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A new regionally consistent exposure database for Central Asia: population and residential buildings

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Abstract

Central Asia is highly exposed to a broad range of hazardous phenomena including earthquakes, floods and landslides, which have cause substantial damages in the past. However, disaster risk reduction strategies are still under development in the area. We provide a regional-scale exposure database for population and residential buildings based on existing information from previous exposure development efforts at regional and national scale. Such datasets are complemented with country-based data (e.g. building census, national statistics) collected by national representatives in each Central Asia country (Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, Uzbekistan). We also develop population and residential buildings exposure layers for the year 2080, which support the definition of disaster risk reduction strategies in the region.

Short summary (plain text)

Central Asia is highly exposed to multiple hazards, including earthquakes, floods and landslides, for which risk reduction strategies are currently under development. We provide a regional-scale database of assets at risk, including population and residential buildings, based on existing information and recent data collected for each Central Asia country. Population and number of buildings are also estimated for the year 2080 to support the definition of disaster risk reduction strategies.

1. Introduction

Central Asia is highly exposed to a broad range of hazardous phenomena including earthquakes, floods and landslides. Such disasters can affect single countries but often have trans-boundary consequences. In addition, disaster risk and subsequent losses are expected to increase under the effect of climate change (Yu et al., 2019). For these reasons, a regional-scale approach is needed to support, plan and coordinate Disaster Risk Reduction (DRR) strategies in the Central Asia region. Such approach should rely on evidence-based technical and scientific assessments of all elements that concur to risk. In particular, exposure plays a paramount role in disaster risk reduction by supporting the identification of the number and type of assets damaged or disrupted by hazardous phenomena (Pittore et al., 2017). For DRR purposes, it is particularly relevant to know the number and characteristics (e.g. demographics) of occupants to define mitigation measures (e.g. evacuation plans) and long-term preparedness programs (e.g. education activities). Knowledge on the typology and characteristics of residential buildings is also paramount in order to assess which buildings can suffer damages and the potentially harmed or

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stranded occupants. Finally, exposure layers provide a financial indicator on the exposed assets value, in particular buildings, to support regional disaster risk reduction and financial risk mitigation activities.

In Central Asia, strong efforts were devoted to assessing expected hazard and to estimating risk for specific hazardous phenomena (e.g. earthquakes). However, most risk assessment efforts were focused on single countries and hazards, such as during the project "Measuring Seismic Risk in Kyrgyz Republic", developed by World Bank in the period 2014-2017. During the EMCA project (Earthquake Model Central Asia, https://www.emca-gem.org/), a first important step was taken towards unifying hazard, exposure, vulnerability and risk assessment at the regional scale for Central Asia. However, the effort was focused on seismic risk, while less attention was devoted to assessing impacts of other hazardous (floods, landslides) at the regional scale. Flood hazard, nonetheless, has become increasingly relevant in Central Asia causing impacts that were often exacerbated by the difficulties of trans-boundary cooperation (e.g. concerning reservoirs' operation and maintenance, UNECE 2017). Following earthquakes and floods, landslides are the third most prevalent natural hazard in Central Asian (CACDRMI, 2009) and are often triggered by natural events such as earthquakes, floods, rainfall and snowmelt (Saponaro et al., 2014; Strom and Abdrakhmatov, 2017). The population of Central Asia is steadily growing and is expected to exceed the 100 million people by 2050, with a much higher growth rate than the world average (36.9% against 26.2%, https://www.eurasian-research.org/publication/un-population-prospects-case-of-central-asia/). The most populated country are Uzbekistan and Kazakhstan but population density is unevenly distributed in the region with almost 50% of the population concentrated in few densely populated cities (Seitz, 2019). Given the the wide range of impacts that might be caused by earthquakes, floods and landslides and their potential interaction beyond country boundaries, a regional-scale exposure database is nowadays of paramount importance. The only regional-scale exposure dataset of residential buildings available at the time (April 2023) is provided by Pittore et al., (2020) and relies on ground-based and remote sensing data in Kyrgyz Republic and Tajikistan (Wieland et al., 2012; 2015). The dataset provided by Pittore et al. (2020) was designed for the purpose of seismic risk assessment and has a variable spatial resolution, obtained by Voronoi tesselation, which is coarser in rural areas. For the purpose of flood and landslide risk assessment, the resolution had to be increased. In addition, reconstruction costs provided by Pittore et al., (2020) were derived based on costs obtained from specific studies developed on Kyrgyz republic (ARUP, 2016), but required additional validation based on more recent country-based data for all 5 countries of Central Asia. For these reasons, a regionally-consistent exposure dataset with latest information on population, residential buildings and associated reconstruction costs was needed. In this study, we assembled the first regionally consistent exposure database of population and residential buildings using the last available census of population and buildings and recent construction costs provided by local partners of the consortium in each of the 5 countries of Central Asia.

