancy, in Europe the large majority of retail businesses are micro-businesses employing fewer than 10 people (but there are large retail companies that employ few thousand people, OXIRM, 2014). In this work, we assumed that retail companies accommodate on average 5 people, and we did not account for large retail companies.

Reconstruction costs of commercial buildings:

Structural cost for commercial buildings was based on the residential structural costs provided by local partners for each typology (EMCA typology) and averaged based on their relative presence (Figure 5 and Figure 9). As for the content, their costs were assumed as a percentage of the building structural costs following the approach of HAZUS (HAZUS inventory technical manual (2021). The percent of content cost with respect to the structural cost is 100% for most commercial and services buildings with the exception of hospitals (150%, here tackled separately under the healthcare facilities). The content cost of both commercial building typologies (wholesale and services, and retail, Table 12) is therefore equal to the weighted combination of structural costs estimated in this project residential buildings (Table 6) for the residential typologies used for the definition of the taxonomy.

Table 12. Structural and content costs for commercial wholesale and services (first two columns) and retail buildings (second two columns).

Country	Wholesale structural cost (USD/m²)	Wholesale Content cost (USD/m²)	Retail structural cost (USD/m²)	Retail content cost (USD/m²)
Kazakhstan	400	400	230	230
Kyrgyz Republic	280	280	165	165
Tajikistan	290	290	160	160
Uzbekistan	320	320	230	230
Turkmenistan	335	335	140	140

The number of buildings quantified based on the abovementioned method for the two commercial building typologies (wholesale/services and retail) were then distributed spatially in order to assemble an exposure spatial layer. Both retail and commercial/wholesale buildings were distributed in urbanized areas (provided by the GRUMP dataset, CIESIN, 2021) based on the population density, so that a higher fraction of buildings was distributed on highly-populated areas. This approach is similar to the one adopted in the SERA project (Crowley et al., 2020). Commercial areas identified in OSM were inspected but their coverage was deemed insufficient, so the OSM polygons were not used to locate commercial buildings. Table 13 shows the number of commercial and industrial buildings per type and total structural cost (without accounting for the content) in each country.

Table 13. Number (N) of commercial and industrial buildings per type and total structural cost (without accounting for the content) in each country and for Central Asia.

	Commercial buildings					Industrial buildings	
Country	N retail	N wholesale and services	Cost retail (million USD)	Cost wholesale (million USD)	Total cost (million USD)	N industrial	Total cost (million USD)
Kazakhstan	842,246	5,769	67,750	1,100	68,850	65,838	39,760
Kyrgyz Republic	206,446	1,420	7,300	200	7,500	21,793	11,845
Tajikistan	137,928	940	4,550	150	4,700	13,309	7,502
Uzbekistan	1,098,108	7,543	100,900	1,150	102,050	118,704	64,517
Turkmenistan	138,475	950	3,900	150	4,050	33,727	12,220
Central Asia	2,423,203	16,622	187,150	2,700	189,850	253,371	135,844

Schools

Digital maps of schools are available for Kyrgyz Republic, Kazakhstan (provided by local partners) and Tajikistan (source: https://geonode.wfp.org). The location of schools in Uzbekistan and Turkmenistan was not available, but local partners provided the number of schools in each Oblast (10287 and 1868 in total, respectively).

As for school typologies, a previous UNICEF project in Kyrgyz Republic collected the main exposure characteristics for 1260 schools constituted by 8380 building units (e.g., separate blocks), which were surveyed separately. Statistics were performed on the UNICEF layer assuming that each building block is a separate school sample. According to the dataset, all surveyed schools are constituted by LBM (load-bearing masonry) or PC (80 and 20%, respectively), and the vast majority is found in rural areas (88%). This is similar to the overall distribution of residential buildings in Kyrgyz Republic, which, according to Pittore et al., 2020, has more than 90% of LBM buildings (both EMCA1 and EMCA4 typologies, that is, masonry and adobe). However, the fraction of PC residential buildings in Kyrgyz Republic is lower than 20%. Thus, the school building stock in Kyrgyz Republic is quite similar to the residential one, but with a larger fraction of PC buildings. We assumed that, in absence of specific data for schools in other countries, all Central Asia schools have the same characteristics surveyed in Kyrgyz Republic. Based on the Kyrgyz Republic schools' dataset (developed under the UNICEF project), statistics were produced for school material, age of construction, area and occupancy. According to dataset, LBM schools are in general older than PC ones (many of them were built in the 1960-1970 decade) and host a lower number of students. In both urban and rural areas, the large majority of schools is constituted by load-bearing masonry. However, the analysis of schools' data in Kyrgyz Republic points out substantial differences between the characteristics of schools in urban and rural areas. Schools in urban areas are bigger (mostly between 500 and 1000 m^2) while in rural areas they are smaller (mostly <50 m^2). This is supported by the occupancy statistics for schools, which shows that more than half urban schools accommodate 200-400 students, while rural ones accommodate fewer students (between 50 and 200 on average, but with a wide variability). Finally, while in both areas a large percentage of buildings was constructed between 1960 and 1990, urban areas have a larger fraction of modern schools (15% constructed after 2000) while rural areas have 15% of buildings constructed before 1960. Percentages are rounded up.

Based on the abovementioned analyses, two school typologies were defined (rural and urban) and the most frequent age, area and occupancy value was associated with each school type. In case of ranges of values, such as for the occupancy, the average value was taken as reference and is included between brackets. As for the material, we defined a material class that combines the presence of LBM and PC and, therefore, it includes the characteristics of all school buildings in Kyrgyz Republic. Such typology will be associated with a vulnerability curve defined based on the weighted combination of the two fragility curves defined for the EMCA1 (LBM, masonry) and EMCA3 (PC, precast concrete) building typologies. The two types of schools considered in the exposure layer are:

- Urban schools

  Material: weighted combination of the most common school typologies in Kyrgyz Republic (59% EMCA1, 10% EMCA3, 31% EMCA4)

  year of construction: 1960-1990

  area: 500-1000 m² (750 m²)

  occupancy: 300 students

  Taxonomy: UNK + YBET:1960,1990

- Rural schools

  Material: weighted sum of the most common school typologies in Kyrgyz Republic (56% EMCA1, 22% EMCA3 and 22% EMCA4)

  year of construction: 1960-1990

  area: 50-500 m² (275 m²)

  occupancy: 50-200 students (125)

  Taxonomy: UNK + YBET:1960,1990

These two school typologies were then associated with the single school locations (points) in the spatial layer, under the assumption that all school buildings in urban and rural areas of Central Asia have the same characteristics of the urban and rural schools in the Kyrgyz Republic database. Under this assumption, the typologies found in the Kyrgyz Republic dataset (mentioned above) were applied to all schools in urban and rural areas of Central Asia. Schools in urban and rural areas were identified in Kyrgyz Republic, Kazakhstan and Tajikistan by intersecting their location with the urban area polygons available from the GRUMP dataset (CIESIN, 2021). Such polygons identify the urbanized areas, where the larger fraction of population is found. As for Uzbekistan and Turkmenistan, since the schools were distributed based on the GRUMP urban area polygons (CIESIN, 2021), rural typologies were associated with polygons with an area smaller than 20 km².

Reconstruction costs of schools:

School structural costs were provided by local partners in each country. The value of 550 USD/m² was adopted in agreement with most data provided. However, high discrepancies were found between the cost in Turkmenistan and Kazakhstan (who provided the highest values, ranging between 2000 and 4500 USD/m²) and Kyrgyz Republic (the lowest, 470 USD/m²). Table 15 shows the number of education and healthcare buildings and total structural cost in each country (in million USD).

<u>Healthcare facilities</u>

Location and number of hospitals in all Central Asia countries were extracted from the healthsites database (https://www.healthsites.io/), which contains global-scale hospital and healthcare facilities locations up to 2019. The dataset is described in larger detail by Weiss et al. (2020). The healthcare facilities types contained are: clinics, hospitals, polyclinics and other healthcare facilities. The dataset includes also dentists and doctors' offices, laboratories and pharmacies. In the exposure layer, we included all types of healthcare facilities and associated different building typologies to each of them. Figure 11 shows the map of healthcare facilities (hospitals and clinics) in Central Asia. Dentists, doctors, laboratories and pharmacies belong to a specific class in the dataset and are excluded from the map in Figure 11.

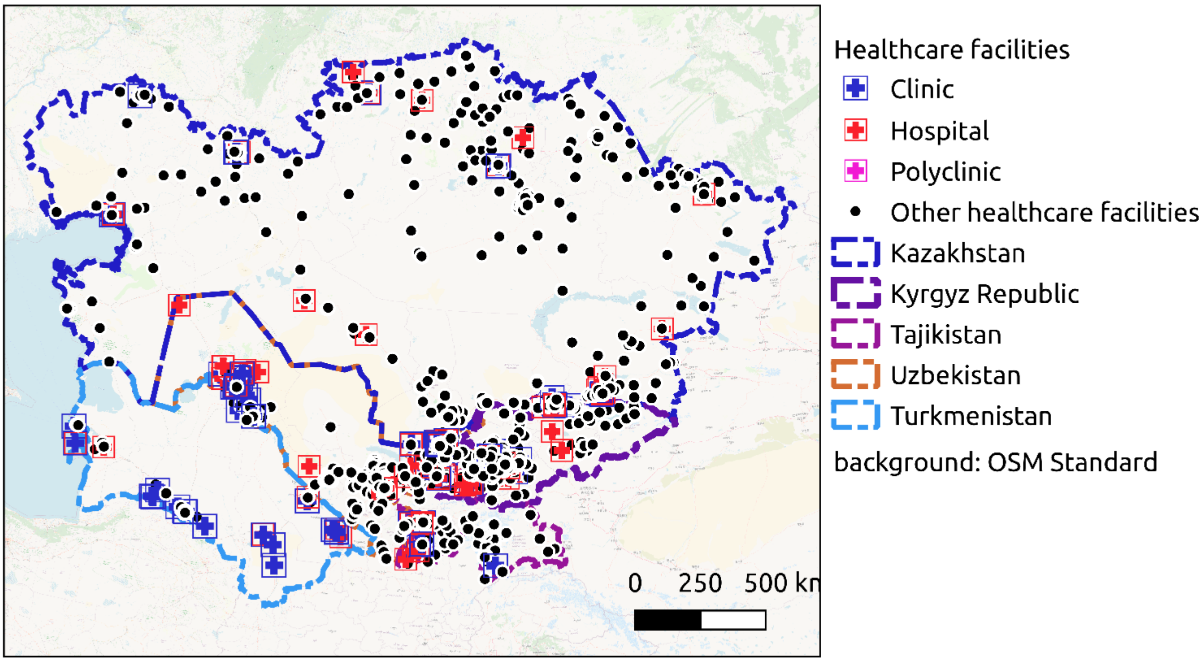

Figure 11. Map of healthcare facilities in Central Asia.

In absence of country-specific data on the hospital building typologies, hospitals characteristics were extracted from the SERA project, which provides non-residential buildings exposure layers for most European countries (World Bank project P173033/TF073473). In particular, we extracted the average area for hospitals from post-soviet countries (Estonia, Latvia, Lithuania and Moldova) and computed the average area. Note that data from the remaining post-soviet countries (Belarus, Russia and Ukraine) are missing. The average hospital area is 9881 m^2, which in this work is rounded up to 10,000 m^2. Similarly, for clinics, the average area was extracted from the SERA dataset of post-soviet countries, getting an average of 989 m^2, which were rounded up to 1,000 m^2. The average hospital area was validated based on the country-based data available from the World Bank portal. For each country, we extracted the average number of beds per country per 1,000 people, and based on the population we identified the total hospital beds per country. Then, we divided the total number of beds by the number of hospitals in our database, and computed the average number of beds per hospital, which, multiplied by the average area per hospital beds (assumed to be 3.5 m^2) gives the average hospital area for each country. Values vary between 5,000 (Kyrgyz Republic) and 20,000 m^2 (Turkmenistan), but the average area is approximately 11,000 m^2 which is compatible with the average value taken from the SERA project. As for hospitals material, they were assumed to be all constructed in reinforced concrete (monolithic or precast, which correspond to the EMCA2 and EMCA3 typology, i.e., in-situ and precast concrete, respectively) which has average area values (Table 5) consistent with the hospitals estimated area range. We created a specific material class, which is associated with a vulnerability curve that accounts for the characteristics of both materials, with a 50% weight each.

Clinics and other healthcare businesses (dentists, doctors, pharmacies) were assumed to have a material similar to the residential buildings in each country. Their typology was defined as the weighted combination of the residential building typologies in each country, based on their fraction, discarding those whose presence is lower than 5%. This is the same assumption adopted for retail commercial buildings, the only difference being that clinics have a larger area. The other healthcare facilities (dentists, doctors and pharmacies) were assumed to have the same building typologies and reconstruction costs of retail commercial buildings (see following paragraphs for details). The typologies defined for healthcare are summarized in Table 14.

Table 14. Healthcare building typologies defined in this project.

Typology	Level	Characteristics
Hospitals	Regional	Material=UNK (weighted sum of 50% EMCA2 and 50% EMCA3) Area=10,000 m² Taxonomy: + HBET:1,16 + YBET:1956,2021
Clinics, Dentists, Doctors, Pharmacies	Country-based	Material= UNK (weighted sum of typologies in residential buildings in each country) Taxonomy: UNK/ + HBET:1,5 + YBET:1930,2021 Area= weighted combination of residential buildings average floor area (for single-family building typologies) or dwelling area (for multi-family building typologies)

Reconstruction costs of healthcare facilities:

Hospital structural costs were provided for each country by local partners. Based on local partners' data, hospital costs can vary within a very wide range (from 1,200 to 4,000 USD/m²). In this work, we adopted an intermediate value of 1,500 USD/m². Hospitals content cost is, according to the Hazus methodology, 150% of the structural cost. The other healthcare facilities (clinics, dentists, doctors and pharmacies) construction and content costs were assumed to be equal to the construction and content cost of the commercial retail building typologies most common in each country (Table 12). Their area was estimated as the weighted sum of the areas of the most common residential building typologies in each country. In particular, the floor area was considered for single-family building typologies, while the dwelling area was used for multi-family building typologies, following the same approach used for medium-to-small retail buildings (Table 11). Table 15 shows the final results in terms of total structural cost for hospital, clinics and schools.

Table 15. Number of hospitals, clinics and schools and total structural cost in each country and for Central Asia (in million USD).

Country	Hospitals	Clinics	Hospitals cost (million USD)	Clinics cost (million USD)	Schools	Total education cost (million USD)
Kazakhstan	442	326	1,658	388	7,462	2,103
Kyrgyz Republic	233	83	870	43	1,260	355
Tajikistan	129	51	484	19	858	242
Uzbekistan	451	353	1,691	583	10,287	2,900
Turkmenistan	129	26	259	9	1,868	527
Central Asia	1,264	839	4,961	1,041	21,735	6,127

2.3.4 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 GDP, respectively (World Bank[2], 2020). The share of national GDP in Kyrgyz Republic and Turkmenistan is 14 and 11%, while the lowest value is associated with Kazakhstan (5%). Cotton and cereals (in particular, wheat) are the dominating cropping system in all Central Asia countries (Kienzler et al., 2012). Based on the Faostat latest data (2019), cotton and wheat account for a fraction of cropland area that varies between 30 (in Turkmenistan) and 80% (Kyrgyz Republic).

The cotton area and yield in each Central Asia country and each sub-national administrative unit (Oblast) was provided by local partners. Such values were used as a starting point for the definition of the exposure layers. The spatial distribution of different croplands was inferred based on two global datasets:

- Global crop dominance map. This layer classifies croplands at global scale in 9 classes (Teluguntla et al., 2015, Table 16) on a 1-km grid.
- Global land cover cropland fraction (https://lcviewer.vito.be/download). This layer contains the percentage of croplands (all included into a generic class) in each cell of a raster of 100m resolution, for 2019.

Based on these two layers, the information provided by local partners was distributed spatially in order to produce cropland exposure maps for cotton and wheat.

2 https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS

Table 16. Cropland classes in Teluguntla et al. (2015)

Class Label	Name	Description
0	Ocean	Ocean or Water areas
1	Irrigated	Wheat and Rice
2	Irrigated Mixed Crops 1	Wheat, Rice, Barley, Soybeans
3	Irrigated Mixed Crops 2	Wheat, Rice, Cotton, Orchards
4	Rainfed	Wheat, Rice, Soybeans, Sugarcane, Corn, Cassava
5	Rainfed	Wheat, Barley
6	Rainfed	Corn, Soybeans
7	Rainfed Mixed Crops	Wheat, Corn, Rice, Barley, Soybeans
8	Fractions of Mixed Crops	Wheat, Maize, Rice, Barley, Soybeans
9	Non-Cropland	Non-Cropland areas

Cotton is found in the Global crop dominance class 3 (Irrigated Mixed Crops 2), together with wheat, rice and orchards. Firstly, we extracted the 1-km cells that belong to this class and, secondly, we kept only the 100m cells that have a cropland fraction greater than zero. This is due by intersecting the two above mentioned global layers with the QGIS tool. Similarly, having identified the areas where cotton is found, we distribute the total hectares of cotton provided by local partners proportionally to the cell cropland fraction. Wheat is found in the Global crop dominance classes 1,2,3,4,5,7 (Table 16). Class 8 was not considered since the wheat fractions is considered negligible with respect to the other crop dominance classes. However, these classes also include a number of croplands such as wheat, rice, barley, soybeans, sugarcane, corn and orchards. Cells where wheat croplands are present were identified with the same procedure adopted for cotton. Having identified the areas where wheat is found, we distributed the total hectares of wheat provided by local partners proportionally to the cell cropland fraction.

The taxonomy for croplands corresponds to the one proposed by GED4ALL taxonomy (https://docs.riskdatalibrary.org/ged4all.html). CRP1+1 was used for wheat and CRP9+5, generic for flower crops, was used for cotton, adding a specific description explaining that the layer contains cotton crops only (http://stats-class.fao.uniroma2.it/WCA/crops/Cotton_(all_varieties)).

Information on the cotton and wheat price was collected for all countries except Tajikistan, for which the average value computed over the values provided collected for the other Central Asia countries (Table 17).

Table 17. Prices of cotton and wheat for each Central Asia country.

Country	Wheat (USD/Ton)	Cotton (USD/Ton)
Kazakhstan	91	304
Kyrgyz Republic	150	600
Tajikistan	141	421
Uzbekistan	93	300
Turkmenistan	229	482

Figure 12 shows the regional-scale raster map of cotton and wheat cultivated area (a, b respectively) produced in this project. The cell resolution of the raster layer is of approximately 100 m.

Based on the collected information on production and cost, we calculated the exposure of cotton and wheat croplands. Table 18 shows the total cotton area, yield and production in each Central Asia country and Oblast and the corresponding cost. Similarly, Table 19 shows the total wheat area, yield and production in each Central Asia country and Oblast and the corresponding costs. Oblasts where cotton production was null or very low were not included in the table.

