Development of a Building Inventory and Vulnerability Database for Pakistan

Syed Tariq Maqsood[1] and Jochen Schwarz[2]

1. Corresponding Author. Research Associate. Earthquake Damage Analysis Center, Bauhaus-University Weimar, 99423, Germany
   E-Mail: tariq.maqsood@uni-weimar.de

2. Head of Earthquake Damage Analysis Center, Bauhaus-University Weimar, 99423, Germany
   E-Mail: schwarz@uni-weimar.de

Abstract

Pakistan has experienced several devastating earthquakes resulting in a large number of casualties and building damage. During the last six years, two damaging earthquakes struck different parts of the country, i.e., 2005 Kashmir earthquake and 2008 Baluchistan earthquake. They have provided an opportunity to assess building performance under strong earthquakes, and have informed the development of a building inventory database.

A comprehensive and accurate database of building inventory is a crucial part of an earthquake risk assessment methodology and appropriate definition of building classification leads to a more accurate attribution of building vulnerability. For the present study area in Pakistan, typical building types are identified and a detailed database of the building inventory has been compiled for the country. The distribution of typical building types in all tehsils (administrative regions) of the country has been mapped in a Geographical Information System (GIS) environment.

The developed database has been validated in six field surveys, carried in selected cities of Pakistan. Results from these field surveys demonstrated the damage cases and identified the damage contributing parameters along with type of failure mechanisms which were observed in the above mentioned events.

The study presented here provides useful data layers for earthquake risk assessment at a national level in Pakistan and has a close relation with the recent developments in the field of earthquake risk assessment, i.e., USGS's Prompt Assessment of Global Earthquakes for Response (PAGER) and the Global Earthquake Model (GEM).

Keywords: building types, vulnerability, building damage, casualties

1. INTRODUCTION

In order to assess the consequences of an earthquake on the building stock, it is essential to know the predominant building types and their performance in past earthquakes, the prevalent local construction practices and the distribution in the study area. It is evident from the past two earthquakes in Pakistan that the existence of vulnerable buildings in high seismic zones resulted in great human losses.

This paper concentrates on presenting the description of typical building types and their vulnerability in Pakistan and their distribution across the country along with population characteristics which are the major elements exposed to earthquake shaking. Each data layer is examined in terms of the collection of data and analysis of the relevant information for the territory of Pakistan.

2. TYPICAL BUILDING TYPES

As an outcome of several field surveys, typical building types constructed in Pakistan are identified, which are adobe, stone masonry, concrete block masonry, brick masonry and timber. Reinforced concrete structures are only constructed in big cities and their percentage is quite small as compared to other building types. A description of primary, secondary and tertiary elements is provided for each building type in Table 1.

Table 1: Description of typical building types (Maqsood and Schwarz, 2008a)

Type	Elements		Description
Adobe Structure	Primary	Adobe walls	Low strength adobe walls are used which normally don't have any vertical wooden post.
	Secondary	Adobe walls	No additional system such as crown beam or pilasters is provided to restrain the out of plane failure.
	Tertiary	Wooden and straw roof	Wooden beams with heavy mud roof and straw are used
Stone Masonry Structure	Primary	Simple or rubble stone masonry walls	Simple or rubble stone masonry walls are normally used in lean cement sand mortar, often with mud mortar and sometimes even without any mortar.
	Secondary	Simple or rubble stone walls & wooden vertical post, if provided	The walls don't have a proper connection among the stone layers. The walls are normally without any vertical post but occasionally wooden posts are also provided.
	Tertiary	Wooden/mud roof	Wooden beams with heavy mud roof and straw are used
Concrete Block Masonry Structure (Confined and Unconfined)	Primary	Concrete block masonry walls	Low to medium quality concrete blocks with compressive strength of about 5-6 MPa are used. Generally cement sand mortar of 1:8 ratio is used for this type of building. The dimension of the block is 300mm x 150mm x 150mm
	Secondary	Simple or rubble stone masonry walls & wooden vertical post, if provided	Concrete block masonry walls resist the lateral loads. Lintel beams are provided over the openings of doors and windows but generally they do not run continuously throughout the perimeter. Ring or connecting beams between roof and masonry walls are rarely provided. In some constructions, concrete or wooden posts are provided for lateral load resistance.
	Tertiary	Cement or GI sheet roof	The roof slab is made of cement or GI sheets which normally has a low weight. Sometimes a 150 mm thick RC slab is also used.