Exposure databases do not only support current risk assessment estimates, but can inform strategies for the mitigation of future risks, which might be exacerbated by long-term phenomena (e.g. climate change). This requires projecting the exposure to represent the future situation, e.g. at the end of the century. At the time, no future dataset of population and residential buildings are currently available for Central Asia. Shared Socio-economic Pathways (O'Neill et al., 2014) represent possible developments scenarios over a century timescale based on different economic, environmental and social policies. Here, we present the first exposure dataset for 2080 developed for three selected SSPs in order to support the definition of long-term disaster risk reduction strategies at the regional scale. Future urban area layers were developed at global scale for different SSPs developed specifically for Central Asia (Pedde et al., 2019). The work was developed within the SFRARR program ("Strengthening Financial Resilience and Accelerating Risk Reduction in Central Asia"), promoted by European Union, aims at leveraging all risk-related data and assessments in order to quantify financial disaster risk in Central Asia. The program focused on earthquakes, floods and landslides, and envisaged the creation of the first regionally-consistent exposure database for Central Asia.

2. Data collection

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The regional-scale exposure layers for Central Asia were developed based on data collected at two spatial scales: Global/regional and national/sub-national.

- Global/regional. Global and regional-scale data were collected from existing official sources and literature works, following the suggestions of international experts in the region, such as the Regional Scientific-Technical Council (RSTC), constituted in the framework of the EU SFRARR Program. In general, these databases have a large coverage, but often with lower spatial resolution. For the development of population exposure layers, the Facebook global dataset was retrieved for the year 2020, available at the Humanitarian Data Exchange webpage (https://data.humdata.org/organization/facebook). It contains the total population at 30-m resolution and the fraction of population by gender and age classes. As for residential buildings, the regional-scale layer of Pittore et al. (2020) is the most recent available exposure database for the region. The spatial distribution of urban and rural areas was retrieved from the Global Human Settlement Layers (JRC, 2021) at 1km resolution for the years 2000 and 2015. Spatial layers of expected urban area in 2080 under different SSPs were provided Chen et al. (2020) at 1 km resolution.

- National/sub-national scale. The data collection was performed by the exposure working group, constituted by contact persons for each of the 5 countries of Central Asia who collected data both from national ministries (e.g., census data) and from past projects carried out in their country. Local partners collected the population census for the latest year available (2021 for Uzbekistan, 2020 for Kazakhstan and Kyrgyz Republic, 2019 for Turkmenistan, and 2018 for Tajikistan). For two countries, Kazakhstan and Uzbekistan, information about the number of households by Oblast and load-bearing material was available. National and sub-national official data are usually provided by recognized institutions (e.g. national ministries) and have higher spatial resolution with respect to global or regional data. However, their availability is limited to some countries, such in the case of building census. In addition, local experts can provide additional data related to their judgment (e.g. expert opinion) which support the exposure development.

3. Methodology

The exposure assessment is based on the combination of data collected at two spatial scales: global/regional and national/sub-national. The underlying assumption is that recent country-based data (national or sub-national scale) are more reliable than global or regional layers. Based on these considerations, existing global/regional layers were complemented with national or sub-national scale, as described in the following subsections for population and residential buildings.

3.1 Development of population exposure layers

The population exposure layer was developed based on the Facebook high-resolution dataset (https://data.humdata.org/organization/facebook), which was enhanced using the country-based demographic information. Population data in the Facebook dataset, originally available at 20m resolution, was aggregated at 100m resolution and classified into three age intervals: population younger than 5 years old, older than 60 years old or in the intermediate age class. The Facebook data was then compared with national census data collected by local partners. This includes population data by age and gender in each country and sub-national administrative units (*oblasts*) extracted from the latest available national census (2021 for Uzbekistan, 2020 for Kazakhstan and Kyrgyz Republic, 2019 for Turkmenistan, and 2018 for Tajikistan). Differences on the total population exceeded the 20% in 7 o*blasts*. The estimated difference was then used to refine the Facebook dataset, under the assumption that country-based data are more reliable than regional datasets. The correction was performed on a cell-by-cell basis, and proportionally to the estimated difference between the two datasets. The same procedure was applied at the city scale to a number of cities in Kyrgyz Republic, Kazakhstan and Turkmenistan,

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for which population data were available. Gender and age percentages were also corrected with the exception of the elder fraction because the data at national scale was only available for different age thresholds (e.g., 70 for Kyrgyz Republic and Uzbekistan, 63 for Kazakhstan). The population layer was validated using data collected by local partners for specific cities. The final dataset was produced at a resolution of 100m.

3.2 Development of residential buildings exposure layers

The exposure assessment of residential buildings consists in defining dominant building typologies (codified by taxonomies). For residential buildings, pre-defined typologies were available from a previous project EMCA (The Earthquake Model Central Asia). Typologies were defined based on national-scale surveys in particular in Kyrgyz Republic and Tajikistan and extended to the entire Central Asia region (Wieland et al., 2015). EMCA typologies are described based on the Global Earthquake Model (GEM) building taxonomy (Brzev et al., 2013) In this work we updated the existing typologies with the information collected at national scale by local partners and their associated taxonomy (Table 1). In particular, country-based census were collected for Kazakhstan and Uzbekistan, for which the building census provided the number of buildings per typology aggregated at the *oblast* level. A correspondence was defined between the national census typologies and the ones in the EMCA classification based on the typologies description, pictures and input provided by local partners.