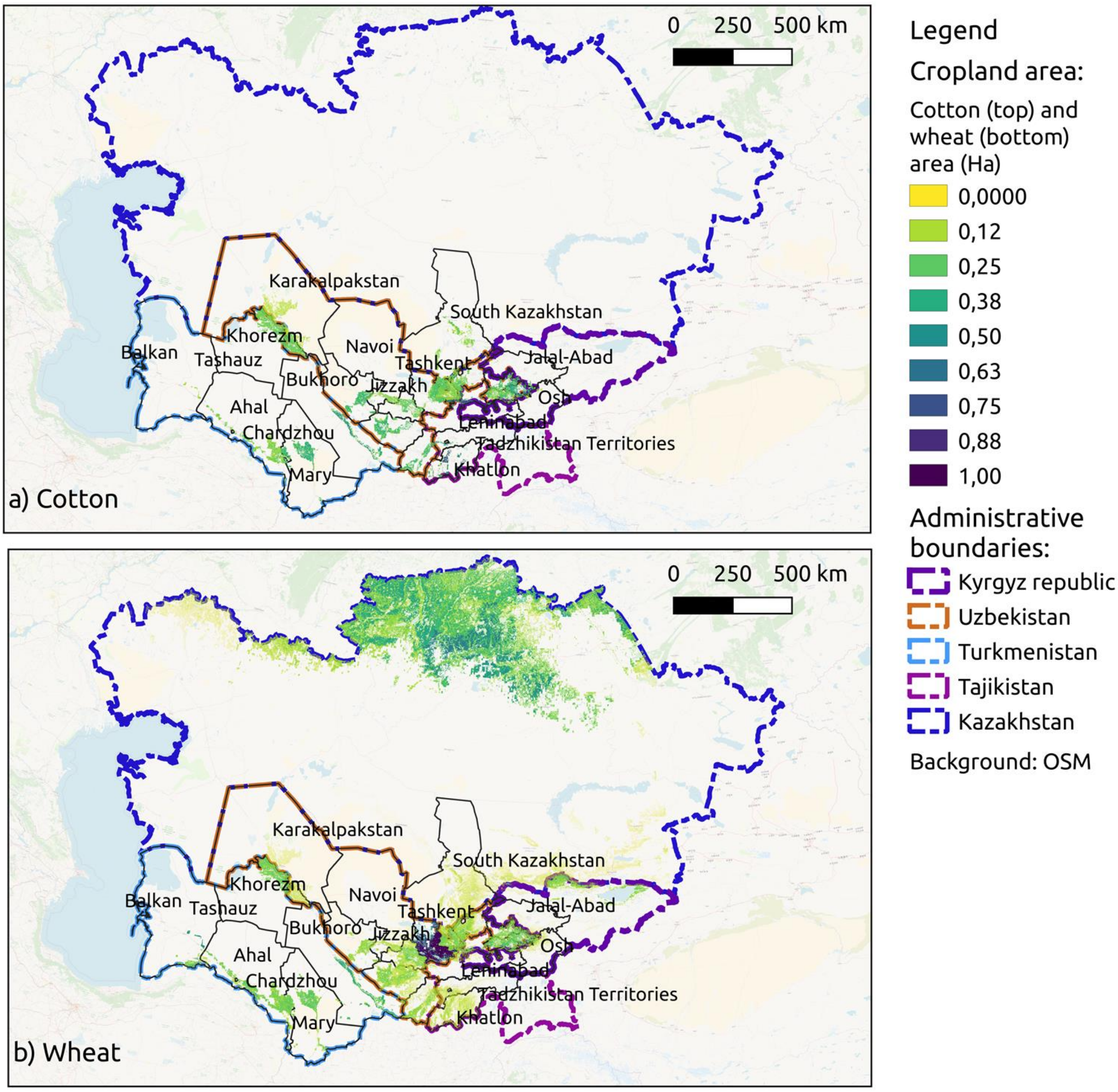

Figure 12. Map of cotton (a) and wheat (b) croplands in Central Asia

Table 18. Total cost of cotton croplands thousandth hectares (kha) in each country's Oblast together with the regional area, yield and annual production. Final row shows the total cotton area, production and cost, and the average cotton yield and price in Central Asia.

Country	Area (kha)	Oblast	Area (thousand Ha)	Yield (Tons/Ha)	Production (Thousand T)	Cost (USD/T)	Exposure (Million USD)
Kazakhstan	126	South Kazakhstan	125	2.6	328	304	99
Kyrgyz Republic	22	Jalal Abad	14	3.4	42	600	28
		Osh	11	3.2	31.0	600	20
Tajikistan	388	Khatlon	52	0.7	193	421	15
		Sughd	85	0.7	66	421	25
		Areas of republican subordination	9	0.7	13	421	3
Uzbekistan	1034	Republic of Karakalpakstan	107	2.3	198	300	74
		Andijan	73	3.2	254	300	70
		Bukhara	45	3.4	333	300	46
		Jizzakh	75	2.8	219	300	63
		Kashkadarya	86	2.9	394	300	75
		Navoi	19	3	98	300	17
		Namangan	59	3.2	203	300	57

		Samarkand	40	2.9	219	300	35
		Surkhandarya	57	3.3	244	300	56
		Syrdarya	65	2.8	203	300	54
		Tashkent	78	3.1	226	300	73
		Fergana	89	3	246	300	80
		Khorezm	62	3.1	257	300	57
Turkmenistan	551	Akhal	144	2	505	482	139
		Balkan	5		127	482	5
		Dashoguz	142		358	482	137
		Lebap	62		429	482	59
		Mary	114		422	482	109
Central Asia (sum and average values)			1,617	2.5	5,608	378	1,397

Table 19. Total cost of wheat croplands thousandth hectares (kha) in each country's Oblast together with the regional area, yield and annual production. Final row shows the total wheat area, production and cost, and the average wheat yield and price in Central Asia.

Country	Area (kha)	Oblast	Area (thousand Ha)	Yield (Tons/Ha)	Production (thousand T)	Cost (USD/T)	Exposure (Million USD)
Kazakhstan	12170	Akmola	3,086	1.1	4,128	91	281
		Aktobe	305	1.1	345		28
		Almaty	127	1.9	241		22
		East- Kazakhstan	428	1.3	520		51
		Zhambyl	150	2.1	318		29
		West-Kazakhstan	167	1.4	237		21
		Karaganda	723	1.1	437		72
		Kostanay	3,334	1	3,455		303
		Kyzylorda	9	1.5	13		1
		North Kazakhstan	2,962	1.4	3,230		270
		Pavlodar	647	0.9	564		53
		South Kazakhstan	204	1.9	386		35
Kyrgyz Republic	248	Batken	14	2.1	26	150	5

		Jalal-Abat	20	2.4	41		7
		Issyk-Kul	57	2.7	151		23
		Naryn	6	2.2	13		2
		Osh	41	2.1	82		13
		Talas	5	2.8	15		2
		Chu	110	2.8	301		46
Tajikistan	226	Areas of republican subordination	41	5.5	237	141	32
		Khatlon	118	7.5	867		124
		Sughd	75	4.6	312		48
Uzbekistan	2726	Republic of Karakalpakstan	61	4.3	228	93	25
		Andijan	71	8.6	652		57
		Bukhara	62	9	547		52
		Jizzakh	1,138	4.5	733		476
		Kashkadarya	204	4.4	886		83
		Navoi	33	4.3	176		13
		Namangan	65	7.5	511		45
		Samarkand	184	5.8	813		99

		Surkhandarya	93	7.1	678		61
		Syrdarya	84	5.5	467		43
		Tashkent	116	5.2	567		56
		Fergana	104	7.6	759		73
		Khorezm	25	6.5	436		15
Turkmenistan	803.9	Akhal	219	2.3	505	229	115
		Balkan	59		127		31
		Dashoguz	168		360		88
		Lebap	174		429		92
		Mary	182		422		96
Central Asia (sum and average values)			15,023	3.4	25,215	141	2,937

2.3.5 Transportation system

For each country, roads and railways were extracted from OSM in digital form. Roads extracted from OSM were also compared with those extracted from the GRIP database. The two datasets match but with some discrepancies partially due to the different classifications. Based on aerial images for specific areas (e.g., Navoi and Karakalpakstan Oblasts in Uzbekistan), we concluded that the OSM layer is more reliable for the identification of the primary road network and is, therefore, used in this assignment. Roads and railways were then classified based on the GED4ALL taxonomy (Table 20), which reflects the OSM typologies. Note that roads in the 'unclassified', 'residential' and 'service' road types and the 'subway', 'tram' and 'unknown' railway types were not included in the analysis. As for bridges, they were first extracted from the OSM layer. However, knowing that the OSM bridges coverage can be partial, we identified bridges also by intersecting the primary road layer with:

- rivers (also extracted by OSM).
- motorways and trunks
- primary and secondary roads
- railways

With this procedure, we found additional bridges in each country that were not in OSM. Bridge typologies were defined based on the data provided by past projects in the region (e.g., 'Measuring Seismic Risk in Kyrgyz Republic', implemented by the World Bank) and those provided by one of the Uzbekistan local partners (TSTU), which has a deep expertise in the construction of railways and bridges in the region.

- Road bridges: In Uzbekistan, 86% of bridges were constructed between 1960 and 1990. Information on bridge material is not available from local partners, but the project 'Measuring Seismic Risk in Kyrgyz Republic' (World Bank project P149630) identified 1500 bridges in Kyrgyz Republic, most of them made of reinforced concrete and steel.
- Railway bridges are mostly made of reinforced concrete (95% of the total) and they are multi-span; the average length of span ranges between 12 and 24 m but most bridges are less than 25m long.

Since GED4ALL does not provide a taxonomy for bridges but uses OSM taxonomy for roads, we classified bridges based on a custom taxonomy (see Table 20).

Table 20. Classification of road and railway typologies considered in this study

Group	Taxonomy	Description
Road network	RDN+MO	Motorway: restricted access major divided highway (i.e., freeway), normally with 2 or more running lanes plus emergency hard shoulder
	RDN+TR	Trunk: the most important roads in a country's system that aren't motorways (not necessarily be a divided highway)
	RDN+PR	Primary: the next most important roads in a country's system (often link larger towns)
	RDN+SE	Secondary: the next most important roads in a country's system (often link towns)
	RDN+TE	Tertiary: the next most important roads in a country's system (often link smaller towns and villages)
Railway network	RLW+LR	Light rail: a higher-standard tram system, normally in its own right-of-way. Often reaches a considerable length (tens of kilometer)
	RLW+MR	Monorail: a single-rail railway
	RLW+RL	Rail: full sized passenger or freight trains in the standard gauge for the country or state
Bridges	RDN+BR	Road bridges: most of them constituted by RC and steel, more than 85% constructed between 1960 and 1990
	RLW+BR	Railway bridges: large majority constituted of RC, most of them with length<25m

Roads' reconstruction costs were homogenized over the Central Asia region based on the information collected by local partners in each country. Given the variability of costs collected, we provided both ranges and average values (Table 21). Note that reconstruction costs can vary considerably based on the local conditions (in particular, local soil) and reach peaks of 24 million USD/km in case of tunnel construction (not considered in this assignment). As for bridge reconstruction costs, we obtained reconstruction costs data from Uzbekistan (both road and railway bridges) and Kyrgyz Republic partners (only road bridges). All costs refer to reinforced concrete bridges of recent construction (since 2017), under construction or planned. Bridges costs in the two countries were in the same order of magnitude, but there is a large variability within the same bridge type. This is due, according to the information gathered, to the heterogeneous soil type and working conditions in Central Asia. For that reason, we included in the table both a range and an average value cost.

Table 21. Road and railway typologies, taxonomy and reconstruction costs (USD/km) defined for Central Asia.

Type	Description	Taxonomy	Range cost (Thousand USD/km)	Average cost (Thousand USD/km)
Roads	Motorway and trunk	RDN+MO / RDN+TR	1,000-3,000	2,000
	primary	RDN+PR	700-1,000	850
	secondary	RDN+SE	300-700	500
	tertiary	RDN+TE	180-300	240
Railways	high speed	RLW+RL	1,600-3,000	2,300
	conventional	RLW+LR / RLW+MR /RLW+TR	1,000-1,600	1,300
Bridges	Road bridges	RDN+BR	5,000,000-15,000,000	10,000,000
	Railway bridges	RLW+BR	10,000,000-34,000,000	22,000,000

The total length of the transportation system and of each road and railway type was then estimated based on the extracted information from OSM and the total reconstruction cost was quantified based on the abovementioned unit costs.

Table 22 shows the total km of motorway/highways/trunk, primary, secondary and tertiary roads in each country, the cost for two selected road types and the total reconstruction cost for all road types.

Figure 13 shows the exposure layer of the railway and road network considered in this project that was developed for Central Asia.

Table 22 Total km of road network of each type (primary, secondary and tertiary, respectively marked with 1ary, 2ary and 3ary) and total reconstruction cost of all road types in each country.

	Road network					Total reconstruction cost (Billion USD)		
Country	km motorway /highway /trunk	km 1ary	km 2ary	km 3ary	Bridges	Cost motorway/ highway/ trunk	Cost 1ary	Cost (all road types)
Kazakhstan	17,430	8,506	19,845	46,414	4,191	34.9	7.2	63.2
Kyrgyz Republic	2,787	1,996	1,878	6,578	1,198	5.6	1.7	9.8
Tajikistan	2,645	1,014	2,856	5,539	1,290	5.3	0.9	8.9
Uzbekistan	6,297	4,414	6,539	16,743	4,047	12.6	3.8	23.6
Turkmenistan	6,402	1,240	1,862	7,762	1,111	12.8	1.1	16.7
Central Asia	35,561	17,170	32,980	83,036	9.137	71.2	14.7	122.2

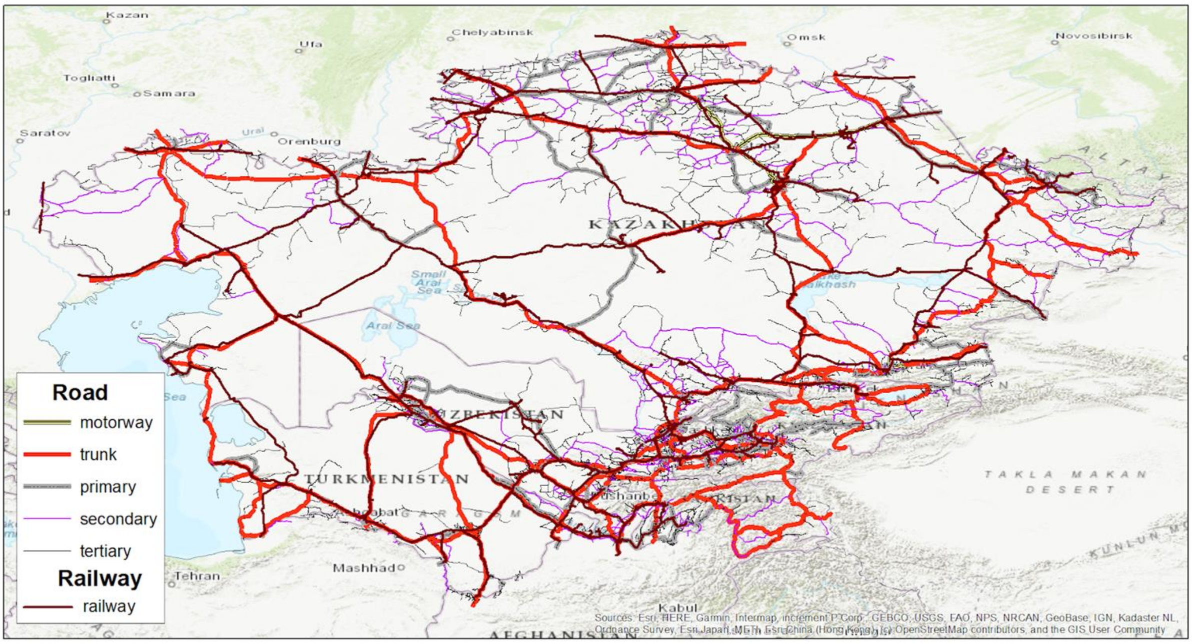

Figure 13. Map of railway and road network in Central Asia.

2.3.6 *Airports and airstrips*

Main international airports were mapped based on the World Bank world airport database (https://datacatalog.worldbank.org/dataset/global-airports). This database also contains the total number of seats in 2019, which is a measure of the importance of airports for passenger traffic.

Minor (national) airports were extracted from the Global Airport database (http://www.partow.net/miscellaneous/airportdatabase/index.html, 2017) if not included in the World Bank dataset. The combination of these two datasets is a spatial layer where airports are defined as points. Exposed features such as airports need to be associated to an area in order to enable spatial-analysis and subsequent risk assessment. Thus, a spatial (circular) buffer was applied to each airport point. The buffer radius was defined based on the following assumptions:

- The minimum runway length was assumed to be 3,000m in international airports and 1500m in national airports. Thus, the minimum buffer radius was set to half of the usual runway length, i.e., 1500 m and 750m respectively for national and international airports. Visual inspection for selected airports (Figure 14) shows that this is compatible with the actual airport extent. These buffers correspond to 7 and 1.8 m², respectively.
- The more important and trafficked the airport, the bigger its extent. International airports were thus classified based on the airport total number of seats in 2019, defined by World Bank as a metric of flow expected at each airport. In Central Asia all international airports have a low-seats number, so the minimum buffer radius of 1500m was adopted.

The buffer was then applied to each airport using the QGIS feature 'spatial buffer'. Figure 14 shows an example of the spatial buffer for the Kulob national airport in Tajikistan (left) and the Bishkek international airport (right). Direct measurement of the airport area using GIS tools gives values of 1.5 and 7 km^2, respectively, which are consistent with the buffer areas defined for national and international airports. Costs for airports were not estimated because not required in this assignment.

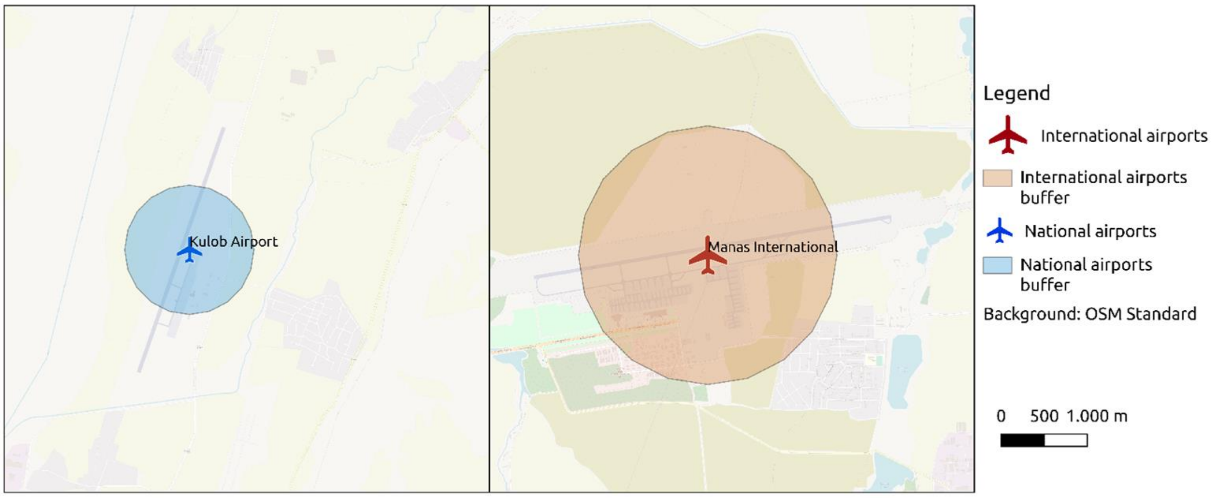

Figure 14. Examples of spatial buffers applied to the Kulob national airport in Tajikistan (left) and the Bishkek international airport (right).

Figure 15 shows the location of main airports in Central Asia. Icon size is proportional to air traffic volume expressed by the total number of seats (World Bank, 2019).