Table 1: Description of typical building types (cont.)

Type	Elements		Description
Brick Masonry Structure (Confined and Unconfined)	Primary	Solid burnt brick walls	Good quality clay brick bricks with compressive strength of about 8 MPa are used. Generally cement sand mortar of 1:6 ratio is used for this type of building. The dimension of the brick is. 230mm x 115mm x 75mm
	Secondary	Solid burnt brick walls with lintel beams. Ring beams & vertical concrete or wooden post, if provided	Solid burnt brick walls resist the lateral loads. Lintel beams are provided over the openings of doors and windows but generally they do not run continuously throughout the perimeter. Ring or connecting beams between roof and masonry walls are rarely provided. In some constructions, concrete or wooden posts are provided for lateral load resistance.
	Tertiary	Reinforced concrete roof slab	The roof slab is made of reinforced concrete having compressive strength of 20 MPa and 150mm thickness. The mixed ratio of concrete is 1:2:4.
Reinforced Concrete Frame Structure	Primary	RC beams & columns	Reinforced concrete frame structures are generally constructed only in urban areas. These are not designed for earthquake loads normally and most of the old structures were designed only for gravity loadings.
	Secondary	Masonry infill walls	Masonry walls are provided to fill the frames and no provisions are provided to isolate them from the RC frame. Hence are used to enhance the stiffness of the structure.
	Tertiary	RC roof slab	150 mm RC slab is provided with mix ratio of 1:2:4.
Timber Structure	Primary	Timber frame: with infills	Timber frames, placed in longitudinal and traverse directions, are filled with masonry walls. Most of the buildings are found to be rectangular in shape.
	Secondary	Timber frame: with infills	Timber frames, placed in longitudinal and traverse directions, are filled with masonry walls.
	Tertiary	Wooden and mud roof	The floor structure is made of timber planks. The roofing material is usually light when it is made from galvanized iron sheets. Timber planks with heavy mud roof & straw are also used as a roof.

2.1. Building Statistics

Building statistics were obtained from the 1998 national census conducted by the Population Census Organization, Government of Pakistan (PCO, 1998) to derive the typical building types and its composition throughout the country (see Table 2). The geographical distribution of each building type is presented at tehsil level (administrative unit) in a GIS format for the whole country as shown in Figure 1.

Table 2: Distribution of building types in Pakistan - in percentage (Maqsood and Schwarz, 2010c)

Region	Rural areas					Urban areas				
	Adobe	Stone masonry	Block masonry	Brick masonry	Timber	Adobe	Stone masonry	Block masonry	Brick masonry	Timber
N.W.F.P.	42.6	34.6	8.5	11.8	2.5	25.3	21.6	12.6	39.2	1.3
F.A.T.A.	59.1	32.8	2.8	3.1	2.2	64.4	11.7	8.1	14.9	0.9
Punjab	40.8	35.1	10.7	12.6	0.8	9.6	34.3	12.4	43.2	0.5
Sindh	55.8	0.0	12.1	6.4	25.7	11.4	3.2	32.2	50.6	2.6
Baluchistan	77.8	4.9	2.6	1.4	13.3	54.2	0.0	17.7	20.2	7.9
Pakistan	46.8	25.5	10.0	10.4	7.3	12.8	20.7	19.7	45.3	1.5