Table 1: Building typologies defined for residential buildings in Central Asia, based on the previous work of Wieland et al., (2015) and Pittore et al., (2020). Each EMCA typology and sub-typology is associated with age and storey number (expressed in ranges), average floor area, number of households and average occupancy. The taxonomy in the GEM format (Brzev et al., 2013) is also provided.

Typology	**Sub-typology**	**Age**	**Storey number**	**Floor area (m^2)**	**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		190	/CR + CIP/LDUAL + DNO/FC/HBET:4,9 + YBET:1957,2021
	RC3	1957-2021	2-5	1500		152	/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	5000			/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 +

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							YPRE:2021
	WOOD2	<1980	1-2	150			/W+ WLI/LO + DUC/FW/HBET:1
EMCA6	STEEL	n.a.	1	2000	1	3.8	/S/LFM +DNO/FME/HBET:1

The spatial distribution of building typologies was derived from the layer provided by Pittore et al., (2020) which collects all the previous information generated by the EMCA project. The original layer has a variable resolution ranging from a few hundred meters in urban areas to several km in rural areas and was developed specifically for earthquake risk assessment purposes. The spatial resolution was increased to produce a residential buildings exposure layer on a 500-m-resolution grid and support risk assessment for flood hazard. The procedure, exemplified in Fig. 1 for Kazakhstan. comprised three main steps:

- Each cell of the variable-resolution layer was identified as urban or rural based on the 2015 Global Human Settlement Layers layer (JRC, 2021). GHSL cells associated with a city code were classified as urban, while urbanized areas without city code, which correspond to villages, were assumed to be rural. Each urban/rural area was associated with a distribution of EMCA building typologies, provided by Wieland et al. (2015) for each Central Asia country.
- The collected country-based information for Kazakhstan and Uzbekistan was integrated in the layer of Pittore et al. (2020) maintaining its original spatial resolution. The number of buildings in each EMCA typology was distributed on the variable-resolution grid, using the total population in each cell (included in the layer of Pittore et al., 2020) as a proxy. The procedure was performed for each EMCA typology and accounted for the different building types distribution in urban and rural areas identified in the previous step.
- Distribution of residential buildings on a regular grid of 500m. This was done in two steps: first, the buildings in each variable-resolution cell were distributed on on a new, regular grid of 30-m resolution based on the Facebook population layer. Population density in the 30-m layer was therefore used as a proxy of the buildings presence. The final residential buildings exposure layer was assembled by aggregating the values at 500-m resolution.

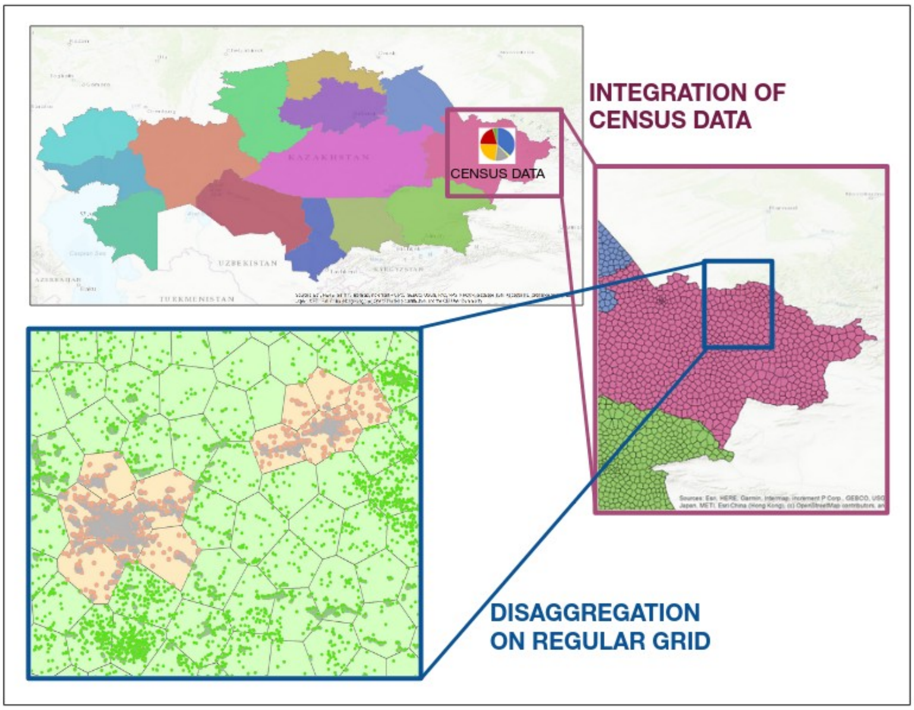

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Fig.1: Methodology for obtaining the exposure layer of residential buildings at 500-m resolution, exemplified for Kazakhstan. First, the existing exposure layer of Pittore et al., (2020) is integrated with country-based information provided by local partners for each Oblast. Secondly, the information is disaggregated on a regular 500-m grid. The different distribution of building typologies in urban and rural areas was accounted for following Wieland et al., 2015. Background map data extracted from OpenStreetMap are available from https://www.openstreetmap.org (Openstreetmap contributors, 2023) under the Open Data Commons Open Database License (ODbL)