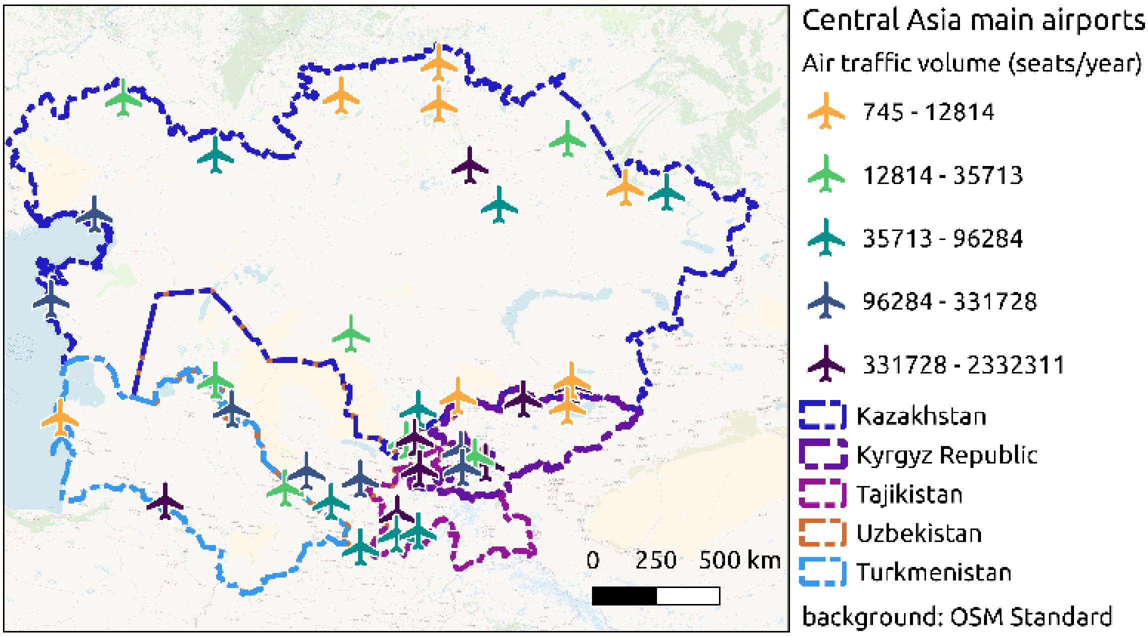

Figure 15. Map of main airports in Central Asia.

2.3.7 Primary commodities and extraction sites

Central Asia has a large number of extraction sites and plants devoted to the processing of primary commodities. Mineral mines, oil and gas fields and industrial plants for a number of commodities (aluminum, cement, coal, copper, gold, iron and steel, lead, nickel, petroleum, salt, silver, and zinc) were gathered from a report provided by United States Geological Survey (USGS) and the associated dataset (Baker et al., 2010). The dataset contains information on the status (active/inactive), the commodity and the capacity. Such data were added to the exposure layers. Replacement costs' estimates for extraction and processing sites were not required during this assignment.

Table 23 shows the number of mines, plants and oil and gas extraction sites in each country. The number of uranium mines is shown within brackets in column 2. The average volume of uranium mines is 1.2 to 5 thousand metric tons per year. Most of the extraction and processing sites contained in the database could potentially contaminate soil, water and air. In particular, Kazakhstan and Tajikistan also have a large number of gold mines, which, together with mercury mining, are among the top contaminating mining types.

Table 23. Number of mines, plants and oil and gas extraction sites in each Central Asia country.

Country	Mines (Uranium)	Plants	Oil and gas	Total
Kazakhstan	69 (5)	44	18	131
Kyrgyz Republic	24 (2)	10	14	48
Tajikistan	33	9	2	44
Uzbekistan	39(1)	15	4	58
Turkmenistan	37	12	7	56
Central Asia	202	90	45	337

Figure 16 shows the map of industrial plants and extraction sites in Central Asia. The country with a larger number of mines and industrial sites is Kazakhstan.

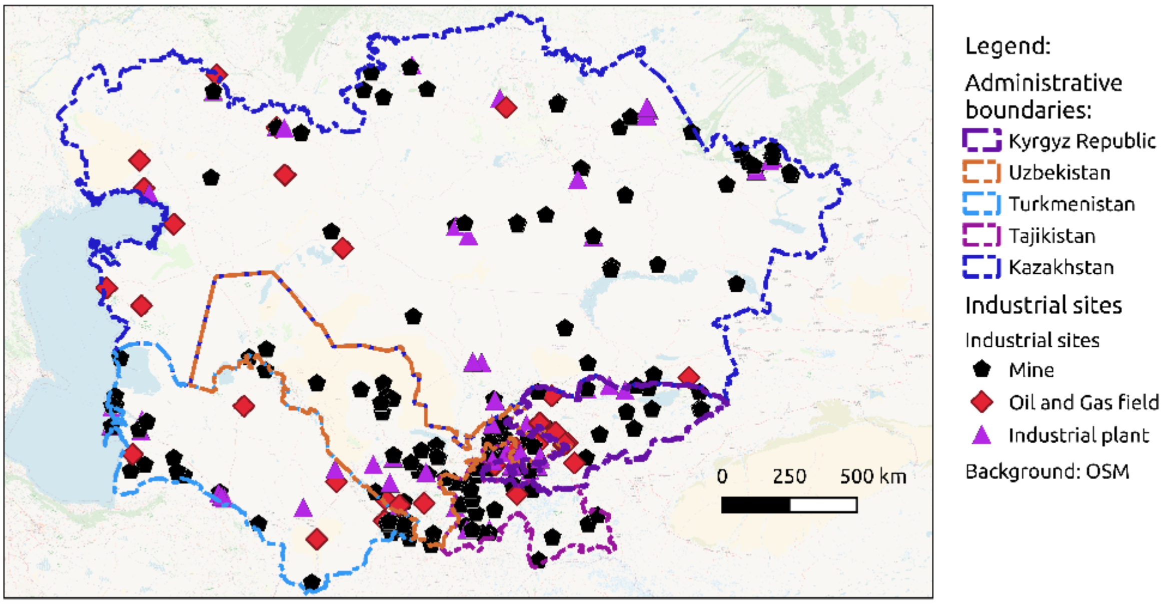

Figure 16. Map of industrial sites by type in Central Asia.

2.3.8 Supply infrastructure

<u>Oil and gas pipelines</u>

Kazakhstan, Turkmenistan and Uzbekistan are the three main Central Asia gas exporters to China, with Turkmenistan holding the larger fraction of gas exports. However, maps of the spatial location of oil-gas pipelines were provided only by local partners in Turkmenistan. For the other countries, the locations of main pipelines were assembled from online sources (e.g., The Oxford Institute for Energy Studies, 2019). Note that this can introduce errors due to the approximate georeferencing. Figure 17 shows the map of main oil and gas pipelines assembled in this project. Costs' estimates for oil and gas pipelines' replacement were not required during this assignment. However, Turkmenistan and Kazakhstan partners provided indicative costs per km. in Turkmenistan, one km of oil-gas supply pipeline can vary between 122,000 and 760,000 USD (for pipelines of diameter and thickness of 530/8 and 1,420/16 mm, respectively). In Kazakhstan, one km of oil-gas pipeline can cost on average 588,000 USD. These values can be used to produce first-level estimates of the expected reconstruction cost of pipelines of similar characteristics in Central Asia.

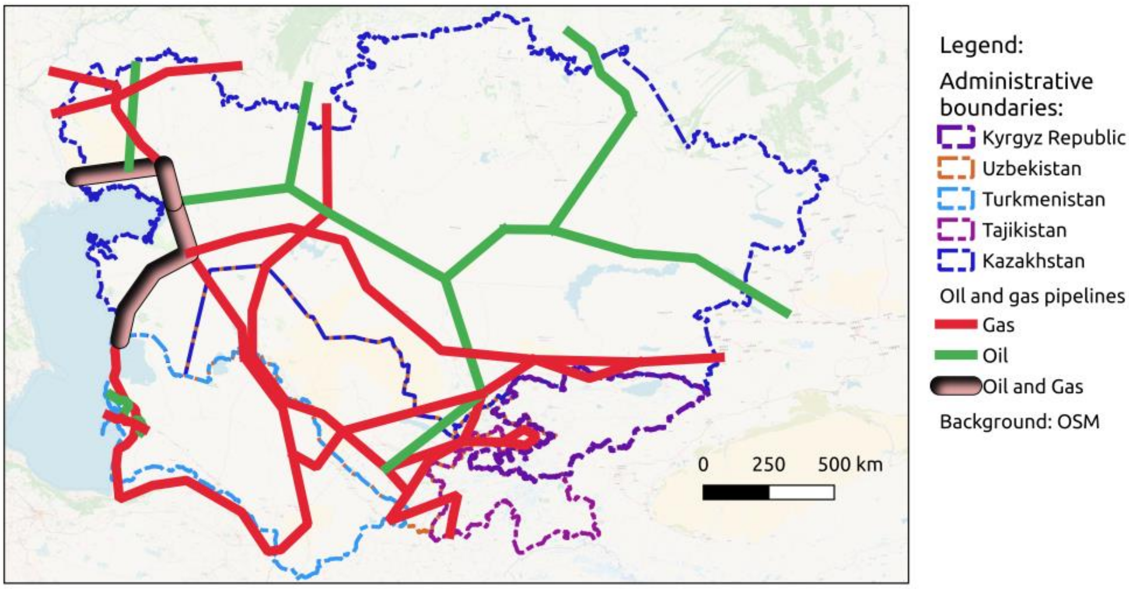

Figure 17. Map of main oil and gas pipelines in Central Asia.

Table 24 contains the total estimated length of main oil/gas pipelines in each Central Asia country based on our layer. The total length of main gas and oil pipelines in the Central Asian region included in the exposure layer is approximately 17,000 km.

Table 24. Total estimated length of main oil/gas pipelines in each Central Asia country

Country	Km of oil-gas pipelines
Kazakhstan	10,500
Kyrgyz Republic	120
Tajikistan	320
Uzbekistan	3,100
Turkmenistan	2,500
Central Asia	16,590

Power generation and supply

The location and type of power plants was extracted from the Global power plant database (Byers et al., 2021, Global Energy Observatory, 2018). Power plants were then classified based on the GED4ALL taxonomy into the different types (e.g., EN/HYD for hydroelectric plant, see Table 29 for the full classification). The power distribution grid is available at a global scale from a layer produced by the World Bank (available at: https://energydata.info/dataset/global-transmission-network/resource/e0f33c3e-6dab-41d1-919d-d266f300d0bc). This layer, extracted from OSM, does not include the characteristics of the supply network and seems to have a scarce coverage. Specific characteristics are nonetheless available for Kazakhstan (https://energydata.info/dataset/kazakhstan-electricity-transmission-network-2016) and

Uzbekistan (https://energydata.info/dataset/uzbekistan-electricity-transmission-substation-2016) for which the location of power substations and supply network and the KV are available. Such maps also include the main power network (220, 500 KV) in other Central Asian countries. The abovementioned digital maps were compared with the Central Asian Power System (CAPS) non-digital maps (Eurasian Research Institute, 2016 contained in Sakal, 2015). The available digital maps were consistent for all countries except for the area in the boundary between Tajikistan and Turkmenistan, where we georeferenced an additional 500-KV distribution line. Figure 18 shows the final map with the power plants classified by type (top) and the supply network assembled (bottom).

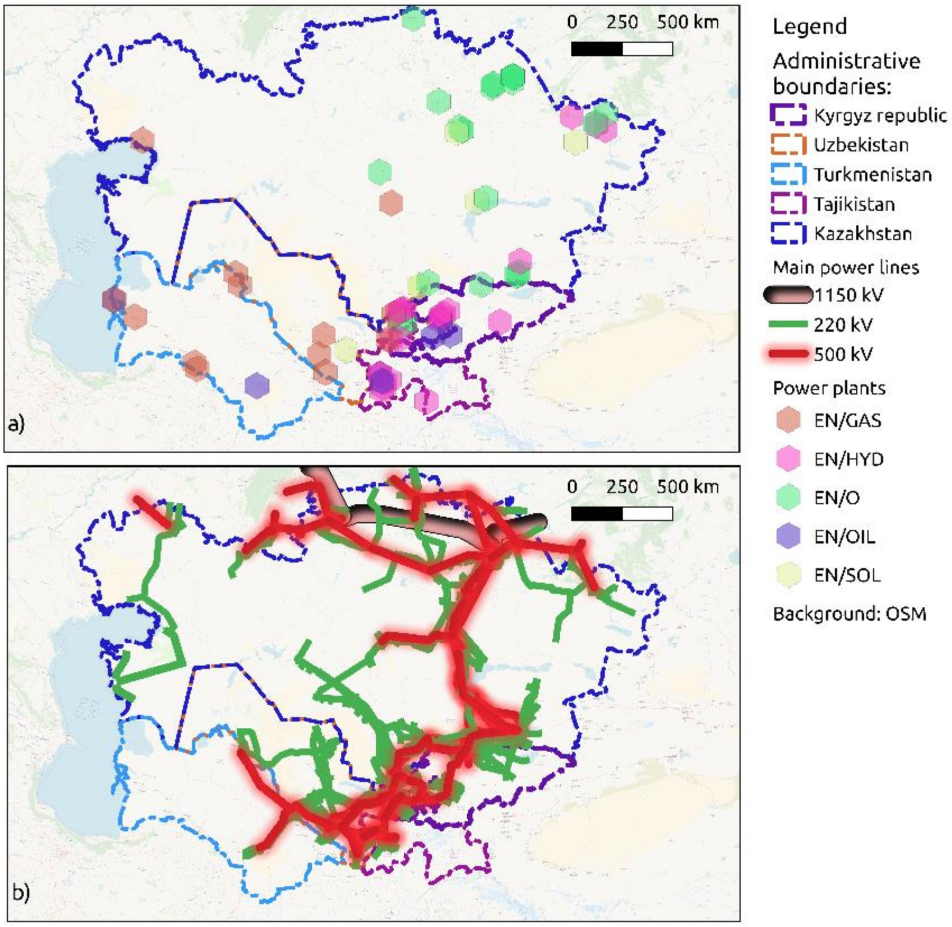

Figure 18. Map of Central Asia power plants classified by type (a) and the supply network assembled in this project (b). Power plant types are defined in Table 28.

The total length of the Central Asia primary power grid network is approximately 50,000 km, constituted by 35,000 km of 220 KV lines, 13,000 km of 500 KV lines and 1,350 km of 1,150 KV lines. Table 25 shows the number of power plants by type in each country. The country with a larger number of power plants is Kazakhstan.

Table 25. Number of power plants by type in each Central Asia country

Country	Number of OIL/GAS power plants	Number of coal power plants	Number of solar power plants	Number of hydropower plants
Kazakhstan	2	22	5	4
Kyrgyz Republic	1	1	-	6
Tajikistan	2	-	-	8
Uzbekistan	7	2	1	6
Turkmenistan	7	-	-	-
Central Asia	19	25	6	24

Water supply

The wide majority of available surface water in Central Asia is used for agricultural purposes (reaching the 95% use of available water in Turkmenistan, https://ideas.repec.org/p/ags/huaedp/7142.html). Moreover, most dams are used for irrigation purposes and, in Kazakhstan and Turkmenistan, for water supply purposes (Aquastat, 2013) as well. The location of water basins was extracted from the Grand database (Lehner et al., 2011, last updated in 2019), which contains the main dams in Central Asia, and the Aquastat database (Aquastat, 2013) which also contains smaller dams. The two datasets were compared and complemented. Table 26 shows the number of dams, the total water volume and the construction year range for each Central Asia country. The total dam's volume is 219,000 million cubic meters, and most dams have been constructed between 1950 and 1990.

Table 26. Number of dams, the total water volume and the construction year range for each Central Asia country.

Country	Number of dams	Total volume (million m³)	Average dam volume (million m³)	Construction year (range)
Kazakhstan	15	92,000	6,100	1953-1988
Kyrgyz Republic	21	43,000	2,000	1956-1986
Tajikistan	18	42,000	2,300	1948-2011
Uzbekistan	37	31,000	800	1963-2002
Turkmenistan	17	11,000	650	1941-2004
Central Asia	108	219,000	2,370	1941-2011

Figure 19 shows the map of Central Asia dams classified by reservoir capacity (million cubic meters) based on the assembled dams from the Grand database (2019) and the Aquastat database (2013).

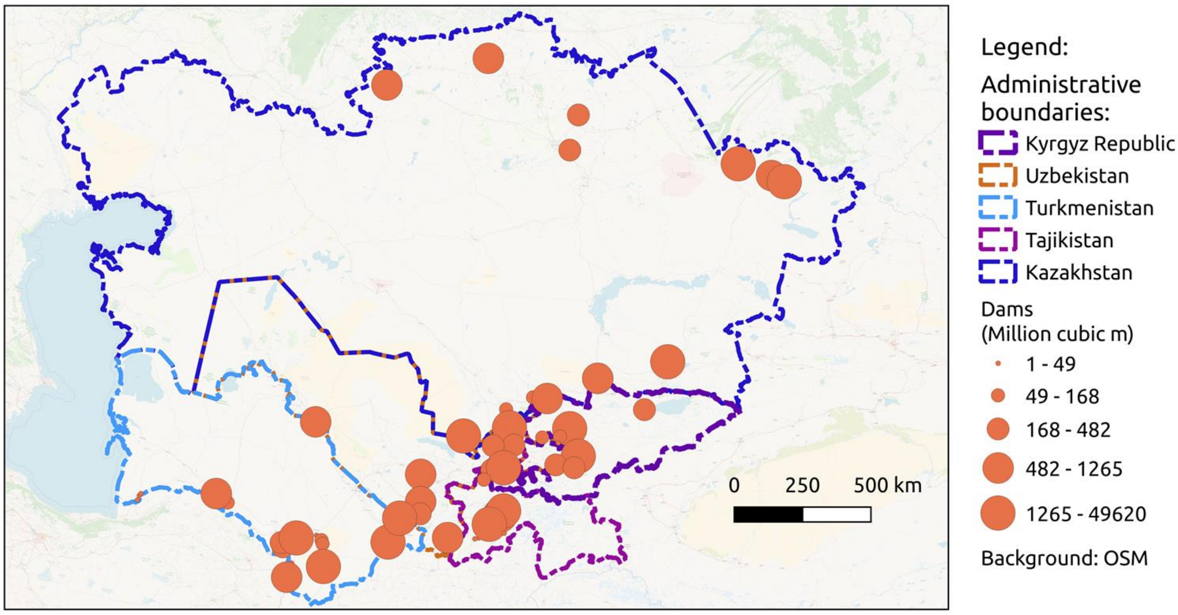

Figure 19. Map of Central Asia dams classified by reservoir capacity (million cubic meters).

The information on the water infrastructure related to the main river basins is only available in non-digital format (http://www.cawater-info.net/amudarya-knowledge-base/index_e.htm) and could not be included in the digital exposure datasets. We envisaged the possibility of adding this information in the future, and discussed the possible ways to update exposure datasets in Appendix A2. As for the water supply network, we collected information from online sources about the total length of the network in each Central Asia country in 2009 (Table 27). In general, the coverage is lower in rural areas and higher in urban areas (Global Water Partnership, 2009).

Table 27. Length and average age of water distribution system and number of water treatment facilities in each country of Central Asia.

Country	Water distribution system (km)	Water treatment facilities	Average age of the water supply network
Kazakhstan	23,500	>300	>40 years
Kyrgyz Republic	> 9,600	> 30	>40 years
Tajikistan	6,060	> 100	>35 years
Uzbekistan	>30,000	> 200	>40 years
Turkmenistan	12,600	17	>40 years

After 2009, most Central Asia countries have started enhancing the water supply network, mostly due to the increasing issues related to clean water availability (https://documents1.worldbank.org/curated/pt/622731504073608228/pdf/119162-WP-v2-P154105-PUBLIC.pdf). In Tajikistan, cooperation projects are currently enhancing the water supply (https://projects.worldbank.org/en/projects-operations/project-detail/P162637?lang=en) and sanitation (https://www.adb.org/projects/50347-002/main) infrastructure. Similarly, in Kyrgyz Republic, there are several efforts to enhance the water supply and sanitation network in rural areas (https://www.adb.org/news/adb-help-improve-rural-water-supply-sanitation-kyrgyz-republic; https://www.oecd.org/env/outreach/KR_NPD%20Overview.pdf). However, no information was available to assemble digital maps. Spatial information was collected only regarding the location of main sewerage facilities in Uzbekistan (source: Water Services and Institutional Support Project (P162263), Annex 4 - internal report, available at: https://projects.worldbank.org/en/projects-operations/project-detail/P162263) and the main water supply pipelines in Turkmenistan (provided by local partners). Figure 20 shows the map of main sewage facilities in Uzbekistan and main water supply pipelines in Turkmenistan. No information was available on the location of the water supply distribution network for the other countries. Costs' estimates for water supply network were not required during this assignment.