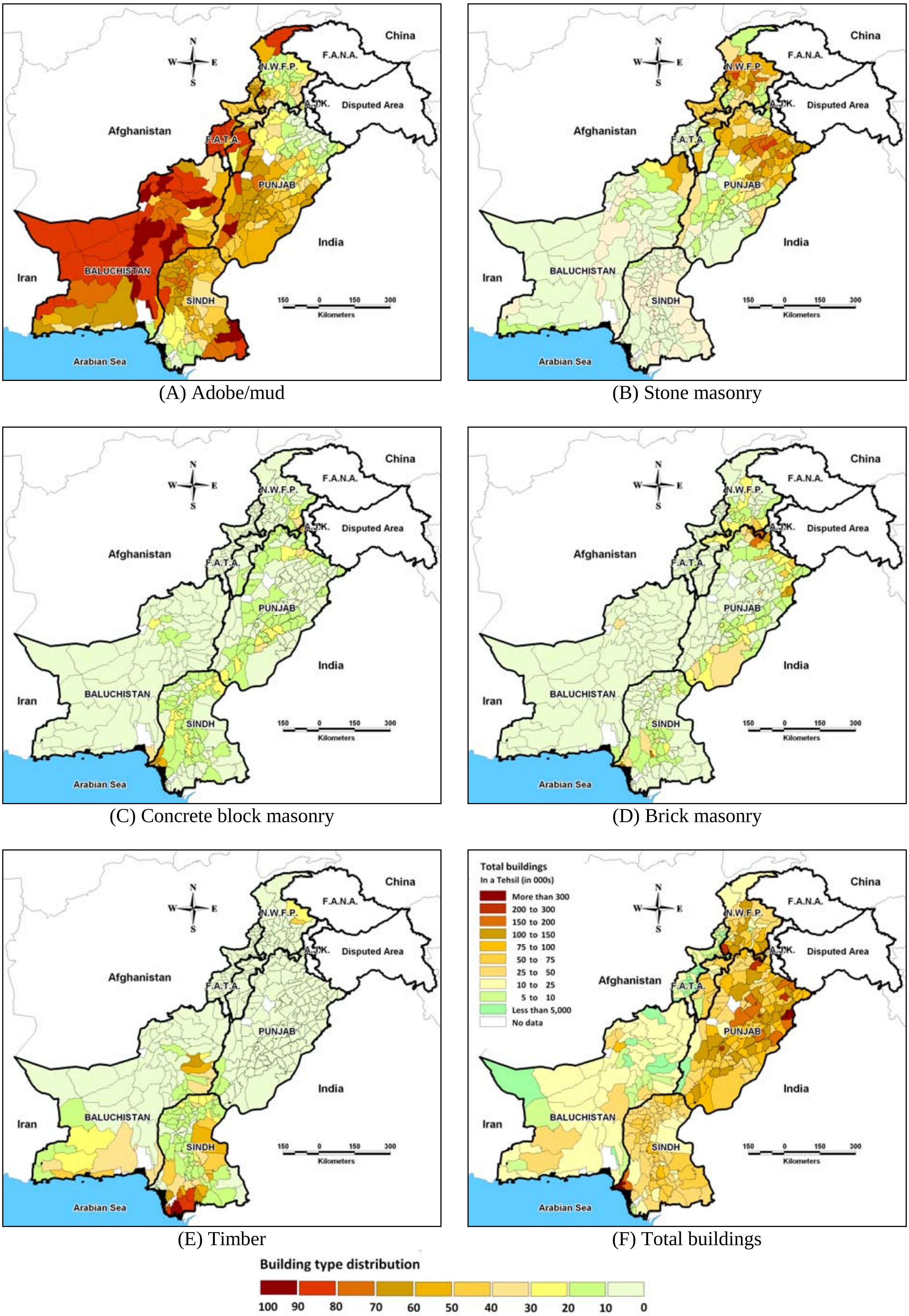


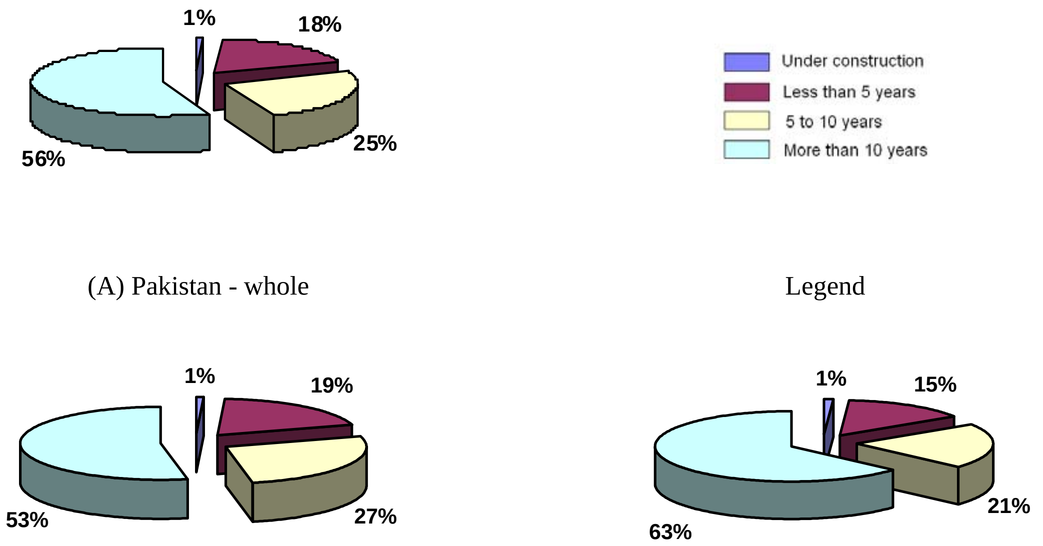
Figure 1: Building type distribution in Pakistan (Maqsood and Schwarz, 2008b)