Reconstruction costs were defined based on country-based values provided by local partners for each building typology. Costs were provided in USD/m2 or, when provided in local currency, converted following the conversion rate at the time of the calculation (Fall 2021). 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.
- In the case of Turkmenistan, where costs were provided per unit of volume, we converted into 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, we harmonized costs making sure that the relative costs ratio between less costly construction (e.g. URM) and more expensive ones (e.g. RC frames or shear walls) are reasonable. In particular, the costs ratio between EMCA2 and EMCA1 (averaged across the two sub-typologies) does not exceed the value of 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.
Table 2 shows the residential building typologies and the country-based costs. For the case of EMCA1, given the strong differences between URM and CM/RM, two sub-typologies were identified. Reconstruction costs are referred here to the structural cost, while the content costs were estimated as 50% of the building structural cost, following the procedure described in the HAZUS inventory technical manual (2021).g dife Costs for each building unit are then found by multiplying the average reconstruction cost by the average building area for each typology, similarly to ARUP (2016).

Table 2: Country-based reconstruction costs expressed in USD/m2 for each building typology and sub-typology in Central Asia.

		Reconstruction cost (USD/m2)				
Typology	Sub-typology	Kazakhstan	Kyrgyz Republic	Tajikistan	Uzbekistan	Turkmenistan
EMCA1	URM1, URM2	190	175	175	175	105
	CM, RM-M, RM-L	300	300	300	285	150
EMCA2	RC1,2,3,4	570	400	425	400	180
EMCA3	RCPC1,2	425	425	425	400	180
EMCA5	WOOD1,2	330	330	177.5	300	648
EMCA4	ADO	125	125	125	190	125

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EMCA6	STEEL	175	175	175	175	175

Residential buildings exposure layers were validated for each country based on data provided by local partners for specific cities. Such data were not used in the development of the exposure layer because they only contained the total number of households, but not the building types. Differences were lower for Kyrgyz Republic and Tajikistan (which are the countries where Pittore et al., 2020 deployed most field surveys), and larger in Uzbekistan for which the country-based building census showed largest discrepancies with the previously available information. A comparison of the fraction of building types was made for the city of Ashgabat (Turkmenistan), for which the approximate percentage of buildings of each type was available. The 65% of buildings are constituted by load-bearing masonry, while a 35% is reinforced concrete (pre-case or cast in situ). The comparison with the exposure dataset developed here shows a good agreement with differences smaller than 5% between building fractions.

3.3 Development of exposure layers for 2080

Exposure layers for 2080 were developed based on 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, unequal investments and economic disparities and exploitation of fossil fuels together with increased energy consumption (SSP1, SSP4 and SSP5, respectively). The projected exposure layers are developed starting from the population and residential buildings' exposure layers developed in this work (2.1 and 2.2).
The projected population is then estimated by decreasing/increasing the population according to the future population trends expected under each scenario. Expected population trends were extracted from the IIASA SSP database (https://tntcat.iiasa.ac.at/SspDb/dsd?Action=html page page=about) which provide country-based indicators based on the studies of Dellink et al. (2017), Crespo Cuaresma (2017) and Samir et al. (2019). According to these studies, the population is expected to decrease between 3 up to more than 50%, with the exception of Tajikistan where, for SSP4 scenario, population is expected to increase. In order to obtain the projected population layer, the country-based increase or decrease was applied on a cell-by-cell basis to the total population value, maintaining constant the gender and age fractions.
Despite the expected population decrease, Central Area is expected to undergo a progressive urbanization, associated with a strong GDP increase (see IIASA SSP database for details). Urbanization is also assumed to be associated with a modification of building typologies, with the progressive substitution of deprecated building types in favor of modern ones. The projected residential buildings layer is thus developed by modifying the number and typology of buildings. This process was simulated using simple rules, defined based on expert judgment provided by practitioners during 5 country-based capacity building workshops organized in Central Asia (Peresan et al., this volume). In particular, unreinforced masonry and adobe buildings will be progressively replaced with modern masonry houses (in particular, low-rise family houses). As for new multi-family apartments, they are expected to be both reinforced concrete frames or wall type buildings, but with high level of earthquake-resistant design (RC3 and RCPC2, Table 1). Wood buildings are expected to be constructed with modern techniques (WOOD2, Table 1), while steel buildings are assumed to remain unvaried. The conversion between the number of old and new buildings was performed using conversion factors (Table 3), obtained as the ratio between the occupants per square meters in the new and the old building type. The occupants per square meter for each typology are computed based on the average building area (Table 1). 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 same replacement rules were adopted in the whole region. Buildings reconstruction costs are maintained constant and equal to the ones in the current exposure layer. Estimating the costs in 2080 equivalent to the current ones would be associated to a large uncertainty, given the large variability of inflation rates in the region, and could lead to unrealistic values.