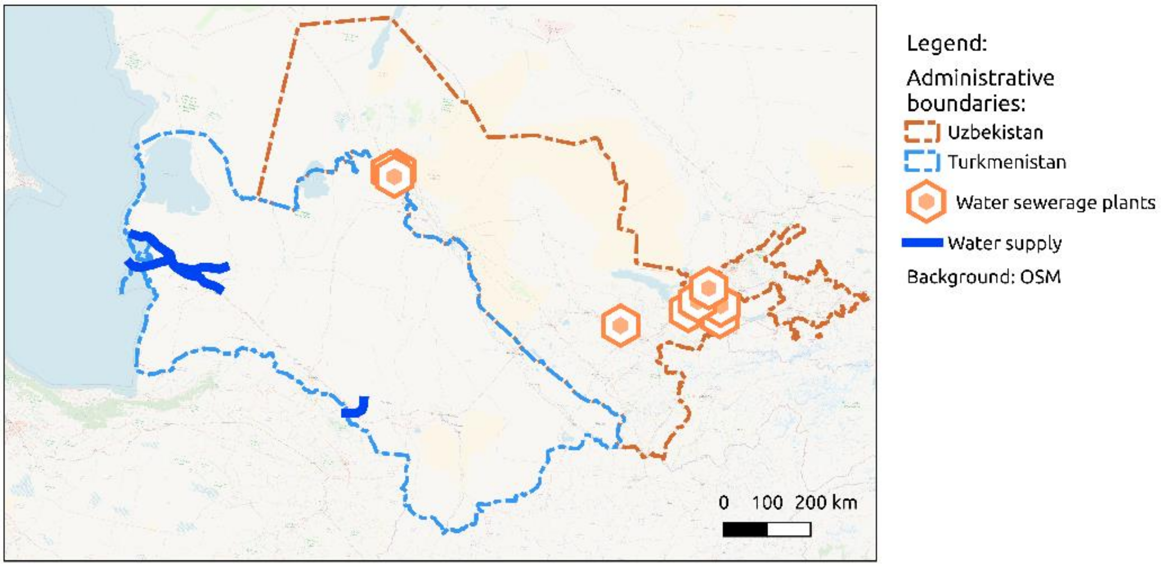

Figure 20. Main sewerage facilities in Uzbekistan and main water supply pipelines in Turkmenistan.

<u>Communication</u>

No digital dataset was found on communication networks in Central Asia. The main terrestrial transmission lines were therefore assembled based on the available online information (UNESCAP 2009, 2014, 2020). According to these sources, most lines in Central Asia are made of optic fibers with the exception of a microwave line in Kyrgyz Republic (https://www.itu.int/itu-d/tnd-map-public/). Figure 21 shows the map of the main communication infrastructure, assembled for Central Asia in this project. The infrastructure is entirely constituted by trunk fibers with the exception of Kyrgyz Republic where both trunk fibers and microwaves cables are present. Most communication infrastructure is located close or in correspondence with the main transportation network (roads and railways).

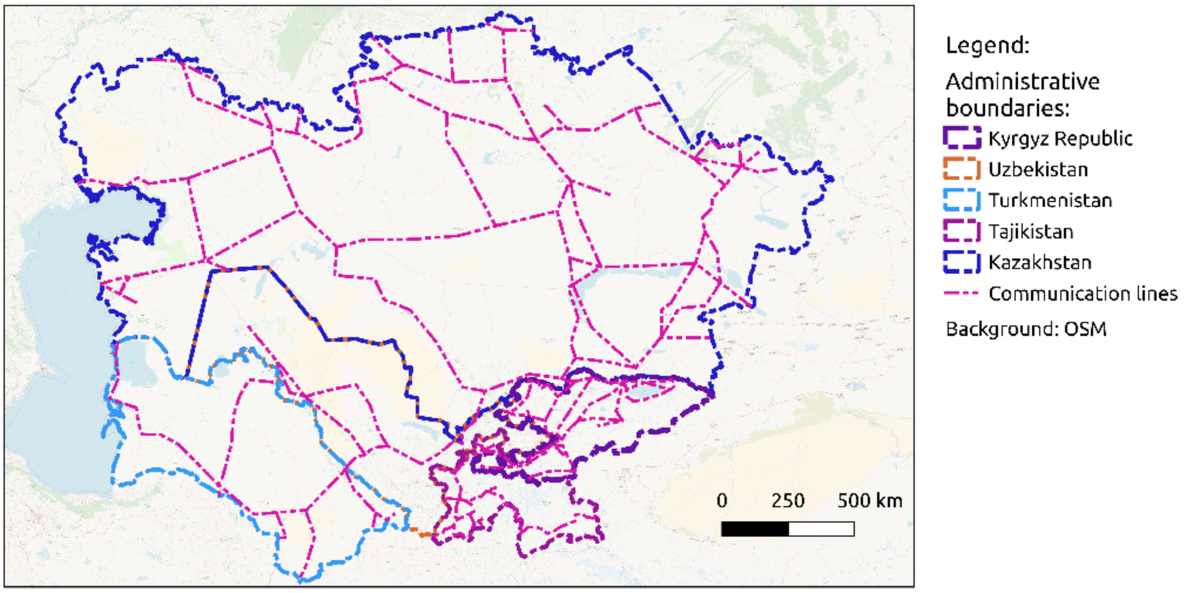

Figure 21. Map of the main communication infrastructure in Central Asia.

Note that the process of georeferencing based on static images can introduce errors in the features location. The total length of communication infrastructure was estimated based on the assembled layer. Table 28 shows the length of communication infrastructure in each Central Asia Country. The total length of the communication infrastructure in the region is approximately 25,000 km. Note that this value is obtained counting only once the distance covered by multiple fiber cables developed by different operators. Thus, despite these values providing an idea of the spatial coverage of the network, the risk assessment should be developed for the total cable length, which could be larger.

Table 28. Length of communication infrastructure in each Central Asia country and for the Central Asia region.

Country	Length communication infrastructure (our layer)
Kazakhstan	15,600
Kyrgyz Republic	3,700
Tajikistan	1,900
Uzbekistan	1,400
Turkmenistan	1,300
Central Asia	23,900

All the considered supply infrastructures will be combined into a final exposure layer. Table 29 summarizes the energy and supply infrastructure typologies identified in this assignment and the corresponding GED4ALL taxonomy (https://docs.riskdatalibrary.org/ged4all.html).

Table 29. Taxonomy adopted for energy and supply infrastructure

Type	Description	Taxonomy
Oil/Gas pipelines	Oil pipelines	PPL/COL
	Gas pipelines	PPL/CGS
Power supply	Power plant - Coal	EN/O
	Power plant - Gas	EN/GAS
	Power plant - Solar	EN/SOL
	Power plant - Oil	EN/OIL
	Power plant - Hydro	EN/HYD
	Power distribution	PWG
Water supply	Dams	DAM
	Water supply (generic)	PWR
Communication	Communication facilities	COM

2.3.9 2080 projections

Projected disaster risk in 2080 can inform territorial planners and support long-term strategies for adaptation. To this aim, we developed projected population and building stock for the year 2080 under three development scenarios. Exposure data was projected based on three Shared Socio-economic Pathways: SSP1 (sustainability), SSP4 (inequality) and SSP5 (fossil-fuel development). The three SSPs represent three possible development paths for Central Asia, and deal with aspects that are open challenges in the Central Asia region (e.g., trans-boundary cooperation, inequalities, water scarcity, fossil fuel resources). Pedde et al. (2019) defined specific narratives for Central Asia, summarized below:

- SSP1: *"This scenario is characterized by cooperation between nations in the region and between external actors. [...] Countries start to collaborate effectively thanks to the establishment of an effective supervisory intergovernmental body in key common policy areas such as energy diversification, water policy and food production. Population grows steadily. Thanks to effective long-term oriented governance, larger shares of the population have access to resources and global markets. [...]"*
- SSP4: *"This scenario is characterized by large and growing inequalities particularly within countries, with a powerful elite established in all countries of Central Asia. These strong and connected elites ensure a high level of stability within and across countries through international connections and collaborations. [...] The elite is furthermore responsible for effective management of migratory fluxes with China and Russia; establishment of common environmental standards across Central Asia; cross-regional cooperation related to infrastructural projects; water management; and exploitation of natural resources. [...]"*
- SSP5: *"The global scene is characterized by a positive attitude to competitive markets, innovation and participatory societies to produce rapid technological progress and development of society. As a result, the economic*

development is generally good and international trade is intensified. Partly this is driven by exploitation of fossil fuel resources. There is also a lack of environmental concerns in the world and the lifestyle is 'globalized' with high material consumption. The implementation of the Sustainable Development Goals (SDGs) has been relatively successful with regard to reducing inequality between countries, but less successful with regard to environmental issues. Also, in Central Asia, there is a competitive economic development largely based on the fossil fuel industry. The region experiences a boom and there is an inflow of investments and people, partly reinforced by an international development of increased international mobility and opening of labor markets. Also, the agricultural sector has seen a good development of its productivity, partly due to improved technologies within this sector. However, the environment in Central Asia pays a high price for the development, and governments mainly focus collaboration on issues that are of importance for the economic development."

Population and GDP projections under the three selected SSPs were retrieved from the IIASA SSP database (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=html page page=about) whose indicators are based on the studies of Dellink et al. (2017), Crespo Cuaresma (2017) and Samir et al. (2019). Table 30 shows the expected GDP and population percentage variation, calculated based on the SSPs projections provided by IIASA. While GDP is expected to increase under all scenarios and for all countries, population is expected to decrease, in particular in Kyrgyz Republic, Tajikistan and Uzbekistan, and in particular for the SSP4 and SSP5 scenarios.

Table 30. Percentage variation between 2020 and 2080 of GDP and population for the three considered SSPs.

SCENARIO	COUNTRY	GDP	POPULATION
		Expected % variation (source: IIASA SSP database)	
SSP1	Kazakhstan	205	-3
SSP4		43	-9
SSP5		216	-2
SSP1	Kyrgyz Republic	834	-16
SSP4		305	-19
SSP5		1,024	-31
SSP1	Tajikistan	989	-23
SSP4		291	26
SSP5		767	-56
SSP1	Uzbekistan	402	-14
SSP4		244	-18
SSP5		515	-25
SSP1	Turkmenistan	249	-11
SSP4		268	-16
SSP5		429	-17

In order to develop exposure projections, it is also relevant to analyze past land use trends. The analysis of the past trends was performed based on the Global Human Settlement Layers (GHSL, https://ghsl.jrc.ec.europa.eu/), in particular based on two datasets, one for population and one for urban area classification. Population layers are available at 1km resolution for 2000 and 2015. The yearly percentage difference between the two layers was computed on a cell-by-cell basis at regional scale. This allows identifying areas where population has been increasing or decreasing the most. The population percentage difference allows identifying areas where population has been increasing, as shown by Figure 22. The maximum percentage decrease of population is of 5.6%, while the median population percentage growth value is 1.39%. The maximum increase is of more than 2000%, but is associated with very few points where new urbanization was constructed. This is demonstrated by the fact that the third quartile of the differences distribution is 3.13%.

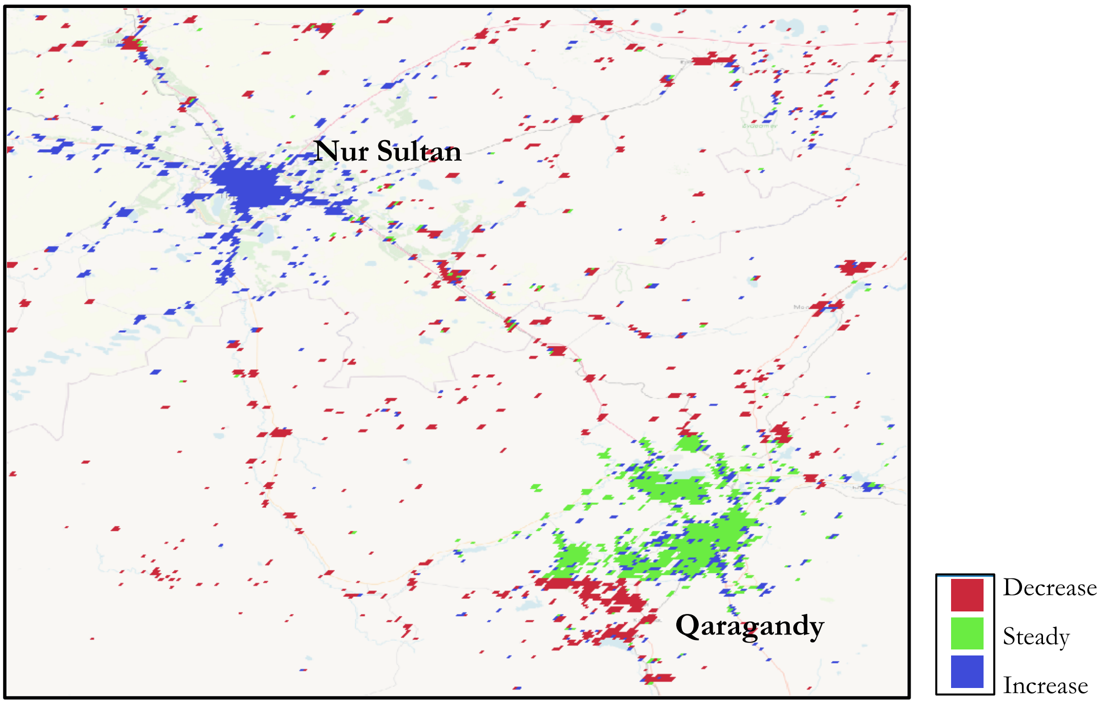

Figure 22. Yearly population difference displayed in three simplified classes (decrease, steady, increase). Map shown for northern Kazakhstan (Nur Sultan and Qaragandy oblasts). Nur Sultan is associated with a yearly population increase, while Qaragandy sees a steady population trend. Rural areas around the cities are mostly associated with a negative trend.

The GHSL dataset provides also urbanized areas at 1km resolution, classified into 7 classes. Such classes comprise different types of urban development (ranging from low-density rural areas to high-density city centers). This classification was simplified into three main classes: rural, sub-urban (which includes sub-urban and peri-urban areas) and dense urban areas. Population statistics were computed separately for each simplified urban area class in order to identify the regional trends. Results (Table 31) show that, between 2000 and 2015, population has been increasing in all areas, but with the stronger population growth happening in urban peripheral areas.

Table 31. Population growth in the period 2000-2015 in each urban area class in the GHSL database. Mean and median were estimated on a cell-by-cell basis in each urban area class.

Scenario	Urban area class	Median population growth value	Mean population growth value
SSP1	Rural areas	1.39	14
SSP4	Sub-urban areas	1.57	25
SSP5	Dense urban areas	1.51	9

The higher degree of growth in urban peripheral areas with respect to rural areas (with subsequent migration of population towards the urban areas) is compatible with what observed in many developing countries in the past, and is already documented in Central Asia both at regional (UNESCAP, 2013) and national scale (e.g., https://migrants-refugees.va/country-profile/uzbekistan/ for Uzbekistan).

Cheng et al. (2020) provide spatial layers of expected urban area in 2080 under different SSPs. Urban area is expected to increase in all countries and under all considered SSPs, as also found by other studies such as Yuyu et al. (2019) and Li et al. (2019). Table 32 summarizes the expected urban area changes according to Cheng et al. (2020). The greater changes are expected in Kazakhstan, where the urban area is expected to increase of more than 160% under the three SSPs. Substantial changes are also expected in Kyrgyz Republic (between 80 and 90%) and Turkmenistan (between 65 and 85%). Lower percentages are found in Tajikistan and Uzbekistan, ranging between 30 and 40%. The spatial layers provided by Cheng et al. (2020) support the identification of areas that are expected to be classified as urban in 2080 (and which are expected to suffer the most changes in building stock).

Table 32. Urban area in 2015 (derived from the GHSL database) and 2080 (derived from the Cheng et al., 2020 database). The percentage difference is estimated in order to show the expected variation in each country and under each SSP.

Country	Scenario	Urban area in 2015 (GHSL) - km²	Urban area in 2080 (Cheng et al., 2020) - km²	Percentage difference
Kazakhstan	SSP1	1722	4761	166
	SSP4		4706	173
	SSP5		4582	166
Kyrgyz Republic	SSP1	359	687	91
	SSP4		671	87
	SSP5		657	83
Tajikistan	SSP1	504	698	38
	SSP4		675	34
	SSP5		665	32

Uzbekistan	SSP1	3279	4529	38
	SSP4		4379	34
	SSP5		4365	33
Turkmenistan	SSP1	419	776	85
	SSP4		736	76
	SSP5		697	66
Central Asia	SSP1	6283	11432	82
	SSP4		11171	78
	SSP5		10970	75

Based on the indicators collected on the expected population and urban development trends, it is possible to estimate, under specific assumptions, the projected changes of exposure for each SSP.

<u>Population</u>

The projected population is estimated by decreasing/increasing the current population according to the trend identified under each scenario (Table 33). This decrease is assumed to happen in a uniform way in Central Asia. Thus, for each country the percentage decrease is equally applied to the current population exposure layer on a cell-by-cell basis. Gender and age fractions are kept constant and equal to the ones in the current layer

Table 33. Total projected population in 2080 under the three considered SSPs.

Country	Scenario	Total population in 2080
Kazakhstan	SSP1	18,436,178
	SSP4	17,295,795
	SSP5	18,626,243
Kyrgyz Republic	SSP1	5,771,572
	SSP4	5,565,443
	SSP5	4,740,934
Tajikistan	SSP1	7,239,496
	SSP4	11,846,450
	SSP5	4,136,854
Uzbekistan	SSP1	29,517,066
	SSP4	28,144,177
	SSP5	25,741,625

Turkmenistan	SSP1	6,027,565
	SSP4	5,688,937
	SSP5	5,621,212
Central Asia	SSP1	66,991,876
	SSP4	68,540,802
	SSP5	58,866,868

Residential buildings

The residential building stock is assumed to undergo the progressive substitution of deprecated building types in favor of modern ones. This is expected to happen in areas that, according to Cheng et al. (2020), are expected to be urban in 2080 under the three different SSPs. This includes areas that were already classified as urban in 2015, but also areas that are expected to become so between 2015 and 2080. Based on the expert opinion collected from local partners and during the exposure development workshops (see section 5 for details), the deprecated typologies were identified and replaced with the ones that are expected to be used in future. The main trend is the progressive replacement of unreinforced masonry and adobe buildings with modern masonry houses (in particular, low-rise family houses). As for multi-family apartments, the new ones are expected to be both reinforced concrete frames or wall type buildings, but with high level of earthquake-resistant design (RC3 and RCPC2, see Table 5). Other typologies, such as wood buildings, were assumed to be replaced by modern wood buildings. Steel buildings were not modified. Table 34 shows the building types conversion, which was done based on the projected population in each point. The conversion factor was calculated as the ratio between the occupants per square meters in the new and the old building type. Note that the new and old building type have different average areas, which are used to estimate the occupants per square meter and subsequently the conversion factor. Also, note that in rural areas the deprecated building types (Table 34) are maintained in the 2080 exposure layer in order to avoid underestimating the risk related to weak typologies which might still be in use, or not demolished, despite their age.