It has been observed that in Baluchistan province, the majority of buildings are made of adobe or mud. Stone masonry is widely used in northern part of Pakistan, e.g. NWFP and Punjab provinces. Concrete block masonry is found to be used in majority in northern area but also common in central and south Pakistan. Brick masonry is used in urban areas of Pakistan while timber structure is more common in rural areas. It is to be pointed out that reinforced concrete frame structures are built only in urban areas. The percentage of these structures is very less as compared to other types and hence incorporated in brick masonry structures.

After the 2005 Kashmir earthquake, the use of confined masonry is becoming more common. Reinforced concrete members are used both in concrete block masonry and in brick masonry structures for the purpose of confinement (Maqsood and Schwarz, 2010a). The building authorities in the affected area have made the use of confinement mandatory for new construction.

2.2. Construction period

Pakistan has seen a rapid growth in building construction in last two decades due to growth of population and improved economic conditions. That is why, according to 1998 Census, the major part of building stock is relatively new as shown in Figure 2, where about 44% of structures are less than 10 year old. During the last couple of years, concrete block and brick masonry structures are being built in urban areas, and as mentioned above, the use of confined masonry is also becoming popular especially in the affected areas of 2005 Kashmir earthquake. However, in rural areas, adobe/mud structures are found in abundance and are being built despite its high vulnerability. The enforcement of building code regulations in Pakistan has been quite poor and no quality control procedures were followed prior to the 2005 earthquake resulting in low quality and highly vulnerable building stock. However, after the 2005 earthquake, a new building code has been prepared which is supposed to be implemented in newer construction.



(A) Pakistan - whole

Legend

(B) Pakistan - rural areas

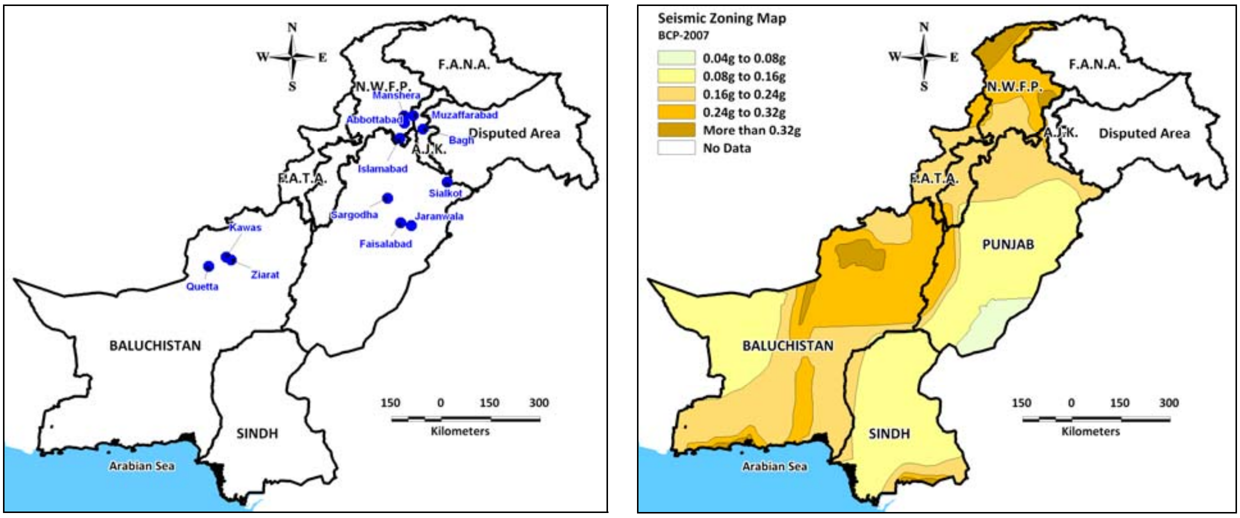
(C) Pakistan - urban areas

Figure 2: Age of Building stock in Pakistan (source: PCO, 1998)