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Table 3: Conversion factors between the number of old and new EMCA building types and sub-typologies (column 1 and 4, respectively), characterized by different occupation values, used to develop the 2080 residential buildings exposure layers.

Current exposure layer			**2080 Exposure layer**			**Conversion factor**
Current building type	**Average occupants per building**	**Average occupants per square meter**	**2080 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

The exposed value of residential buildings Central Asia is therefore expected to vary due to the population variation and the progressive buildings replacement. The calculation is done in each point of 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 conversion factors. The calculation was performed making sure that the population and residential buildings values in the projected database is realistic and, in particular, that no points were associated with negative population.

The modification of the building stock is assumed to happen only in areas which are expected to be urban by 2080, while no changes are applied to the building stock in rural areas. Urban areas in 2080 were identified based on the urban development trends provided by Chen et al. (2020) under the three different SSPs. Current urban areas were extracted from the GHSL dataset (JRC, 2021) for the latest available year (2015). The dataset comprises 7 classes that were simplified into three main ones: rural, sub-urban (which includes sub-urban and peri-urban areas) and dense urban areas. Comparing sub-urban and urban areas in 2015 with the ones for 2080, we identified areas which, under the three different SSPs, are expected to be urban in 2080. This includes areas that were already classified as urban in 2015, but also areas that are expected to become so between 2015 and 2080.

4. Results

4.1 Population exposure

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Figure 2 shows the population layer produced at 100m resolution at regional scale for an urbanized area in Aqtöbe (Kazakhstan). In each point of the grid, the total population and the number of men, women, elder and young population (over 60 and under 5 years old, respectively) are provided. Total values were also computed for each country and Oblast.

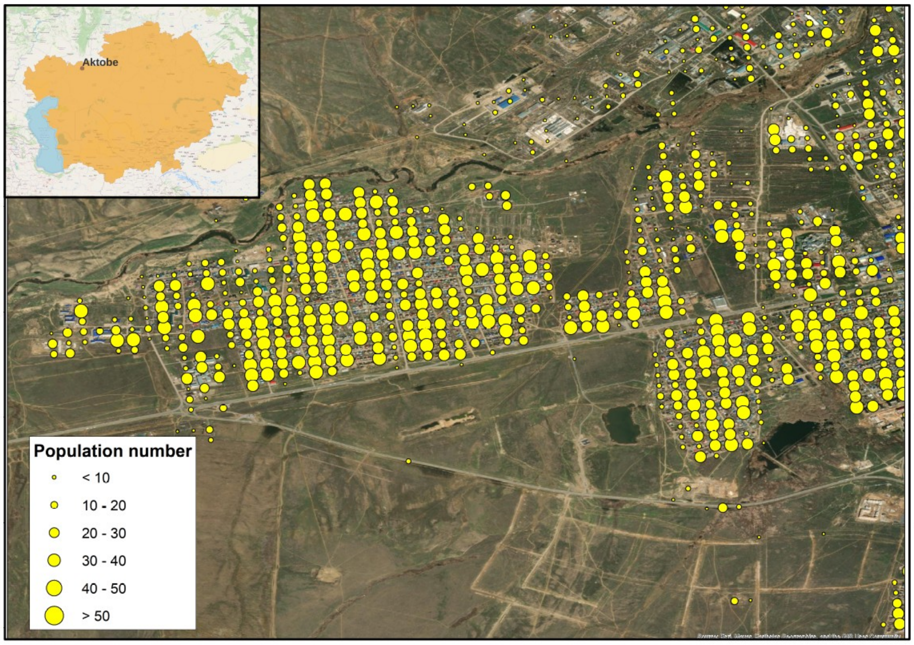

Figure 2: Example of the population layer produced at 100m resolution for a selected area in the town of Aqtöbe in Kazakhstan. The figure shows an urbanized area with different uses (industrial, in the top of the image, residential, in the center of the image, and rural with low or null population density). Background map data extracted from OpenStreetMap are available from https://www.openstreetmap.org (Openstreetmap contributors, 2023) under the Open Data Commons Open Database License (ODbL)

4.2 Residential buildings exposure

Fig. 3 shows the spatial distribution of one sub-typology of the EMCA1 typology (Table 1), the unreinforced masonry (URM). Map shows the spatial distribution of buildings in the entire Central Asia region and for one selected study area, at 500-m resolution. Similar maps can be produced for other building typologies.