The calculation of the projected exposure layers is performed directly on the current residential buildings' exposure layers. The calculation is done point-by-point on the 500m regular grid. First, the number of buildings in the current exposure layer is converted into the corresponding buildings to accommodate the 2080 projected population. Then, deprecated typologies are converted into modern ones based on the conversion factor in table 5. Finally, the other exposure layer fields are updated accordingly (e.g., for the case of unit area, reconstruction costs). An example of the results is shown in Figure 23 for the city of Dushanbe. The left column shows population and buildings number (a, c respectively) under the SSP4 scenario, which assumes a 26% population increase in Tajikistan (Table 30). Panels b, d show population and buildings under the SSP5 scenario, which expects a strong decrease (-56%) in the population (and a subsequent variation in the buildings number in Tajikistan.

Table 34. Conversion table between current building types (see Tables 4 and 5 for details) and building types in the 2080 projections. Not all types are substituted with modern ones: some are left unvaried (e.g. EMCA6) or converted into a modern typology with conversion factor 1 (which means their number is unvaried, e.g. EMCA3, EMCA5). The occupants per square meter for each typology are computed based on the average building area (see table 5 for details). The conversion factor is calculated as the ratio between the occupants per square meters in the new and the old building type.

Current exposure layer			2080 Exposure layer			Conversion factor
Building type	Average occupants per building	Average occupants per square meter	Building type	Average occupants per building	Average occupants per square meter	
EMCA1 (URM1, URM2)	3.8	0.008	EMCA1 (RM-L)	5.2	0.002	0.25
EMCA2 (RC1, RC2)	152	0.014	EMCA2 (RC3)	152 (unvaried)	0.014 (unvaried)	1
EMCA2 (RC4)	190	0.017	EMCA2 (RC3)	152	0.014	0.8
EMCA3 (RCPC1)	152	0.03	EMCA3 (RCPC2)	152 (unvaried)	0.03 (unvaried)	1
EMCA4	5.2	0.052	EMCA1 (RM-L)	5.2 (unvaried)	0.002	0.04
EMCA5 (WOOD1)	3.8	0.004	EMCA5 (WOOD2)	3.8 (unvaried)	0.004 (unvaried)	1
EMCA6	3.8	0.002	EMCA6 (unvaried)	3.8 (unvaried)	0.002 (unvaried)	1

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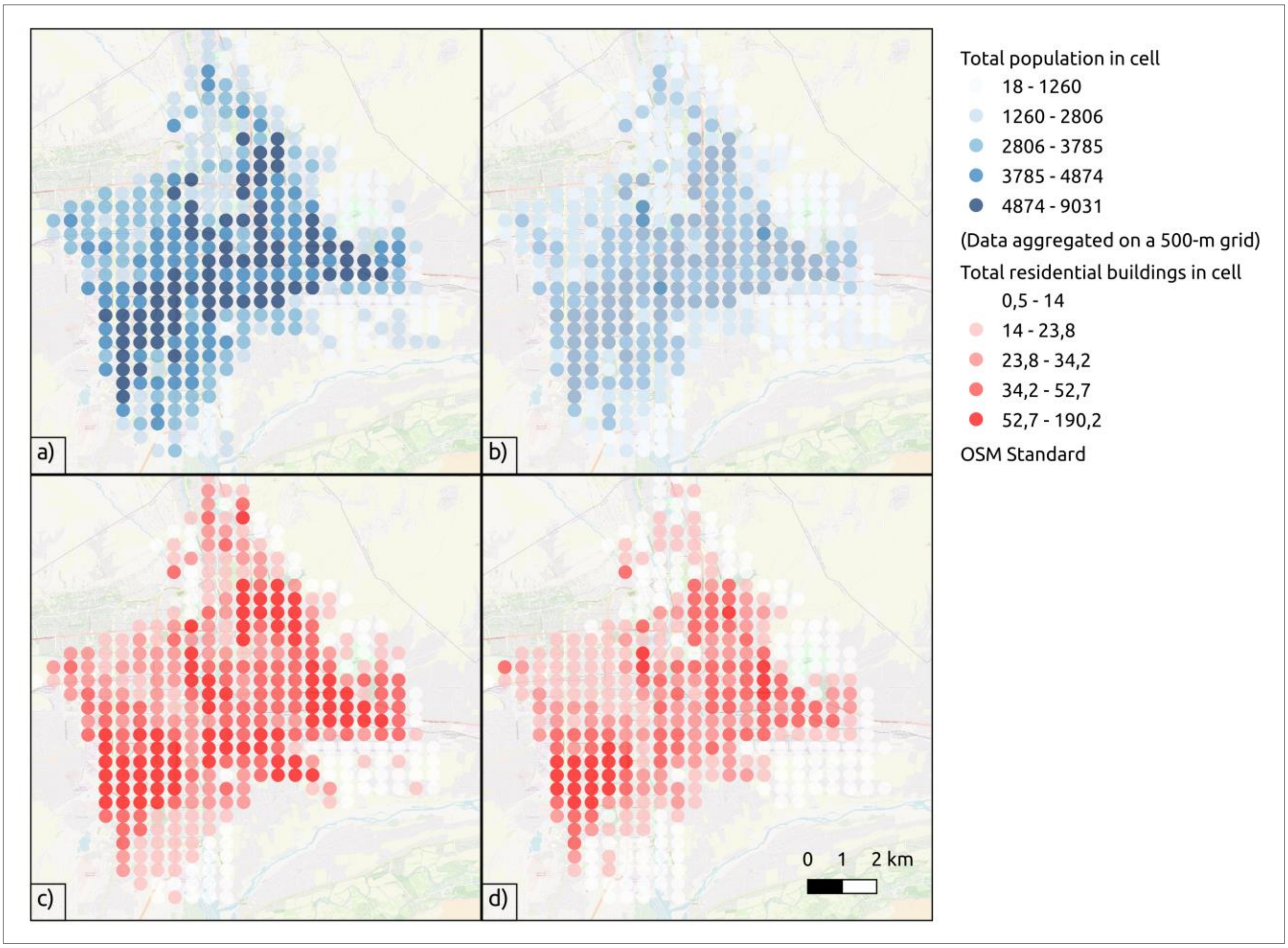

Figure 23. Examples of the spatial layers of projected total population (a, b) and total residential buildings (c, d) in Dushanbe under the SSP4 and SSP5 scenarios (a, c and b, d, respectively). The resolution of the layer is of 500m.

In addition, the deprecated building types are expected to be substituted by new typologies. Figure 24 shows the building stock composition in the Dushanbe province in current scenario (a) and future exposure for the SSP4 and SSP5 scenarios (b and c, respectively). The charts show the effect of the building stock upgrading: the presence of EMCA4 is strongly reduced (they are maintained only in non-urban areas) while the presence of EMCA1, and in particular of reinforced masonry, increases (see Table 34 for details on the building type conversion).

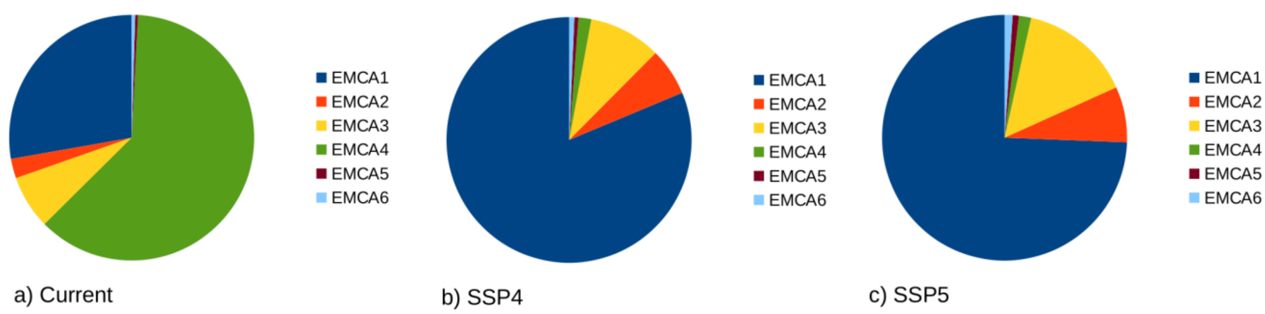

Figure 24. Pie charts of the building typologies in Dushanbe province in the current exposure layer and according to the SSP4 and SSP5 scenarios.

During the calculation, we made sure that the population and residential buildings values in the projected database is realistic. In particular, it was checked that no points were associated with negative population and that the buildings and population density per 500-m point are realistic. During the calculation, statistics were also performed to identify the cells with the largest number of buildings in the whole Central Asia 500-m grid. The maximum population density is in the order of 32.000 people per square km, while the maximum building density is in the order of 10.000 buildings per square km. However, these values are found only in a few areas located in Kazakhstan and Uzbekistan, while maximum values are much lower for Kyrgyz Republic, Tajikistan and Turkmenistan. Most points in the exposure layer grid have lower density values (Figure 25). In particular, the median value of occupants per square km is of 48 and 40 in current and 2080 exposure, respectively.

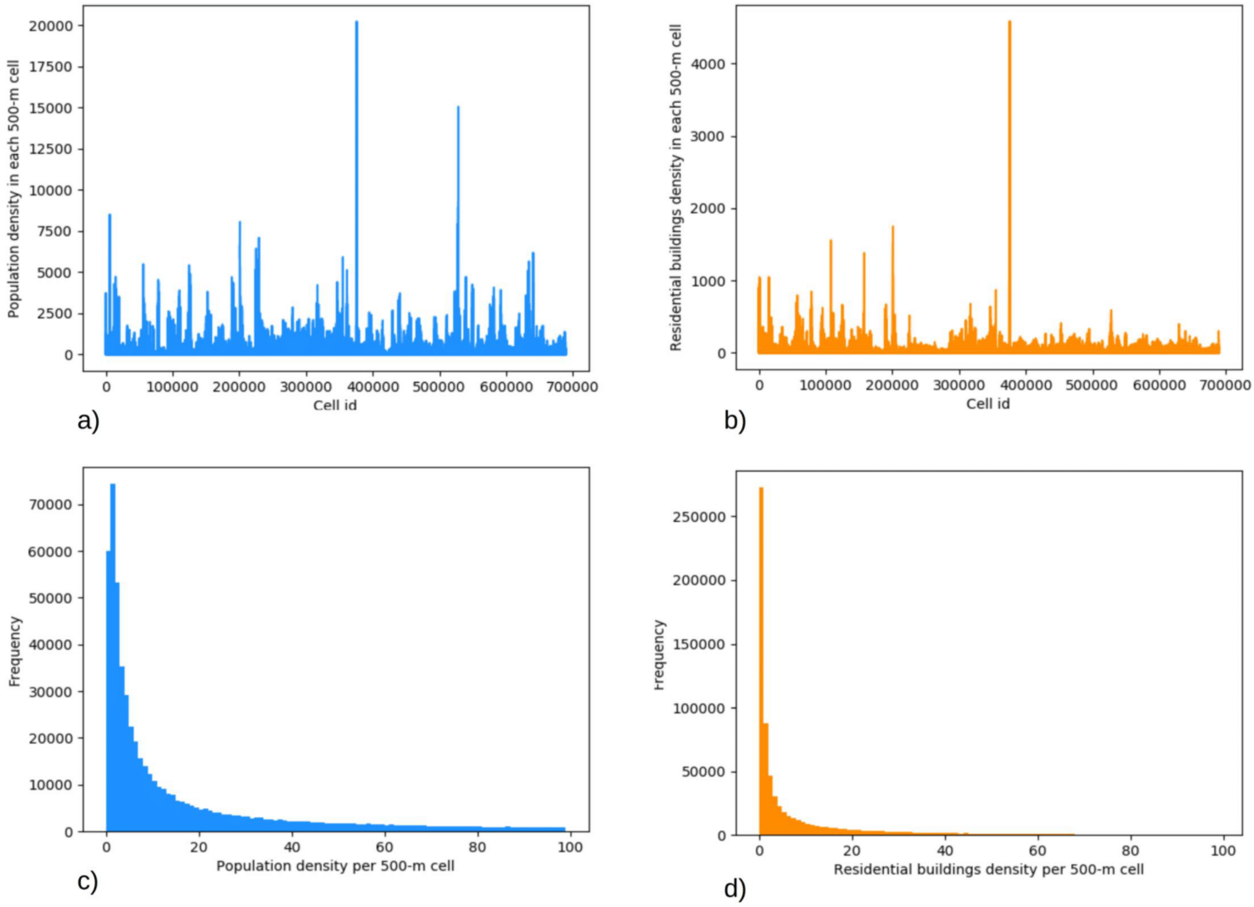

Figure 25. a) population and b) buildings density in each 500-m cell in the domain (population of building number in y-axis; cell ids on x-axis). Plots c) and d) show the histograms for population and building density, showing that the frequency decreases towards 0 for values lower than 100 and 20, respectively.

Table 35 shows the total projected number of buildings for each typology in 2080 under the three considered SSPs. Figure 26 shows the percentage variation of buildings number under the three considered SSPs.

Table 35. Total projected number of residential buildings for each typology and total number of residential buildings in 2080 under the three considered SSPs. EMCA3, EMCA5 and EMCA6 are not included since their number is not expected to vary. The last column shows the expected percentage variation of buildings number between the current and the 2080 exposure layers.

Country	Scenario	EMCA1	EMCA2	EMCA4	Total buildings	Building number % variation
Kazakhstan	SSP1	472,375	40,339	695,387	2,110,243	-11.3
	SSP4	472,335	40,136	696,946	2,111,560	-11.2
	SSP5	474,034	40,351	699,854	2,116,377	-11.0
Kyrgyz Republic	SSP1	164,631	2,679	347,354	524,066	-11.6
	SSP4	164,743	2,676	348,490	525,312	-11.4
	SSP5	164,710	2,665	349,026	525,805	-11.3
Tajikistan	SSP1	221,392	2,421	550,154	790,097	-6.4
	SSP4	229,984	2,722	550,843	799,681	-5.3
	SSP5	214,863	2,188	551,524	784,708	-7.1
Uzbekistan	SSP1	3,452,457	62,974	430,587	4,230,863	-25.9
	SSP4	3,476,750	62,931	432,429	4,256,952	-25.4
	SSP5	3,484,427	62,822	432,522	4,264,616	-25.3
Turkmenistan	SSP1	90,955	10,358	151,620	266,390	-5.0
	SSP4	90,816	10,358	151,676	266,305	-5.0
	SSP5	90,947	10,358	152,302	267,064	-4.7
Central Asia	SSP1	4,401,810	118,771	2,175,102	7,921,659	-19.2
	SSP4	4,434,628	118,823	2,180,384	7,959,810	-18.8
	SSP5	4,428,981	118,384	2,185,228	7,958,570	-18.8

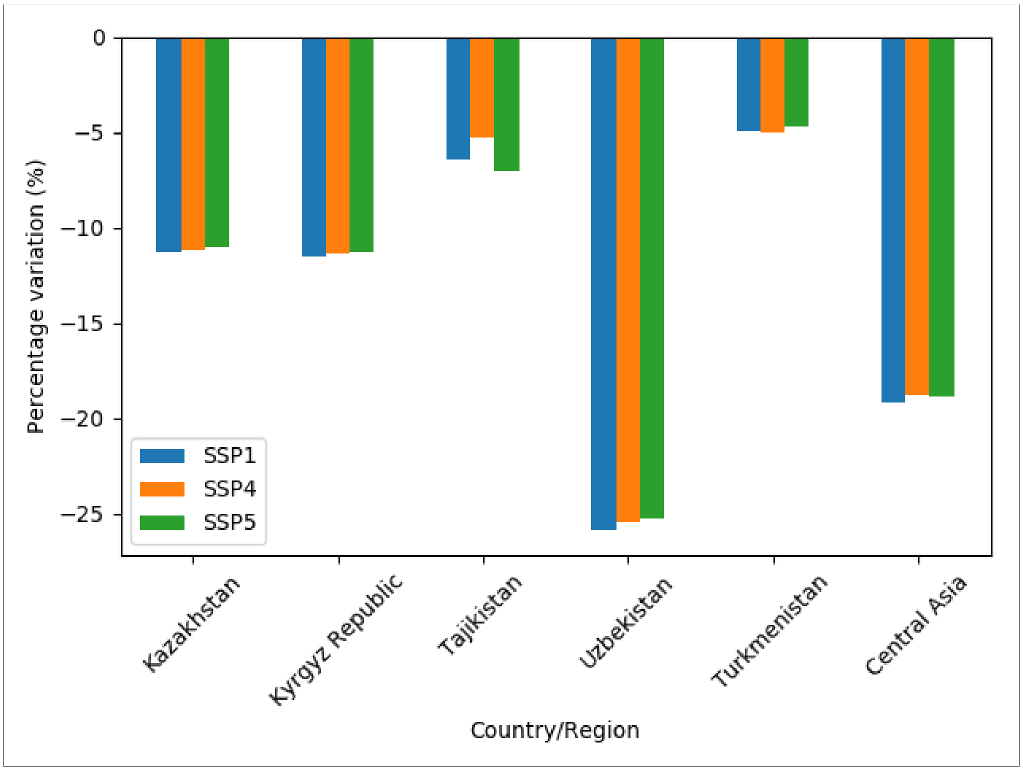

Figure 26. Percentage variation of buildings total number between current exposure and layers under the three considered SSPs. Note that buildings number decreases under all scenarios and reaches a peak of 25% variation for Uzbekistan.

Road transportation network:

The total road length was computed based on the analysis of Meijer et al. (2018) who provides expected increase of road network by country under different SSPs. Table 36 shows the percentage of expected increase of road network length for the considered scenarios. Applying this percentage to all road types considered in the assessment (Highway/motorway/trunk, primary, secondary and tertiary roads) it is possible to estimate the expected transportation network length, and reconstruction cost, in 2080. This is due under the assumption that the percentage increase is constant across all road types. Due to the lack on the spatial distribution of roads, the projections are be provided in aggregated form for each country. Results summarized in Table 36 allow estimating the exposure increase due to the transportation system projected growth. The average growth rate and the length of transportation network at the regional scale is included in the final rows.

Table 36. Total projected length of roads for each typology in 2080 under the three considered SSPs based on the expected road length percentage increase proposed by Meijer et al. (2018).

Country	Scenario	Expected % increase (Meijer et al., 2018)	Projected road length in 2080 (km)			
			Highway/motorway/trunk	Primary	Secondary	Tertiary
Kazakhstan	SSP1	6	18,555	9,055	21,125	49,409
	SSP4	3	17,887	8,729	20,365	47,630
	SSP5	9	18,970	9,258	21,599	50,516
Kyrgyz Republic	SSP1	32	3,686	2,640	2,484	8,700
	SSP4	28	3,564	2,552	2,401	8,411
	SSP5	27	3,545	2,539	2,389	8,367
Tajikistan	SSP1	26	3,321	1,273	3,586	6,954
	SSP4	37	3,628	1,391	3,917	7,597
	SSP5	11	2,946	1,130	3,181	6,170
Uzbekistan	SSP1	14	7,300	1,414	2,123	8,851
	SSP4	10	7,059	1,367	2,053	8,558
	SSP5	14	7,274	1,409	2,116	8,820
Turkmenistan	SSP1	23	7,760	5,440	8,058	20,633
	SSP4	19	7,518	5,270	7,806	19,988
	SSP5	20	7,577	5,311	7,868	20,146
Central Asia	SSP1	20	40,622	19,822	37,376	94,547
	SSP4	19	39,654	19,309	36,543	92,184
	SSP5	16	40,313	19,647	37,153	94,020

Results of exposure projections in 2080

Having estimated the number of assets (building, roads) under each SSP, we computed the reconstruction cost for each SSP for each country and for the Central Asia region. Reconstruction costs are maintained constants and equal to the ones estimated at the time of the assignment (2021). The process of estimating the costs in 2080 equivalent to the current ones should be based on the projected inflation rate, which is associated to a large uncertainty and could lead to unrealistic values. However, varying the building type and distribution influences the building stock (see Figure 24) and its overall exposed value. For the purpose of the assignment, it was decided to perform the analysis keeping the costs constant in 2080 and estimating the expected variability of exposed value due to the projected changes in building stock. The exposure variation is then estimated in percentage over the total exposure in 2021.