3. STRUCTURAL VULNERABILITY

For the structural vulnerability assessment, the methodology of European Macroseismic Scale – 1998 (Grünthal et al. 1998) is followed, where, for a set of structural types, a most likely vulnerability class with probable and less probable ranges is defined. A solid line shows a probable range (a few strengths or weaknesses will allow the building to be classed within this range) and a dotted line shows the range in extreme cases (many strengths that are particularly remarkable or weaknesses that are very severe, allow the building to be classed within this range). The methodology has been implemented in several risk studies successfully (Abrahamczyk et al. 2008; Schwarz et al. 2008; Langhammer et al. 2006; Schwarz et al. 2005).

Furthermore, building surveys were carried out in several cities of Pakistan to determine how well Pakistani building types correspond to the standard structural types of the EMS-98. The surveyed locations are shown in Figure 3A. The locations were selected by keeping in view the seismic hazard presented by (BCP, 2007) as shown in Figure 3B, building type composition, population distribution, available resources and urban/rural settings.



(A) Selected test areas in Pakistan (B) Seismic zoning map of Pakistan (BCP, 2007)

Figure 3: Test areas and seismic zoning map of Pakistan

The Proforma used in the field surveys includes the parameters like type of usage (residential, commercial, industrial), building shape (rectangular, L-shaped, T-shaped, U-shaped), wall material (adobe, stones, concrete blocks, bricks, timber), roof material (reinforced concrete, metal sheets, timber), building position with respect to surroundings (corner, middle, free), building age and typical vulnerability class.

Table 3: Results of field surveys

Area	**No. of building surveyed**	**Type (%)**		**No. of Storey (%)**				**EMS-98 Vulnerability Class (%)**			
		Resi-dential	**Comm-ercial**	**One**	**Two**	**Three**	**Four**	**A**	**B**	**C**	**D**
Muzaffarabad	749	69	31	43	47	8	2	9	68	20	3
Islamabad	110	88	12	46	54	0	0	5	54	41	0
Jaranwala	53	89	11	47	53	0	0	50	48	2	0
Sialkot Urban	72	89	11	49	51	0	0	38	51	11	0
Sialkot Rural	38	84	16	45	55	0	0	63	37	0	0
Sargodha	104	91	9	98	2	0	0	57	40	3	0
Bagh	141	35	65	62	38	0	0	33	34	30	3

Table 4: Typical building types in Pakistan and their vulnerability class (Maqsood and Schwarz, 2008b)

Building Type	**EMS-98 Vulnerability Class**						**Built in**
	A	**B**	**C**	**D**	**E**	**F**	
Adobe	○						R
Stone Masonry	|——	—○					R
Unconfined Concrete Block Masonry	|——	—○					R
Confined Concrete Block Masonry		|——	—○·····	·····|			R+U
Unconfined Brick Masonry		|——	—○				R+U
Confined Brick Masonry		|——	—○·····	·····|			U
Reinforced Concrete Frames	|······	···——	—○·····	·····|			U
Timber Structures		|······	······——	——○			R

R: Rural U: Urban ○ Most likely vulnerability class ········ Less probable range ——— Probable range

In addition, parameters like soft storey, large openings, quality and workmanship, geometrical and structural regularity (in plan or in elevation), state of preservation and the level of earthquake resistant design were also noted to assess the structural vulnerability. The city of Muzaffarabad was surveyed at micro level, i.e., almost each building was surveyed in the city, while other cities were surveyed at macro level, i.e., some selected numbers of buildings were surveyed randomly in the city. Some of the results of the surveys are presented in Table 3.