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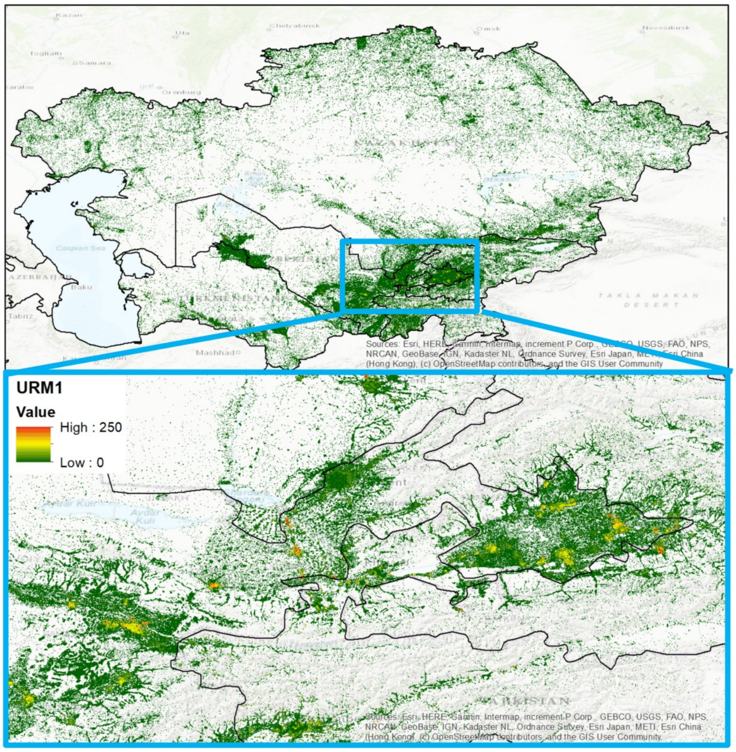

Figure 3. Number of buildings in each 500-m cell belonging to one sub-typology of EMCA1 (unreinforced masonry, URM1, see Table 1) in the entire Central Asian region (top) and on a selected area (bottom). Map data from OpenStreetMap available from https://www.openstreetmap.org (Openstreetmap contributors, 2023) under the Open Data Commons Open Database License (ODbL)

Table 4 provides the total number of exposed buildings per typology and country and their associated structural cost expressed in Billion USD. The total structural cost of residential buildings in Central Asia is of approximately 1,200 Billion USD, and the higher fraction is associated with Uzbekistan and Kazakhstan (the 62 and 29%, respectively).

Table 4. Total number of residential buildings in each EMCA typology and the total structural cost for each country and 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	356
Kyrgyz Republic	592,637	196,419	2,647	4,216	384,169	4,702	467	35
Tajikistan	844,336	218,439	2,226	10,939	607,539	4,582	599	58
Uzbekistan	5,708,009	4,790,954	64,795	122,579	567,415	145,899	16,330	773
Turkmenistan	280,358	97,760	10,357	6,989	158,785	5,887	567	20
Central Asia	9,804,432	5,917,768	121,056	179,966	2,539,521	830,239	215,656	1,242

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315 Figure 4 shows the structural reconstruction cost fraction of building typologies in the 5 considered countries. The greatest contribution to the total costs comes from EMCA1 (Masonry) followed by EMCA3 (Precast reinforced concrete) in all countries.

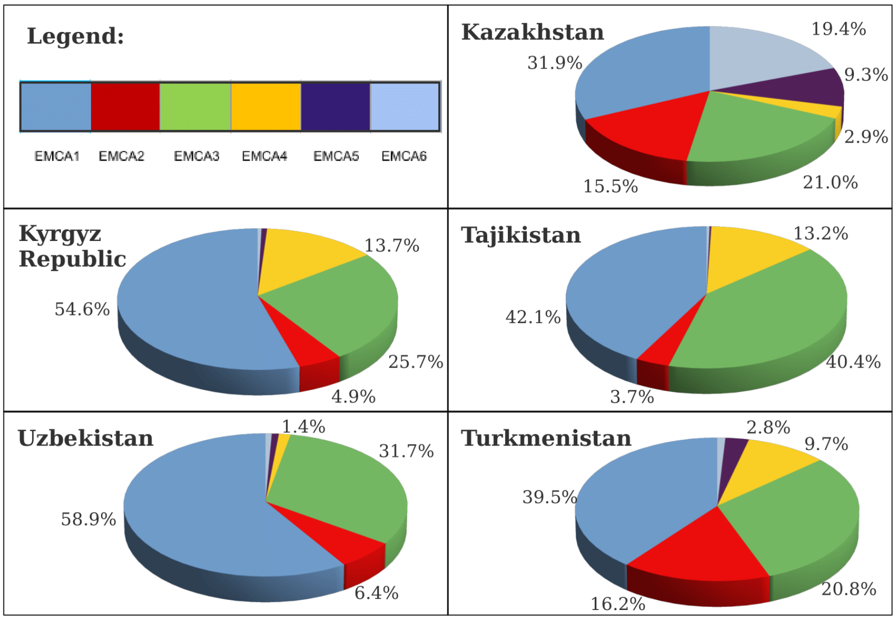

Figure 4: Fraction of reconstruction costs (expressed in percentage of the total reconstruction costs) associated with each building typology (EMCA 1 to 6) in the 5 Central Asia countries.