The three considered SSPs produce different outcomes in terms of exposure assessment. Population of Central Asia is expected to decrease in rural areas, and the total population is expected to decrease from 75 million to 66, 68 and 58 million (respectively under the SSP1, SSP4 and SSP5). Table 37 shows the final financial exposure estimated for 2080 based on the method described above (values are rounded up). Note that the country which will undergo the greatest increase in terms of reconstruction cost is Uzbekistan.

Table 37. Total reconstruction costs estimated for 2080 for buildings and roads and expected reconstruction cost % variation between 2080 and current exposure layer. Values are shown for the three considered SSPs.

		Reconstruction costs in 2080 (Billion USD)		Reconstruction costs (% variation)		Reconstruction costs per capita (% variation)	
Country	Scenario	Residential buildings	Road network	Residential buildings	Road network	Residential buildings	Road network
Kazakhstan	SSP1	330.0	67	-5.7	6	-2.8	10.0
	SSP4	336.4	65	-3.9	3	5.6	13.0
	SSP5	306.7	69	-12.4	9	-10.6	11.3
Kyrgyz Republic	SSP1	29.0	13	-6.5	32	11.4	54.1
	SSP4	32.3	13	4.2	28	28.6	54.5
	SSP5	32.3	12	4.2	27	51.0	80.4
Tajikistan	SSP1	54.0	11	-3.6	26	25.2	61.4
	SSP4	56.2	12	4.2	37	-20.4	7.7
	SSP5	55.5	10	4.2	12	125.2	150.6
Uzbekistan	SSP1	681.0	29	-11.1	21	3.4	99.2
	SSP4	688.3	28	-10.1	18	9.6	102.4
	SSP5	688.7	28	-10.1	18	19.9	123.0
Turkmenistan	SSP1	19.0	19	0	12	12.4	-11.1
	SSP4	19.9	18	4.7	8	24.7	-8.9
	SSP5	19.9	19	4.7	11	26.2	-5.0
Central Asia	SSP1	1113.0	139	-8.9	13	3.8	29.3
	SSP4	1133.1	136	-7.3	11	3.3	23.3
	SSP5	1103.1	138	-9.7	13	17.1	46.1

Figure 27 shows the percentage variation of total reconstruction costs for buildings under each SSP. Note that it decreases for Kazakhstan and Uzbekistan while it increases in Kyrgyz Republic and Turkmenistan. Kyrgyz Republic and Tajikistan show both increase and decrease depending on the considered scenario. The average reconstruction cost *per capita* in each country is nonetheless expected to increase for most scenarios due to the population decrease and the adoption of building types associated with a higher reconstruction cost. The higher residential buildings reconstruction cost *per capita* is expected in Tajikistan under the SSP5 scenario (which is associated with the stronger population decrease, see Table 30).

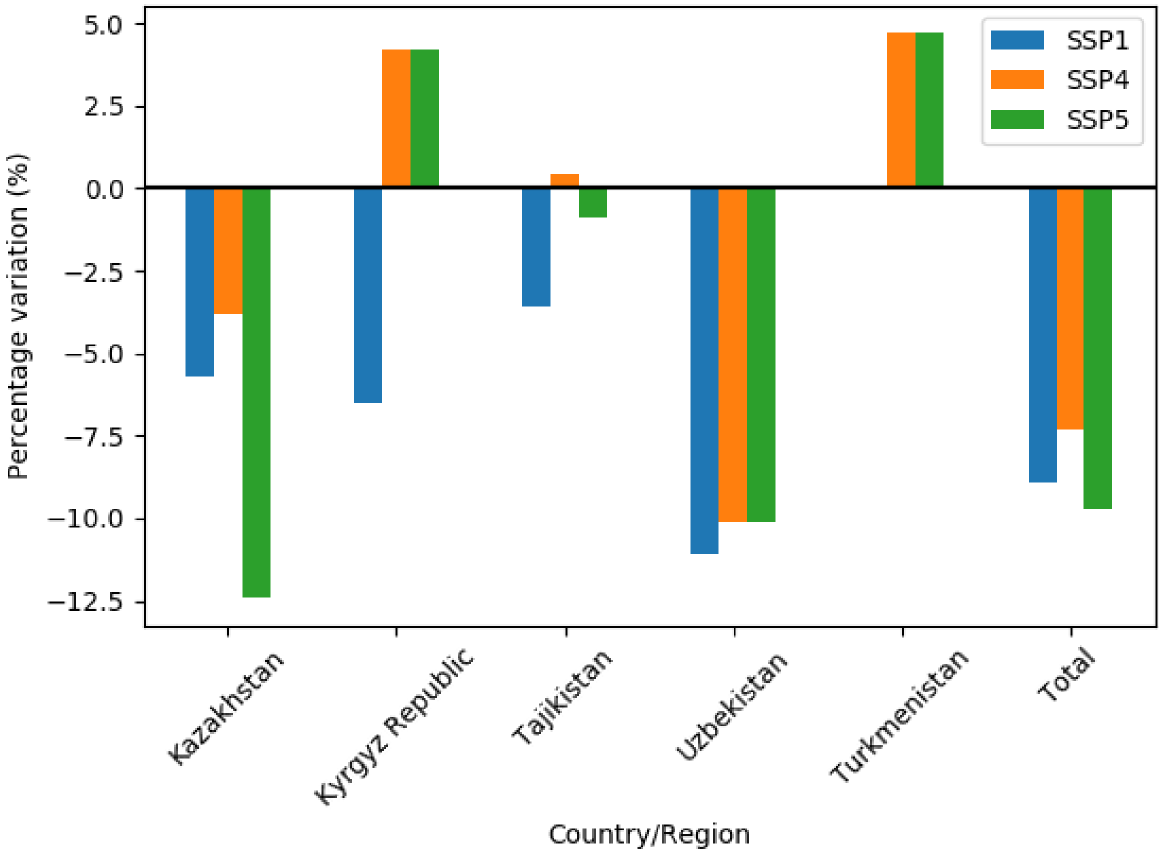

Figure 27. Buildings cost percentage variation with respect to current exposure for each considered scenario.

It is worth mentioning that exposure comprises not only residential buildings but also infrastructure, non-residential buildings and other exposed assets. Considering the possible increase of exposed value due to the expected changes in all exposed assets is nonetheless quite challenging. This is mainly due to the uncertainties associated to the exposure layers and to the difficulties of assessing the spatial distribution of assets in future, which might be conditioned by global, national or local-scale phenomena (e.g., population migration, development trends, etc.) Results in Table 37 show that the value associated to the transportation network can increase substantially, and that it accounts for a low, but not negligible percentage (between 4 and 5%) of overall exposure in the region.

The variation or total reconstruction cost between the current road network exposure and the one projected for the three scenarios is summarized in Figure 28. The average reconstruction cost *per capita* was also analyzed and shows larger increases in Kyrgyzstan and Tajikistan, while it is expected to decrease in Turkmenistan under all considered SSPs. Figure 28 shows the expected variation of reconstruction costs for the road network in Central Asia under the three scenarios considered. Note that road reconstruction costs are expected to increase in all scenarios and for all countries. The largest increase is expected for Tajikistan and Kyrgyz Republic.

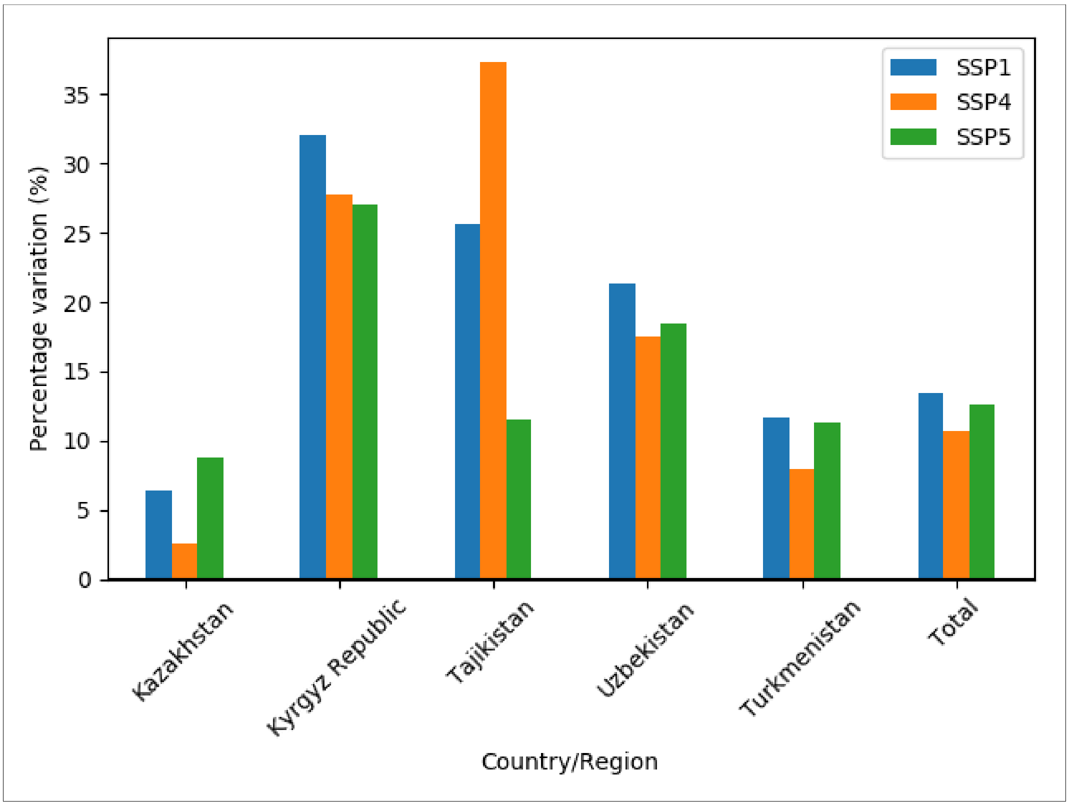

Figure 28. Expected variation of the road network reconstruction costs under the different SSPs with respect to the current scenario.

<u>Discussion and conclusions</u>

The analysis presented here, which allows producing exposure projections for 2080 under three scenarios, is based on a number of assumptions:

- population decrease is assumed to happen in a homogeneous way in each country

- the building stock is assumed to be renovated only in urban areas

- the replacement of deprecated typologies follows the same rules in the Central Asia region

- road network percentage increase is assumed to be the same for all road types

- buildings reconstruction costs are maintained constant and equal to the ones in the current exposure layer.

Non-residential buildings are not projected in this assignment due to the large uncertainties associated with the exposure layers, but might be as well taken into account in the development of future projections. The availability of up-to-date, reliable exposure data and the integration of such information with recent development plans should allow to refine these projections in future.

The projections produced under this assignment are based on recent and robust academic literature studies that provide the expected trends of population and urban area. In addition, they are performed starting from the recently developed exposure layer, which was developed using the most recent data available from the region and combining global layers with national and sub-national information. Results of the analysis can support risk assessment and identify what are the main changes expected in future financial exposure. However, the results and the spatial exposure layers are produced for the scope of a regional-scale assessment. Such layers provide a starting point for analyses at a higher resolution (e.g., at local-scale), but should be complemented with additional analyses on the local context.

3 Validation

This section describes the validation process and its results. The consortium made all reasonable efforts to validate, to the extent possible, all the layers using local-scale data, when available. In their absence, the validation relied on other data provided by other sources not used for the development of the exposure (e.g., online digital maps). For example, local-scale data provided by local partners were used for the development of exposure layers, while online maps not available in digital format allowed to validate qualitatively the exposure maps. Similarly, for other layers, the validation was performed based on aerial images or OSM layers. This section provides evidence of the validation exercise for exposure datasets including population, buildings, croplands, transports and supply infrastructure.

3.1 Population

The population layer was validated using data collected by local partners for specific cities. Note that the global population layers used in this project had been already corrected based on national-scale data at the Oblast scale. Table 38 shows the percentage of population in one gender and age class at selected locations where local data were provided (with the exception of Tajikistan where no demographics were available for cities). We compared the values provided from local partners with the ones in our dataset. The differences between age fractions in our database and those provided by local partners range from 1 to 5 percentage points for both age and gender.

Table 38. Percentage of population in one gender and age class in selected locations where local data were provided and comparison with the developed exposure dataset ('our layer').

		Total population		Female (%)			Children (%)		
Country	Town	Our layer	Local data	Our layer	Local data	Difference (% points)	Our layer	Local data	Difference (% points)
Kazakhstan	Shymkent	954,648	1,038,152	51	52	1	13	n.a.	n.a.
	Almaty	1,719,402	1,916,822	54	54	0	8	5	3
Kyrgyz Republic	Osh	359,081	312,530	52	52	1	10	15	5
	Bishkek	1,169,727	1,053,915	53	53	0	8	12	4
Turkmenistan	Ashgabat	803,110	1,032,000	51	50	0	9	n.a.	n.a.

3.2 Residential buildings

We validated the exposure layers for each country based on the data provided by local partners that were not used in the development of the exposure layer. All partners provided the total number of households for one or more main cities. Such data can be used to validate the exposure layer by estimating the ratio between households in our layer and in local data (Table 39). Note that for Kyrgyz Republic and Tajikistan we can expect the Pittore et al. (2020) layer to be particularly reliable since it was mostly developed based on local field data (Wieland et al., 2012, 2015). Differences are nonetheless quite large in Uzbekistan probably due to the conversion coefficients between buildings and households (in particular, the large occupancy difference between URM and CM/RM which is largely present in most Central Asia countries).

Table 39. Number of households in selected locations where local data were provided and comparison with the developed exposure dataset ('our layer').

Country	Town	Households (our layer)	Households (local data)	Households ratio
Kazakhstan	Shymkent	510,178	606,500	0.8
	Nur-Sultan	140,772	198,528	0.7
Kyrgyz Republic	Bishkek	261,008	230,624	1.1
Uzbekistan	Tashkent	1,329,286	780,810	1.7
Turkmenistan	Ashgabat	135,385	188,000	0.7

Comparison of the existing building types for selected areas was made based on information collected for specific cities such as Ashgabat. In particular, data were available on the approximate percentage of buildings in each type in Ashgabat. This information was collected during the 5th exposure development workshop. According to the country-based data, residential buildings in Ashgabat are constituted by 65% of masonry buildings, while a 35% of buildings are constituted by reinforced concrete (precast or cast-in-situ). In the exposure layer developed under this assignment, the percentages are in good agreement (60% and 30% respectively). The remaining 10% belongs to other typologies (in particular, 5% of adobe buildings).

3.3 Non-residential buildings

Schools

For Kazakhstan, Kyrgyz Republic and Uzbekistan, where the school location was available in the form of a spatial layer, the school's total number was validated against the data provided by local partners for each Oblast (Table 40). In general, there is an overall good agreement between the local partners' data and the spatial layers retrieved for Kazakhstan and Kyrgyz Republic, while there is a large discrepancy for Tajikistan. For all countries except Tajikistan, the number of schools for 1,000 inhabitants ranges between 0.2 and 0.4 based on local data. Thus, this seems to be a reasonable range, and is one order of magnitude larger than the one in local data. This suggests that the Tajikistan school census might lack a number of schools that are found in the spatial layer. We also compared the totals with the Unicef site (https://projectconnect.unicef.org/map/countries) for the available countries. As for Uzbekistan and Turkmenistan, since schools were disaggregated based on local partners' data, those data could not be used for validation. Thus, we validated them only by comparing the number with the total school number in Uzbekistan (available from the Unicef dataset, https://projectconnect.unicef.org/map/countries) and checking selected locations in Turkmenistan based on google maps.

Table 40. Comparison of number of schools per 1,000 inhabitants in our layer and in the local data collected for each Central Asia country.

	Our layer		Local data		Unicef
Country	Schools	Schools per 1,000 inhabitants	Schools	Schools per 1,000 inhabitants	Schools
Kazakhstan	7,462	0.4	7,319	0.4	6,673
Kyrgyz Republic	1,260	0.2	1,086	0.2	2,080
Tajikistan	858	0.1	106	<0.1	n.a.
Uzbekistan	n.a.	n.a.	10,287	0.3	9,202
Turkmenistan	n.a.	n.a.	1,868	0.3	n.a.

Hospitals

The number of hospitals in each Oblast was validated with the total number of hospitals provided by local partners. Only Turkmenistan partners provided both total hospitals and clinics (within parentheses in Table 41). There is an overall good agreement between spatial layers and local partners' data in Kazakhstan. The comparison between the number of hospitals and clinics in our layer and in local data suggests that Kyrgyz Republic and Tajikistan might be lacking some assets. In Uzbekistan, the number of healthcare and clinics collected at country level is much larger than the in our spatial layer. This suggest that the hospitals and clinics number collected at country level includes other healthcare facilities. During the validation, large discrepancies were found between the number of hospitals in our layer and the data available from local partners in Turkmenistan. Additional data were retrieved and made possible to update the geospatial layer. In absence of exact coordinates of the additional hospitals, they were located in the centroid of the town. The additional data increased the reliability of the exposure database for Turkmenistan. Future work should be devoted to identifying and mapping the missing hospitals and clinics in the exposure layer provided here, in particular for Uzbekistan. A reliability matrix is provided in Section 4 where these aspects are pointed out.

Table 41. Comparison of number of hospitals per 1,000 inhabitants in our layer and in the local data collected for each Central Asia country.

	Our layer				Local data	
Country	Hospitals	Clinics	Hospitals and clinics	Hospital and clinics per 1,000 inhabitants	Hospitals and clinics	Hospital and clinics per 1,000 inhabitants
Kazakhstan	442	326	768	0.04	788	0.04
Kyrgyz Republic	233	83	316	0.05	57	0.01
Tajikistan	129	51	180	0.02	45	0
Uzbekistan	451	353	804	0.02	9,405	0.28

Turkmenistan	129	26	155	0.03	176 (135 hospitals, 41 clinics)	0.03

Commercial buildings

The only available data on commercial buildings are those the OSM layers, which have a partial coverage of Central Asia and therefore include only a small fraction of the existing commercial buildings in the region. Thus, it was not possible to validate the commercial layer at this stage.

Industrial buildings

Again, the only available spatial data on industrial buildings are those in the OSM layers, which include only a small fraction of the existing industrial buildings in the region. The coverage of OSM was checked visually by inspecting selected polygons and comparing them with the corresponding aerial images. Figure 29Figure 29 shows two examples of industrial areas identified from OSM and the underlying aerial image.

Figure 29. Examples of industrial areas identified from OSM and the underlying aerial image.

The total number of industrial buildings estimated in this project (Table 8) was validated by comparing it with the total value computed dividing half of the total industrial built-up area in OSM by the average area of a building according to the SERA dataset (Crowley et al., 2020). Note that areas devoted to mining and other extraction activities were removed from the OSM industrial layer since such activities are not included in the secondary sector. We then compared the two values obtained from OSM and from employment statistics. The comparison is good for Kyrgyz Republic and Turkmenistan (differences of 12 and 3%, respectively) while greater differences are found for Tajikistan and Uzbekistan (33 and 36%). The difference is larger for Kazakhstan where OSM seems to largely overestimate the industrial areas. In this project, it was decided to use the total industrial buildings number inferred from the labor statistics because country-based data are assumed to be more reliable than datasets developed within different contexts.

3.4 Croplands

The first validation was done by comparing total cotton and wheat production (Tons/year) in our database and the FAOSTAT database (FAOSTAT, 2021). Table 42 shows the results, which are overall satisfactory with the exception of the Turkmenistan cotton production. Note that the last update of the FAOSTAT database was done in 2019.

Table 42. Comparison of total cotton and wheat area and production in our database and the FAOSTAT database.