Moreover, typical structural failure mechanisms were recorded during the damage surveys after the 2005 Kashmir earthquake and the 2008 Baluchistan earthquake. Further details of these surveys are provided by Maqsood and Schwarz, 2008a and Maqsood and Schwarz, 2010b. From the observations during the six field surveys conducted between 2005 and 2010, an appropriate vulnerability class for the Pakistani building stock has been defined with probable ranges by taking into account the local construction practices (see Table 4).

4. POPULATION CHARACTERISTICS

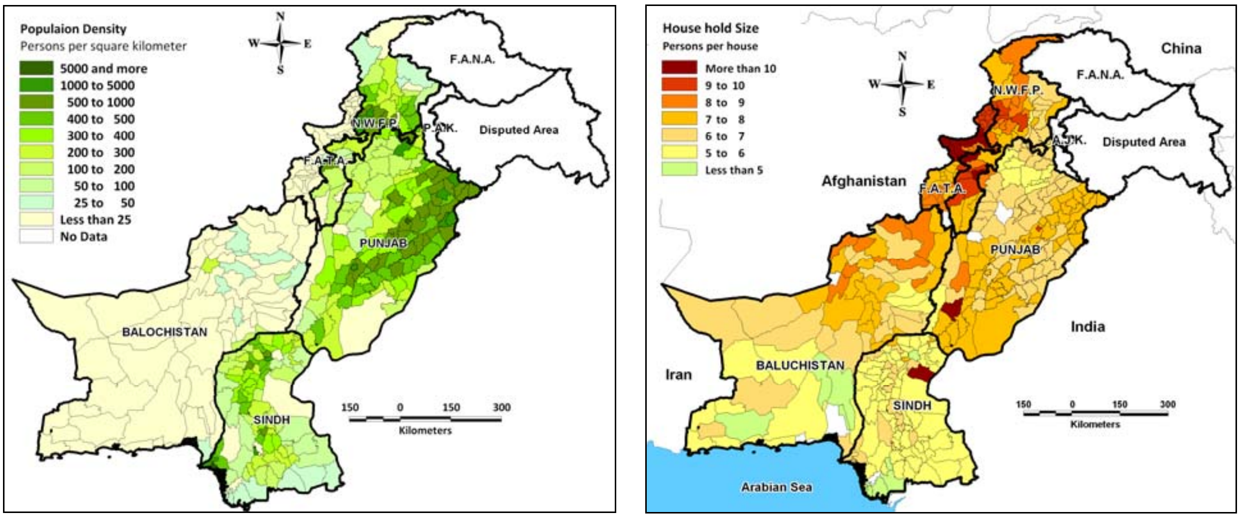
Pakistan's estimated population in 2011 is over 177 million, making it the world's sixth most-populous country (PCO, 2011). According to the last census carried out in 1998 by the Population Census Organization, Government of Pakistan, more than 42% of the population in Pakistan is less than 15 years old which indicates a higher level of social vulnerability in case of earthquakes (Maqsood and Schwarz, 2011).

Table 5 presents the population density distribution in different provinces in Pakistan along with household size. It can be seen that the largest province of Pakistan by area is Baluchistan, however, at the same time it is the lowest populated province. The majority of the population lives in rural areas where the living facilities are not in good condition. The rural areas are less developed and most people who live there are economically poor. This economic poverty has a strong impact on the vulnerability of structures as they cannot afford expensive construction materials of even moderate quality, and therefore, the majority of structures in these areas are made of adobe/mud or stone masonry (Maqsood and Schwarz, 2010b).

Table 5: Population distribution in Pakistan according to 1998 Census (source: PCO, 1998)

Administrative Unit	**Area (km^2)**	**1998 Population**				
		Total Population	**Rural (%)**	**Urban (%)**	**Population density (Persons/km^2)**	**Ave. Household Size**
NWFP	74,521	17,743,645	83.1	16.9	238	8.0
FATA	27,220	3,176,331	97.3	2.7	117	9.3
Punjab	205,345	73,621,290	68.7	31.3	358	6.9
Sindh	140,914	30,439,893	51.2	48.8	216	6.0
Baluchistan	347,190	6,565,885	76.1	23.9	19	6.7
Pakistan	**796,096**	**132,352,279**	**67.5**	**32.5**	**166**	**6.8**

Pakistan has diverse characteristics with regard to population density (see Figure 4A), which ranges from less than 25 (in Baluchistan province) to more than 5000 (in Punjab province) persons per square kilometres across the country. Similarly, the household size varies from one to more than ten according to the last national census of 1998 (see Figure 4B). The large household size is found to be a critical parameter in the severity of an earthquake in terms of human casualties as the occupancy rate would be significantly higher as compared to small household size community (Maqsood and Schwarz, 2011).