320 **4.3 Exposure layers for 2080**

Table 5 provides the total projected buildings number and the associated reconstruction costs for 2080 and the % variation (total and per capita) with respect to the layer developed for the present time (2021). Figure 5 shows the percentage cost variation with respect to the current total reconstruction costs for each considered scenario. Costs are expected to decrease for Kazakhstan and Uzbekistan and increase in Kyrgyz Republic and Turkmenistan. Kyrgyz Republic and Tajikistan show
325 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 countries and 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).

330 **Table 5.** Total residential buildings and expected percentage variation (columns 3 and 4, respectively) and total reconstruction costs estimated for 2080 and expected reconstruction cost % variation between 2080 and current exposure layer, total and per capita (column 5, 6 and 7, respectively). Values are shown for the three considered SSPs.

Country	Scenario	Total buildings	Building number % variation	Reconstruction costs in 2080 (Billion USD)	Reconstruction costs (% variation)	Reconstruction costs per capita (% variation)
Kazakhsta	SSP1	2,110,243	-11.3	330	-5.7	-2.8

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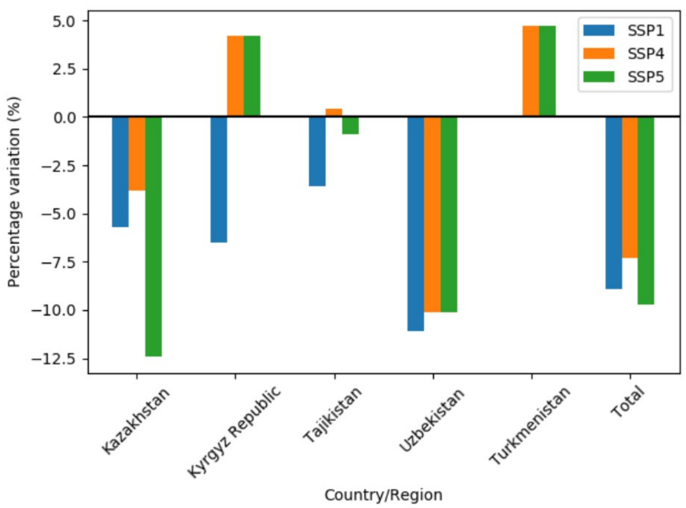
n	SSP4	2,111,560	-11.2	336.4	-3.9	5.6
	SSP5	2,116,377	-11.0	306.7	-12.4	-10.6
Kyrgyz Republic	SSP1	524,066	-11.6	29	-6.5	11.4
	SSP4	525,312	-11.4	32.3	4.2	28.6
	SSP5	525,805	-11.3	32.3	4.2	51.0
Tajikistan	SSP1	790,097	-6.4	54	-3.6	25.2
	SSP4	799,681	-5.3	56.2	0.4	-20.4
	SSP5	784,708	-7.1	55.5	-0.9	125.2
Uzbekistan	SSP1	4,230,863	-25.9	681	-11.1	3.4
	SSP4	4,256,952	-25.4	688.3	-10.1	9.6
	SSP5	4,264,616	-25.3	688.7	-10.1	19.9
Turkmenistan	SSP1	266,390	-5.0	19	0	12.4
	SSP4	266,305	-5.0	19.9	4.7	24.7
	SSP5	267,064	-4.7	19.9	4.7	26.2
Central Asia	SSP1	7,921,659	-19.2	1113	-8.9	3.8
	SSP4	7,959,810	-18.8	1133.1	-7.3	3.3
	SSP5	7,958,570	-18.8	1103.1	-9.7	17.1



335 **Figure 5:** Buildings reconstruction cost variation (expressed in percentage variation with respect to the reconstruction cost in the current exposure layer) estimated for each considered scenario (SSP1, SSP4 and SSP5).

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5. Discussion

The regionally-consistent exposure database presented here is based on the combination of global and regional layers and data collected at national and sub-national scale. Performing a regionally-consistent exposure development requires the harmonization of the exposed assets characteristics, which might vary within the study area. There are nonetheless several challenges associated with the definition of a regionally-consistent exposure database, in particular related to the scattered and inhomogeneous information available (e.g. different time coverage or spatial resolution for the 5 countries in the region). In this work we tried to achieve an optimum balance between the different data availability and reliability, in order to grasp the differences and peculiarities of the 5 countries. Population layers were developed at 100m resolution while residential buildings were aggregated at 500m resolution. Both layers can be resampled for the purpose of more specific analyses, but this should be done carefully and integrating specific information which might become available in the future. Final data, together with metadata and description, is provided in the GED4All format (Global Exposure Database for Multi-Hazard Risk Analysis, Silva et al., 2018) developed by the Global Facility for Disaster Reduction and Recovery (GFDRR) in order to supports risk analyses.

With regards to population and buildings data, further efforts should be devoted to identify procedures to automatically collect and update census data, reducing the effort of in presence surveying. In addition, our analysis does not account for many aspects, such as night-day occupation patterns and socio-economic exposure, which can be included in future in the analysis (e.g. Freire and Aubrecht, 2012). Note that this information is already envisaged in the GED4All taxonomy but scarcely available for many areas at risk worldwide.