	Wheat (thousand T/year)		Cotton (thousand T/year)	
Country	Our layer	FAOSTAT	Our layer	FAOSTAT
Kazakhstan	14	11	328	344
Kyrgyz Republic	603	602	73	58
Tajikistan	1,416	837	272	403
Uzbekistan	7,451	6,093	3,094	2,694
Turkmenistan	1,842	1,500	1,841	582

In order to validate the total hectares of cotton in each Oblast, we followed the following procedures:

- We estimated the fraction of cotton on total cropland area separately, based on the spatial layer produced in this assignment and on the data available for each Central Asia country's Oblast. The cotton fraction on the layer was computed dividing the cotton hectares by the total cropland in the global land cover cropland fraction map. Discrepancies are lower than 15% with the exception of the Khatlon Oblast (Tajikistan) and Akhal, Lebap and Mary Oblasts (Turkmenistan), which show differences of 35, 25, 24 and 36%, respectively.
- We visually compared the spatial distribution of cotton and the total hectares for each Oblast with the values provided by the Wuemoca portal (https://wuemoca.geo.uni-halle.de/app/). Substantial differences in total hectares are found, probably due to the different approach used for deriving the maps and due to the fact that the Wuemoca portal was last updated in 2018. However, the spatial distribution of croplands is consistent.
- We compared cotton spatial distribution with the one provided by the Gadas portal (https://geo.fas.usda.gov/GADAS/index.html). The spatial distribution is consistent.

In order to validate the wheat cropland map, we followed the same procedure. Discrepancies between the wheat area fraction on total cropland area obtained by local partners' data and those obtained from the spatial analysis are lower than 20% for most Oblasts, while they vary between 20 and 38% for 5 Oblasts in Kazakhstan, one in Tajikistan and 2 in Turkmenistan. The comparison of crop distribution with Wuemoca portal data was due only partially, since the portal provides values for non-irrigated areas only. The comparison shows large discrepancies in the hectares' values. In most cases, the hectares estimated by the Wuemoca project are lower than the ones estimated in this project, probably due to the fact that a) the portal is focused on irrigated croplands while here we considered also rainfed croplands which account for a non-negligible percentage of croplands in northern and southern Kazakhstan and northern Kyrgyz Republic (Kienzler et al,. 2012) and b) the latest available data on the Wuemoca portal are from 2019. However, the location and spatial distribution of wheat croplands is consistent.

3.5 Transportation system

The transportation network exposure layer was validated based on national-scale statistics available for Uzbekistan. In particular, local partners in Uzbekistan provided the total number of bridges and the total km of railroads and roads by type in the country. The comparison shows an overall good agreement between the local data and the exposure layer developed within this assignment. The number of bridges is lower than that provided by local partners, but this is probably due to the fact that we identified only the main bridges. Results of the validation in Uzbekistan are provided in Table 43.

Table 43. Comparison between the total km of road and railway network and the number of bridges identified in our layer for Uzbekistan and the data provided by local partners.

Bridges		Total road network		Primary Roads		Railways	
Total number (our model)	Total number (local data)	km (our model)	km (local data)	km (our model)	km (local data)	km (our model)	km (local data)
4,047	14,331	183,000	184,000	33,993	42,695	9,936	9,926

The local partners in Turkmenistan provided non-digital maps of the railway network and estimates of the total length (3,551 km). According to the World Bank database ([3]), the total km of rail lines in Turkmenistan is of 7,680 km. The total Km of railways in our exposure layer is 5,675 km but this discrepancy might be due to two reasons: the fact that in recent times the railway network saw a strong development and the fact that OSM layer contains each single binary track, including double-tracks and secondary binaries (and might therefore increase the total number of km with respect to the railway line length). However, the spatial location of main transportation lines was also compared with non-digital maps of railway lines provided by local partners (e.g., for Turkmenistan) showing an overall good agreement. Future work might be required in order to resolve these discrepancies using country-based specific information. Similarly, the spatial distribution of the road network from online sources (e.g., UNESCAP, 2019 for Kyrgyzstan) is in good agreement with the assembled exposure layer. The identified bridges are much lower than the number of expected bridges in Uzbekistan. This is probably due to the fact that we identify only main bridges associated to main crossroads or rivers. The limitations of the bridges exposure dataset are mentioned in section 4. The location of the transportation network features was also checked based on aerial images (Figure 30). Figure 30a shows railway and road segments (purple and red lines, respectively) extracted from OSM. The yellow triangles locate a bridge identified by

3

https://data.worldbank.org/indicator/IS.RRS.TOTL.KM?locations=TM the consortium in the intersection between main transport infrastructures. Figure 30b shows a bridge identified by intersecting the highway/motorway/trunk road network with the main rivers.

Figure 30. Left: Railway and road segments (purple and red lines, respectively) extracted from OSM. The yellow triangles locate a bridge identified by the consortium in the intersection between main transport infrastructures. Right: Example of bridge identified by intersecting the highway/motorway/trunk road network with the main rivers.

3.6 Primary commodities and extraction sites

The location of a selected number of mines and industrial sites contained in the USGS database was cross-checked using google maps aerial images and the OSM layer. These checks, performed in each country, showed that the mines and industrial sites are effectively identified by USGS dataset used under this assignment. Figure 31 shows an example for a selected mine, identified by an industrial area in OSM. The areas in OSM that corresponded to mines in the USGS dataset were not considered when developing the exposure layer for industrial buildings (see 2.3.3 for details).

Figure 31. Example of mine contained in the global mines dataset (Baker et al., 2010) and the corresponding OSM polygon

3.7 Supply infrastructure

Oil and gas pipelines were validated based on the total length data found online for Turkmenistan and Kazakhstan, which hosts the main Central Asia oil and gas pipelines (Table 44). However, the values are lower than those found online This discrepancy likely occurs because in this assignment we considered only the main pipelines and not the secondary ones.

Table 44. Comparison of the oil and gas pipelines length in our layer and the one gathered from online sources.

	Gas pipelines (km)		Oil pipelines (km)	
Country	Our layer	Online sources	Our layer	Online sources
Kazakhstan	5,600	19,000*	4,600	3,000 **
Turkmenistan	2,510	8,200 ***	300	1,300***

*(https://www.kaztransgas.kz/index.php/en/press-center/press-releases/978-gas-pipeline-system-of-kazakhstan-is-recognized-as-the-best-in-the-central-asia)
** (https://www.hydrocarbons-technology.com/projects/kazakhstan-china-crude-oil-pipeline/)
*** (https://factsanddetails.com/central-asia/Turkmenistan/sub8_7d/entry-4838.html)

The location of dams, extracted from two global datasets (Grand database - Lehrer et al., 2011 and Aquastat, 2013) was validated using aerial images from google maps. Figure 32 shows an example of three dams, included in the Grand database, Aquastat database, or both. The final layer includes the three dams, whose presence was checked against aerial images, in order to make sure that the exposure dataset contains no duplicates. The presence of hydropower plants was also taken into account as a factor for possible presence of dams. Most of the identified locations in the dam dataset correspond to dams visible from aerial images. In some cases, we manually updated the dams position based on the aerial images. Figure 32 shows that our database comprises both large dams (extracted from Grand database) as well as small dams (obtained from the Aquastat database).

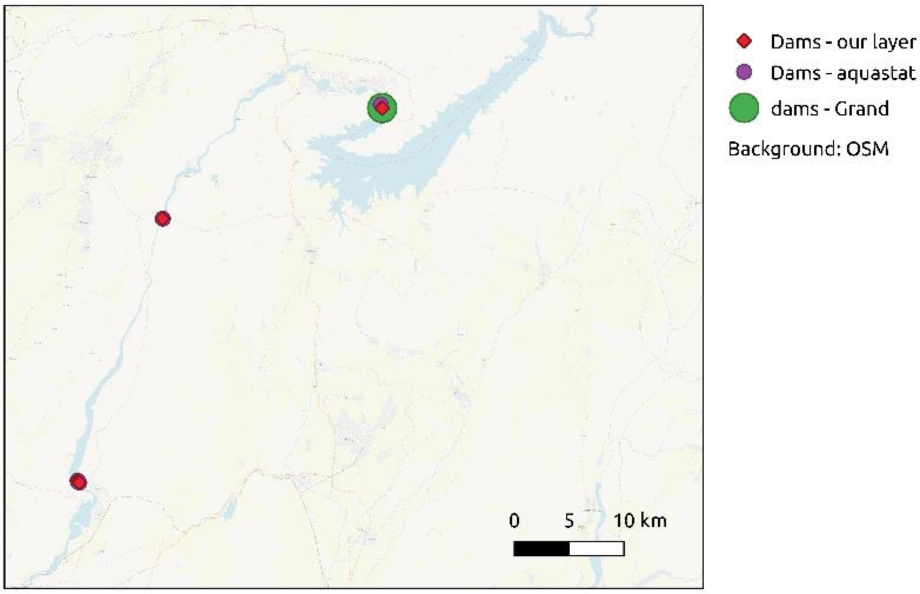

Figure 32. Comparison of dams' locations collected from two different datasets (Grand and Aquastat, displayed with larger and smaller dots, respectively) and those included in our layer (red diamonds).

4 Limitations and reliability

In this work, we developed the first regional-scale comprehensive exposure database for Central Asia. The dataset, produced at regional-scale, encompasses a wide range of asset types and was achieved using several procedures which have some associated limitations. In this section, we discuss the limitations of the methodology, the data gaps and the usability and reliability of the results.

4.1 Limitation of the methodology

The main limitations of the methodology are related with the need for characterizing, classifying and locating a wide number of different asset types on a large and heterogeneous territory. In particular, the main limitations are related to the following aspects:

- Use of methods developed for other areas (e.g., Hazus) for the Central Asia region. Widely adopted method such as Hazus are usually adopted to assess expected risk at global or regional scale. In absence of region- or country-specific data on content costs, we assumed that Hazus is applicable to Central Asia. In particular, we adopted the Hazus methodology to estimate content costs as a function of the structural cost of each building typology.

- Lack of information on the location of the exposure assets. In many cases, exposure data are available in aggregated form, but not in form of maps or spatial layers. Exposed assets were therefore located based on proxies (e.g., based on population density). This is the case, for example, for commercial buildings. This procedure can introduce errors on the location of assets. However, in absence of specific data for the region, it allows to effectively locate exposed assets so that they can be included in a first-level risk assessment.

- Lack of information on the typologies of exposed assets (e.g., commercial and industrial buildings). Commercial and industrial building typologies were characterized based on the SERA exposure dataset for post-soviet European countries. These datasets are quite recent and widely recognized as the reference methods in current practice. We selected post-soviet countries based on the assumption that their economic development (and subsequent construction market) is driven by a similar context. Thus, we expect that the characteristics of their exposed assets in these countries are similar to the ones of the Central Asian countries which also share a long time under area of influence of the Soviet Union. Similarly, in absence of information on the location and type of schools, we inferred the school typologies from the Unicef schools database for Kyrgyz Republic, assuming that school buildings are similar in all Central Asia.

4.2 Data gaps and reliability

During the project, all local partners devoted a strong effort to gathering reliable and up-to-date country-based exposure data. However, the data collection was limited by the impossibility of interacting directly with local contacts. Discussion has been limited to online meetings, while in-person meetings would have facilitated the interaction and the identification of potential data sources. Despite this, a large amount of data was collected for each of the 5 Central Asia countries (Appendix 2). During the process, some data gaps were identified, in particular for:

- commercial buildings

- industrial buildings

- healthcare buildings

- educational buildings

-supply infrastructure (water, power, communication)

Note that the data gaps often include the absence of spatial layers. Most data are in fact available at an aggregated level (e.g., Oblast level) with no information on the location of assets. This is the case for most non-residential buildings with the notable exception of schools for which digital maps are available in Kyrgyz Republic, Kazakhstan and Uzbekistan. A strong emphasis should be put, in future, to the importance of generating digital maps of exposed assets to inform risk reduction.

In addition to the data gaps, there are also issues related to the combination of heterogeneous datasets into a regionally-consistent. Country-based data are in fact provided in different units or derived under different assumptions. This is the case, for example, for building census that provide households or building number. In order to harmonize the different census data it is often required to convert households into buildings, and vice-versa, assuming an equivalent number of households per building type. This process can nonetheless lead to discrepancies in the validation process (e.g., Table 38). In addition, building typologies are defined by different classes in country-based census (e.g., some distinguish between walls and structural material, other don't).

In order to support the use of the exposure database, we provide a reliability matrix (Figure 33) where, for each exposed asset type, a qualitative reliability rating is provided. The rating strongly depends on the quantity and type of information available in order to develop the exposure assessment. The reliability rating can inform risk assessment and guide future exposure development efforts. Note that the reliability rating is defined within the context of a regional-scale exposure assessment.

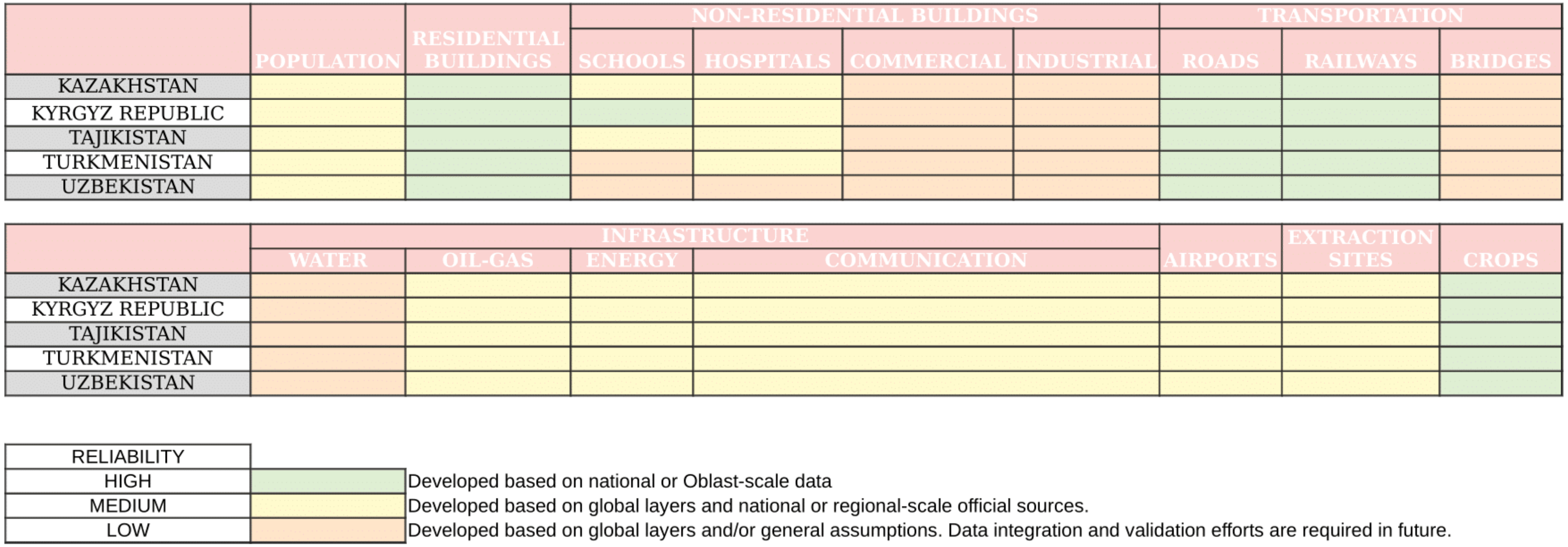

Figure 33. Exposure data reliability matrix

Within the scope of such assessment, specific features such as local-scale variability and secondary elements are not considered. Thus, the high reliability rating in this project should not be compared with local-scale exposure datasets, often developed with highly-granular data sources (often directly collected during surveys) and under different assumptions.

The layers with the higher reliability are those developed for residential building and croplands (based on national and sub-national scale data), as well as those for roads and railways (based on OSM which is considered a reliable source, with the exception of Turkmenistan where some discrepancies were found with country-based data). Other exposed asset types have medium reliability due to the lack of official data or the discrepancies identified during the validation. For example, the overall population is sometimes not aligned with official data in selected Central Asia cities. For most supply networks, official data was available in the form of maps, but these were in non-digital format and comprised only the main supply network. They are therefore associated with medium reliability. The layers with lower reliability are those assembled for bridges and water supply infrastructure. In the case of water supply, this is due to the very few data available. As for bridges, the low reliability is associated to the lack of data for direct validation and to the automated procedure implemented for locating bridges in the region.

As for non-residential buildings, for each type we adopted different assumptions which allowed to assemble regional-scale exposure layers. Thus, the exposure layers for different countries have a different reliability, accounted in the matrix. Both commercial and industrial buildings were characterized based on data collected for countries considered similar (i.e., post-soviet European countries). Industrial buildings were distributed on OSM industrial areas which have a good coverage of the region. The procedure can introduce uncertainties in the buildings distribution, which can lead to discrepancies (and possible overestimation) with respect to the real industrial building presence. For this reason, the industrial buildings layer is associated with low reliability rating. Commercial buildings were distributed spatially using the population density as a proxy, but this procedure has a low reliability because it does not account for urban areas exclusively devoted to commercial activities (whose location is not available at the moment). In addition, local experts pointed out that in Central Asia a fraction of commercial buildings is usually located at the ground floor of multi-storey buildings. Future work should focus on refining commercial building distribution and including the mixed-use typologies in the exposure layers. As for hospitals, the low reliability in some countries is due to the discrepancies identified during the validation process. In the case of schools, the reliability is quite variable depending on the country. In Tajikistan and Turkmenistan, no information was available on the spatial location of schools. In the case of Kazakhstan and Uzbekistan, information was available on the location but not on the type of schools. The exposure layer for Kyrgyz Republic is considered reliable as it includes information on school typologies (e.g., occupancy, area, age) which were also used for the exposure development at regional scale. For most exposure characteristics, we provided the average value but also ranges that might be used in future exposure development and analyses. Also, national statistics on number of students were not available at national scale, nor where the number of schools of different types.

The consortium made all possible efforts to ensure effective communication, interaction and discussion between partners during all phases of exposure development (data collection, development of the methodology and validation). However, the exposure development would have benefit from in-person interactions which were unfortunately disrupted by the Covid-19 pandemic.

The exposure development results (including the spatial layers) provide the first comprehensive exposure layer and a starting point for future improvements based on a strong cooperation with local experts, practitioners and institutions.

5 Capacity building activities

The exposure development has been performed together with local partners who have a large experience in their respective countries. In particular, local experts were involved during the country-based capacity building workshops, which allowed identifying the main communities involved in the exposure development and the expertise that each country has in place.

Four of the five workshops planned during the project were held during the exposure development phase. These workshops were organized in strict cooperation with local partners who contributed by identifying the local experts to be invited to the workshops. Experts participated as speakers, providing an overview of the issues and capacities of the country. The workshops included lectures, tutorials and practical activities which showed how to assess the characteristics of exposed assets such as buildings, infrastructure and croplands. Participants had the chance to compile exercises which allowed assessing the characteristics of such assets based on expert judgment. Participatory mapping was also presented as a tool to develop and enhance the regional exposure database in future. Three out of five workshops were held during the data collection, and supported the identification of exposure data and expert knowledge available in the country. The fourth workshop was held during the exposure development phase, and the fifth workshop took place during the final phase of the exposure development. This partially restricted the possibilities in terms of collecting data useful for the exposure assessment and validation phase in Uzbekistan and Turkmenistan (where the last two workshop were held), but allowed discussing the potential use of the outcomes with more detail.

The country-capacity building activities carried out under this project, allowed identifying the main communities involved in the exposure development and the expertise that each country has in place. A panel discussion was organized at the end of each workshop, where the main issues, challenges and advantages of developing a regionally-consistent exposure database were discussed. Country-based workshops have therefore set the basis for including national-scale expertise, enhancing the exposure database and increasing local capacity. In addition, capacity building activities, such as those carried out during this project, can support the identification of priorities and possible synergies for future enhancement of the database developed within this assignment. The country-based capacity building activity will be described in detail in the Capacity Building report developed under this project.