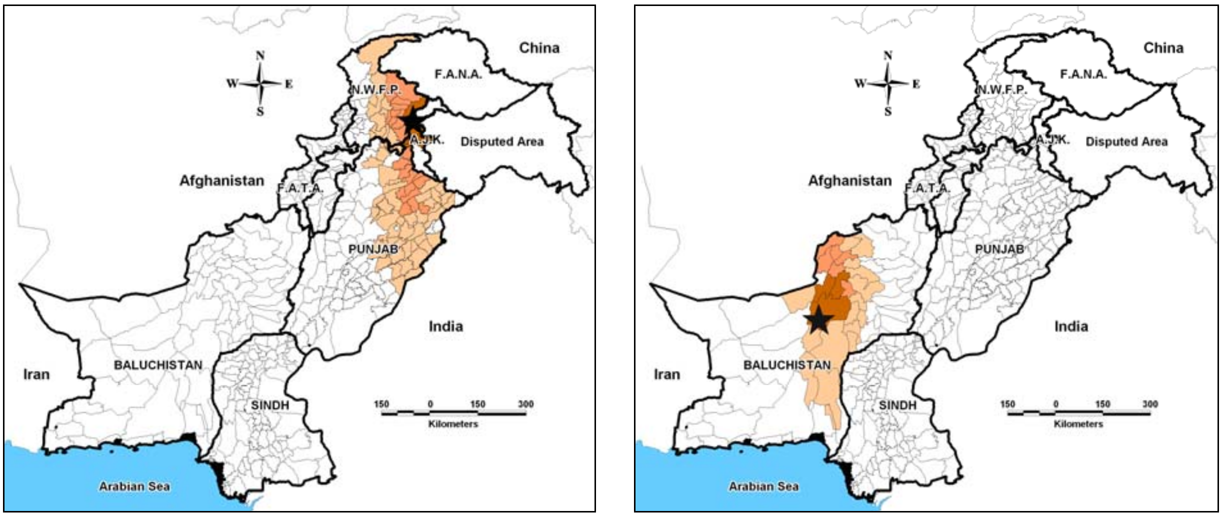
(A) Population density in tehsils of Pakistan (B) Household size in tehsils of Pakistan

Figure 4: Population density and household size distribution in Pakistan (source: PCO, 1998)

5. DISCUSSION

The paper provided an overview of the key data layers for earthquake risk assessment, i.e., inventory of building stock, its structural vulnerability and characteristics of the population in Pakistan.

Structural vulnerability plays a critical role at a regional seismic risk level which provides the estimates of the number of damaged buildings in a specific scenario. It is observed during the field surveys that the majority of building stock in Pakistan is made of adobe and masonry structures. The resistance of these building types to earthquake loading is low and they are vulnerable to damage in any moderate to severe earthquake, as seen in 1935 Quetta earthquake, 2005 Kashmir earthquake and 2008 Baluchistan earthquake.



(A) EMS Intensity IX scenario – Northern Pakistan (B) EMS Intensity IX scenario – Western Pakistan

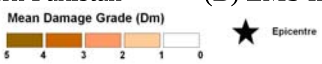


Figure 5: Damage prognosis for selected scenarios (Maqsood and Schwarz, 2010c)

Results of an EMS-98 Intensity IX damage scenario presented by Maqsood and Schwarz (2010c) illustrate that vast destruction in terms of building damage is likely to happen if it occurs in northern or south-western part of Pakistan (see Figure 5).

Such estimations are essential for disaster planning and development of risk reduction policies. Thus, preparedness and mitigation plans should be made on a major scale concentrating on the high risk regions/tehsils of Pakistan with a large proportion of adobe/mud and stone masonry structures in order to reduce earthquake vulnerability and associated risk.

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