As for residential buildings, common but broad typologies were defined, also based on previous projects, so that they are valid across the entire region. Such typologies are associated with sub-typologies that can be analyzed further in the future. In addition, emerging building typologies should be also included (e.g. new type of constructions based on lightweight insulated panels). The fraction of building typologies within the building stock was extracted from national census, when available. However, some census only provided the number of households, and required converting them into buildings, assuming an equivalent number of households per building type. In addition, building typologies are defined by different classes in country-based census (e.g., some distinguish between material of walls and of the load-bearing structure, other don't). The process of combining different census can nonetheless lead to discrepancies. Finally, sub-typologies can be quite different in the Central Asia countries due to multiple factors, including different constructive tradition, climatic zone and other cultural aspects, that should be taken into account in future work. For this reason, a common protocol of data collection could be extremely beneficial both for single countries and for regional-scale approaches.

Despite the overall generalization required to develop a regional-scale exposure database, relevant differences were maintained using country-based buildings reconstruction costs. A comparison with costs provided by ARUP (2016) for Kyrgyz Republic shows that costs of EMCA1, 2 and 3 are quite similar but reconstruction costs of other typologies such as timber and steel have varied, which is probably due to the variations suffered by the raw material price. This is the first attempt to collect construction costs for each of the 5 countries of Central Asia, but any financial assessment should be carried out based on detailed and updated information. As for content costs, they were estimated following the HAZUS methodology as a function of the structural cost of each building typology. HAZUS is widely adopted and, in absence of region- or country-specific data on content costs, was assumed to be applicable to Central Asia.

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 development of such projections is based on a number of assumptions, the main ones being that the population decrease us assumed to happen homogeneously in each country, that the renovation of building stock follows the same rules in all urban areas of Central Asia and that reconstruction costs do not vary. This results in a simple projection that does not account for the complex dynamics behind socio-economic development. The uncertainties related to the projection of economic indicators to 2080 should be taken into account when using such projections for assessing risk. These

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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 therefore 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 dataset of population and residential buildings provided here can support further analyses on the expected damages and risks caused by hazardous phenomena such as earthquakes and floods. Residential buildings are very relevant for disaster risk reduction as they host a large fraction of population, in particular during night time, and are responsible of a large fraction of life losses during earthquakes. Also from the financial point of view, a comparison between the exposed value of residential building with respect to other building types (commercial, industrial, healthcare and educational) shows that residential buildings account for the largest fraction (between 47% and 76%) of reconstruction cost of all building types. The 2080 layers, if opportunely contextualized, could provide additional inputs to defining risk mitigation strategies to deprecate vulnerable residential building typologies.

The work presented here relies on assumptions that are needed in order top produce results at the regional scale. In particular, country-based data are paramount in order to enhance the regional-scale datasets with the specific characteristics of exposed assets. In addition to official data sources, experts opinion was collected on a number of aspects for which data were not available or incomplete. For example, they provided information on census building typologies and their correspondence with EMCA typologies and on their construction costs. They also informed on which building typologies are being gradually replaced in the building stock, supporting the development of future exposure layers. This was made possible by the organization of 5 country-based exposure workshops (Peresan et al., this volume) which enhanced the interaction with local experts, practitioners and representatives of governments. Interactions with local experts are indispensable in order to identify, gather and interpret correctly the different data sources that concur to the development of reliable exposure layers.

6. Conclusions

This work produces the first regionally-consistent exposure database of population and residential buildings in Central Asia. Results of the exposure assessment show that the residential buildings in central Asia are distributed heterogeneously, with large differences between urban and rural areas. We also assessed the value of exposed buildings in Central Asia in terms of reconstruction costs, of which a large fraction is located in Uzbekistan and Kazakhstan which are the larger and more populated countries. The 2080 exposure projections show that, despite a general population decrease, a strong urbanization and economic growth is expected in Central Asia, with subsequent increase of the reconstruction cost per capita. 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 physical, socio-economic and financial impacts of natural hazards in Central Asia.

Data Availability

Facebook population data is available at https://data.humdata.org/organization/facebook. The regional-scale layer of Pittore et al. (2020) is available at https://github.com/GFZ-Centre-for-Early-Warning/EMCA-Exposure. The Global Human Settlement Layers are available at https://ghsl.jrc.ec.europa.eu/ at 1km resolution for the years 2000 and 2015. Spatial layers of expected urban area in 2080 under different SSPs (Gao and O'Neill, 2020) and are available at https://dataverse.harvard.edu/dataverse/geospatial_human_dimensions_data. The spatial layers of exposure for population, residential buildings and 2080 projections developed in this work will be made available at the World Bank data portal (https://datacatalog.worldbank.org) together with the technical reports produced during the SFRARR project. Data are associated with metadata following the Ged4ALL system (http://riskdatalibrary.org/resources).

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Author contribution

CS, AT, EF developed the exposure assessment methodology, and CS and AT carried out the analyses. All co-authors contributed to the data collection and to the discussion of results. CS prepared the manuscript with contributions from all co-authors.

Competing interests

The authors declare that they have no conflict of interest.

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