6 Discussion and conclusions

During this project, we assembled the first comprehensive regional-scale exposure database for Central Asia. The database contains multiple layers for the considered exposed asset types:

- population
- residential buildings
- non-residential buildings (schools, healthcare facilities, industrial and commercial buildings)
- croplands
- transportation system (roads, railways and bridges)
- airports and airstrips
- mines
- supply infrastructure

The regional exposure database relies on the previous exposure assessments carried out in Central Asia. However, it introduces substantial improvements by including up-to-date local-scale data for each Central Asia country and by homogenizing these data into a single, regionally-consistent database. In particular, the exposure assessment allows to increase the spatial resolution of the previously existing exposure layers, comprise a large number of assets into a single and consistent regional dataset, and include exposure attributes that were not characterized prior to this project (e.g., country-based reconstruction costs).

Results of the exposure assessment show that the exposed assets in central Asia are distributed heterogeneously, with large differences between urban and rural areas. In particular, a large fraction of residential reconstruction costs is located in the main cities and urbanized areas. Exposed assets that belong to different business lines (e.g., transportation, supply) are distributed also in rural areas.

One of the challenges when developing such a comprehensive database is the difficulty of gathering data and combining different data sources together. The work presented here relies on the available global and regional-scale datasets, mostly provided by third-parties, which are paramount in order to collect exposure layers in a timely manner. To the extent possible, such data underwent specific validation procedures, made possible by the use of national and sub-national data and remote sensing images. The global and regional-scale datasets were substantially improved thanks to the large amount of country-based data provided by local partners. Such data were collected for each country in Central Asia as a result of an extensive effort, carried out in cooperation with the consortium partners in the region.

The potential of remote sensing tools was discussed during the whole exposure development process and in particular during country-based workshops. In particular, the primary role of remote sensing for developing exposure datasets was discussed, with specific examples of top-down approaches that allow inferring exposed assets characteristics based on remote-sensing products (e.g., aerial images). This was demonstrated with respect to buildings, infrastructure and croplands providing specific examples during lectures and tutorials. Finally, aerial images were used to complement the training activity (e.g., by providing images of selected target area for exposure development exercises). Remote sensing can therefore complement field-based surveys (e.g., building passportization) increasing the spatial coverage of exposure datasets.

In addition, some exposure variables can vary substantially in time and space. This is the case for reconstruction costs which are subjected to large variation but also spatial heterogeneity (e.g., between different provinces). As for non-residential buildings, often data is provided in aggregated form and needs to be disaggregated spatially based on proxies (e.g., population). Finally, supply infrastructure is undergoing major changes in Central Asia. Water supply, in particular, is increasingly important in Central Asia due to the intensive water use and increasing water scarcity (Sakal, 2015). The current water supply network is mostly outdated and inefficient, and is expected to undergo major improvements in future, also supported by international projects (e.g., World Bank project P162263). Also, the communication network has suffered a strong development in the last decades, with an increased demand for fast communication technologies. Priorities for future development of cross-border and regional communication channels are currently being discussed and will impact the development of future infrastructure (UNESCAP, 2020).

Central Asia is a very dynamic part of the world that is expected to undergo major changes at societal and governance level which will affect the type and distribution of exposed assets. In this work, we provided a projection for 2080 based on the combination of three SSPs defined for Central Asia (Pedde et al., 2019). The three selected scenarios envisage 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 show that, despite a general population decrease, a strong urbanization and economic growth is expected in Central Asia, in particular in Kyrgyz Republic, Tajikistan and Uzbekistan. This undoubtedly affects the exposure, increasing the reconstruction costs in urbanized areas. However, the uncertainties related to the projection of economic indicators to 2080 should be taken into account when using such projections for assessing risk. These projections are in fact intrinsically associated with a large uncertainty widely discussed in the academic literature (e.g., Dellink et al., 2017). Also, according to Dellink et al. (2017), despite the GDP is overall expected to grow at global scale, the GDP growth rates and income growth rates are expected to lower sometime between 2030 and 2040 for all SSPs. Thus, the GDP growth values do not necessarily provide a realistic economic growth indicator for the region. The proposed projections should be improved in the future by including national and regional strategies and development plans and by updating exposure layers accordingly. The projections might as well be complemented by urban simulation modeling for selected cities or Oblasts.

The regional-scale exposure database produced during this project can act as a starting point for current and future disaster risk mitigation activities devoted to reducing socio-economic and financial impacts of natural hazards in Central Asia. This work has been developed in strict cooperation and synergy between a large group of actors: the World Bank, the European and international partners of the consortium, including in particular local partners and institutions from all 5 Central Asia countries and the regional authorities (RSTC, CESDRR) in Central Asia. Such cooperation was paramount in order to carry out the exposure development activities and it is strongly envisaged to continue it in the future.

Appendix 1 – Data collected within the project

Table 45 contains the exposure datasets collected during the project. The data were collected both at broader scale (global/regional) and at national or sub-national level (e.g., Oblast). The data collection process has been characterized by a strong interaction and discussion between the local partners in each country (who coordinated the process) and the other members of the consortium. The report contains the references to the datasets and an explanation on how these data were retrieved and used.

Table 45. Exposure datasets collected during the project.

Category	Type	Global / Regional Data	National Or Sub-National Data				
			Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Buildings	Residential	Pittore et al., 2020;	Building census by material (for Oblasts and main cities) (Republic of Kazakhstan, Agency of the Republic of Kazakhstan on Statistics); Building typologies descriptions and pictures: residential buildings by age in each Oblast	Number of households for each Oblast (National Statistical Committee of the Kyrgyz Republic, data for 2020: http://www.stat.kg/); Building typologies descriptions and pictures: Building exposure available from geonode (https://geonode.caiag.kg/)	Sample of surveyed multistory buildings in Dushanbe (2500+ items) with information on material, presence of basement, age, etc. Building typologies descriptions and pictures; statistics of buildings by material in 8 main cities (IWPHE staff)	Number of households for each Oblast; Building construction period, storey number and floor area, for each EMCA sub-typology (pers.comm., local partners)	Building census by material (for Oblasts and main cities); Building typologies descriptions and pictures

	Commercial/Industrial	OpenStreetMap (https://www.openstreetmap.org)	National employment statistics (https://data.worldbank.org/indicator/)				
	Education	Schools number and location (https://projectconnect.unicef.org/map/countries)	Total number of schools in each Oblast (Bureau of National Statistics of the Republic of Kazakhstan, 2018); Schools location shapefile	School location shapefile; UNICEF school database with information on material and type; Number of schools in each Oblast: School material statistics	Number of schools in each city; Schools location collected from https://geonode.wfp.org	Total number of schools in each Oblast (pers-comm-, local partners)	Total number of schools in each Oblast (pers.comm., ISASUZ)
	Healthcare	Healthcare facilities database (https://www.healthsites.io/)	Total number of hospitals in each Oblast (Bureau of National Statistics of the Republic of Kazakhstan, 2018)	Number of hospitals in each city: Location available from geonode	Number of hospitals in each city	Total number of hospitals in each Oblast (pers-comm-, local partners)	Total number of hospitals in each Oblast (pers.comm., ISASUZ)
Population	Population and demographics	Worldpop (https://www.worldpop.org/); Facebook (https://data.humdata.org/organization/facebook)	Population, age and gender data for Oblasts and main cities (Bureau of National Statistics of the Republic of Kazakhstan, 2019; Electronic government egov.kz, 2020)	Population, age and gender data for Oblasts and main cities	Population total for main districts and cities (IWPHE staff).	Population and gender data for Oblasts and main cities (https://science.gov.tm; Statistical yearbook of Turkmenistan, 2019; data.un.org; USA. The Central Intelligence Agency (CIA). The World Factbook.	Population, age and gender data for Oblasts and main cities (pers.comm., ISASUZ)

						Central Asia. Turkmenistan, www.cia.gov; https://country meters.info)	
Agriculture	Crops	Global crop dominance ma (Teluguntla et al., 2015); Global land cover fraction (https://lcviewer.vito.be/download)	Wheat, cotton and total cereals area, yield production for each Oblast (Bureau of National Statistics of the Republic of Kazakhstan, data for 2020)	Wheat, cotton and total cereals area, yield and production for each Oblast	Agricultural area for each crop type in each district. Crops shapefile at district scale (pers.comm., WPHE staff)	cotton and total cereals area and production for each Oblast (pers-comm-, local partners)	Wheat, cotton and total cereals area. Yield and production for each Oblast (pers.comm., ISASUZ)
Transports	Roads and Railways	Openstreetmap database (https://www.openstreetmap.org)	Description of the transportation network and main highways/railways (IS staff)	Road maps collected from Caiag geonode (https://geonode.caiag.kg/)		Maps and description of road and railway network, (pers-comm-, local partners)	Map of main railroads, total length of railroads per type, railway classified by age of construction (TSTU)
	Airports	International airport database (World Bank); Global airport database (http://www.partow.net/miscellaneous/airportdatabase/index.html)					
	Oil-gas	Map of oil and gas pipelines (The Oxford Institute for Energy Studies, 2019)					
Infrastructure	Power generation and supply	Global power plant database (Byers et al., 2021); Global power grid (World Bank)	Power grid network (https://energydata.info/dataset/kazakhstan-electricity-transmission-network-2016)				Power grid network (https://energydata.info/dataset/uzbekistan-electricity-transmission-network-2016)
			Information from online sources (Global Water Partnership, 2009).				

	Water supply	Grand global dams database (Lehner et al., 2011, 2019); Aquastat database (Aquastat, 2013)				Map of main water supply network (pers.comm., local partners)	Map of main sewerage facilities in Uzbekistan (World Bank project - internal report)
Reconstruction Costs	Costs		Reconstruction costs for schools (IS staff), hospitals (Ministry of Health of the Republic of Kazakhstan), most building types (also by Oblast, Bureau of National Statistics of the Republic of Kazakhstan, 2020), transportation (energyprom.kz), oil-gas supply (IS staff)	Reconstruction costs for schools (gosstroy.gov.kg/ky/), hospitals (ISNASKR staff), most building types (elikta.kg, kargas.kg, fralgma-kg.com, imaratstroy.kg/), power plants (https://ekonomika.media/ulan-kyilyichbekov-v-kyirgyizstane-vyigodno-stroit-malyie-ges/ for mini-power plants) dams (http://mineconom.gov.kg/ru/direct/7/192/178)	Reconstruction costs for most building types and road types and for water supply (pers.comm., WPHE staff)	Reconstruction costs for schools, hospitals, most building types, transportation, water supply, oil-gas supply (pers.comm., local partners)	Reconstruction costs for schools, hospitals, most building types (pers.comm., ISASUZ): railway (including specific reconstruction costs for specific railway sections) (TSTU)
2080 Projections	Projections for selected SSPs	IIASA SSP database (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=html page page=about); Yuyu et al. (2019)					

Appendix 2 – Link between exposure and vulnerability

The exposure database has been developed in strict synergy with the staff working on vulnerability assessment. In particular, exposure typologies were selected in such a way that the buildings in each typology are expected to have a vulnerability to the effects of earthquakes and flood that is distinct to that of buildings in other typologies. This was possible thanks to the high amount of data collected by local partners in each country. However, the quality and resolution of the available exposure data are often higher for residential buildings with regards to non-residential buildings. In this case, general taxonomies were defined with 'unknown' material ('UNK' in the GEM taxonomy) but with an information on the percentage of the relative frequency of each building typology. For example, one industrial building typology was defined based on the combination of the EMCA typologies (Table 5) present in the industrial building dataset considered (Figure 8).

Table 46 shows the exposure typologies defined in this project for non-residential buildings, with a description of the relative fractions of each building typology. This procedure allows associating specific building typologies to single non-residential buildings, achieving the required spatial resolution for the exposure layers.

The percentages in Table 46 are then used to combine the vulnerability curves associated with each EMCA typology. For example, the vulnerability curve for a typical industrial building in Central Asia will be defined combining the curves produced for each EMCA typology with the percentages included in the first row of the table. The reader is referred to the specific report on Seismic Vulnerability for more information.

Table 46. Non-residential building typologies defined within this project.

Building type	Taxonomy	Description	Typology fractions
Industrial	IND_UNK+HBET:1:2	Defined as the weighted combination of the most common industrial taxonomies in post-soviet countries (see metadata for details)	31% EMCA1,25% EMCA2, 7% EMCA3, 4% EMCA5, 33% EMCA6
Commercial wholesale and services	UNK/ + HBET:1,6	Commercial wholesale and services – Defined as weighted combination of the most common commercial taxonomies in post-soviet countries (see metadata for details)	26% EMCA1, 37% EMCA2, 1% EMCA3, 36% EMCA5,
Commercial retail	UNK/ + HBET:1,5 + YBET:1930,2021		KAZ: 26%EMCA1, 35% EMCA4, 28% EMCA5, 9% EMCA6

		Commercial retail – Defined as the weighted combination of the most common residential taxonomies in each country (see metadata for details)	KYR: 31%EMCA1, 67% EMCA4,
			TAJ: 25% EMCA1, 72%EMCA4
			UZB: 84% EMCA1, 9% EMCA4
			TUR: 35% EMCA1, 57% EMCA4
Hospitals	UNK + HBET:1,16 + YBET:1956,2021	Hospitals – Defined as the weighted combination of EMCA2 and EMCA3 typologies	50% EMCA2, 50%EMCA3
Clinics	UNK/ + HBET:1,5 + YBET:1930,2021	Clinics – Defined as weighted combination of most common residential taxonomies in each country (see metadata for details)	KAZ: 26%EMCA1, 35% EMCA4, 28% EMCA5, 9% EMCA6
			KYR: 31%EMCA1, 67% EMCA4,
			TAJ: 25% EMCA1, 72%EMCA4
			UZB: 84% EMCA1, 9% EMCA4
			TUR: 35% EMCA1, 57% EMCA4
Other healthcare facilities	UNK/ + HBET:1,5 + YBET:1930,2021	Other healthcare facilities (dentist, doctor, pharmacy) – Defined as weighted combination of most common residential taxonomies in each country (see metadata for details)	KAZ: 26%EMCA1, 35% EMCA4, 28% EMCA5, 9% EMCA6
			KYR: 31%EMCA1, 67% EMCA4,
			TAJ: 25% EMCA1, 72%EMCA4
			UZB: 84% EMCA1, 9% EMCA4
			TUR: 35% EMCA1, 57% EMCA4
Urban schools	SCHOOL_URB_UNK + YBET:1960,2021	Urban schools – Defined as the weighted combination of most common urban school types in Central Asia	10% EMCA3, 90%URM (31% EMCA4 and the remaining EMCA1)

Rural schools	SCHOOL_RUR_UNK + YBET:1960,2021	Urban schools – Defined as the weighted combination of most common rural school types in Central Asia	22% EMCA3, 78% URM (22% EMCA4 and the remaining EMCA1)

Appendix 3 – Guidelines for using and modifying the exposure dataset

The regionally-consistent exposure database for Central Asia, described in this document will be delivered at the end of the exposure development phase. A companion document will contain the list of exposure layers included in the database. The exposure data will be structured following the GED4ALL format (https://wiki.openstreetmap.org/wiki/GED4ALL). Metadata will be also provided together with the data layers.

The exposure data and metadata will be made available via the World Bank Data Catalog (https://datacatalog.worldbank.org/home). The data will be also shared with the Center for Emergency Situations and Disaster Risk Reduction (CESDRR, https://cesdrr.org/en) and the Central Asia Regional Scientific and Technical Council (RSTC) members.

This appendix provides basic information on how to use and modify the exposure dataset. Actions might be required in order to maintain, enhance or update the exposure layers. This is envisaged in order to guarantee long-term sustainability of the project and to involve Central Asia regional, national and local institutions and experts into the exposure development process.

- How to query the database. There are mainly two ways to extract data from the exposure database. Data can be queried using a GIS interface, one of the most common being QGIS (https://www.qgis.org/en/site/), which is free of charge. Statistics can be performed on both vector (https://docs.qgis.org/2.8/en/docs/training_manual/vector_analysis/spatial_statistics.html) and raster (https://docs.qgis.org/3.4/en/docs/user_manual/processing_algs/qgis/rasteranalysis.html) layers and for specific areas. It is also possible to retrieve the attribute table of vector layers and to perform statistics directly on the table fields.

- How to edit the database. Exposure layers can be edited to modify the values or add new exposed assets with their specific characteristics. This can be done in two ways: using a GIS interface (e.g., the above mentioned QGIS) or retrieving the tabular data and modifying it locally. Layers can be modified in QGIS, in particular by editing the vector layer features or by adding new items (https://docs.qgis.org/2.8/en/docs/user_manual/working_with_vector/editing_geometry_attributes.html). New data should be added carefully, accounting for the metadata format (which includes specific information for example on the units) and the data constraints, in particular:

    - feature IDs should be unique
    - some specific fields should not be left empty (e.g., ID)

  - exposure taxonomy should be consistent with the one adopted for the layers (GED4ALL)
  - information on substantial changes should be included in the metadata

- How to improve the database. The exposure database can be enhanced by adding exposed assets or characteristics of existing features. The layer provided here includes the main exposed assets but their location and type can be updated (e.g., by adding if a pipeline is buried or not) or enhanced (e.g., by adding new railways that may be missing). During the exposure development, the use of bottom-up strategies involving local practitioners and communities was discussed. Local-scale data (e.g., buildings characteristics) can be collected using forms as discussed during the exposure development workshops. These activities can strongly contribute to enhancing the existing exposure layers and at the same time to increasing local capacity.

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Appendix A - List of acronyms

CAPS: Central Asian Power System

CESDRR: Center for Emergency Situations and Disaster Risk Reduction in Almaty

CIA: Central Intelligence Agency

CIESIN: Center for International Earth Science Information Network

CM: Confined Masonry

EMCA: Earthquake Model of Central Asia

EMS: European Macroseismic Scale

ERD: Earthquake-Resistant Design

ERIK: Enhancing Resilience in Kyrgyzstan (project)

ESCAP: Economic and Social Commission for Asia and the Pacific

EU: European Union

FAOSTAT: Food and Agriculture Organization Statistic

GBAO: Gorno-Badakhshan

GDP: Gross Domestic Product

GED4ALL: Global Exposure Database for all

GEM: Global Earthquake Model

GFDRR: Global Facility for Disaster Reduction and Recovery

GHSL: Global Human Settlement Layers

GIS: Geographic Information System

GRIP: Global Roads Inventory Project

GRUMP: Global Rural-Urban Mapping Project

HBET: Hydropower Biological Evaluation Toolset

IIASA: International Institute for Applied Systems Analysis

IS: Institute of Seismology

ISASUZ: Institute of Seismology of the Academy of Science of Uzbekistan

ISNASKR: Institute of Seismology of Kyrgyz Republic

IWPHE: Institute of Water Problems, Hydropower Engineering and Ecology

LBM: Load-Bearing Masonry

NACE: Statistical Classification of Economic Activities in the European Community (French: Nomenclature statistique des Activités économiques dans la Communauté Européenne)

OECD: Organisation for Economic Co-operation and Development

OSM: Open Street Map

OXIRM: Oxford Institute of Retail Management

QGIS: Quantum GIS

RC: Reinforced Concrete

RCPC: Reinforced Concrete Precast

RED: Risk Engineering + Development

RM: Reinforced Masonry

RSTC: Regional Scientific-Technical Council

SDGs: Sustainable Development Goals

SERA: European Seismic Risk Assessment

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

TSTU: Tashkent State Transport University (former TashIIT)

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

UNICEF: United Nations International Children's Emergency Fund

URM: Unreinforced Masonry

USA: United States of America

USD: United States Dollar

USGS: United States Geological Survey