Multi-hazard approach to assess vulnerability of the building stock in Pakistan

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SUMMARY
Pakistan is situated in one of the highest seismic zones of the world, where northern and south western Pakistan could expect a PGA of 0.4g or more, with the 1935 Quetta earthquake and the 2005 Kashmir earthquake the most devastating earthquakes in the country. Furthermore, recently Pakistan has suffered from severe flood events in 2010 and 2011. Recent experiences in the above mentioned events emphasize the need for a multi-hazard approach to assess the vulnerability of typical building types in Pakistan. An effort is made to generate a new multi-hazard zoning map of Pakistan combining the earthquake and flood hazards. Damage scenarios are developed for both earthquake and flood. The damage scenarios indicate the high structural vulnerability of building stock, mainly due to presence of large proportion of adobe or mud structures. These results are useful for the authorities to take necessary actions to mitigate the risk in the future.

Key words: earthquake, flood, multi-hazard, vulnerability, adobe

1. INTRODUCTION

Pakistan is divided in-to the following provinces: Punjab, Sindh, Baluchistan, Khyber Pakhtunkhwa and territories: Islamabad capital territory, Gilgit Baltistan, Federally Administrated Tribal Area (FATA), and Azad Jammu Kashmir (AJK). These provinces are further divided in to administrative units called districts. Pakistan has suffered from some major natural hazards in the last decade including the 2005 Kashmir earthquake, floods in 2010 and 2011, which resulted in enormous damages to both property and human life.

For the first time in Pakistan, major efforts were initiated after the 2005 Kashmir earthquake to evaluate the seismic vulnerability of existing building stock against earthquake. Several field surveys were conducted by the Earthquake Damage Analysis Center (EDAC) Bauhaus-Universität Weimar, Germany, to define typical building types in Pakistan and to observe damages/failure mechanisms of buildings caused by the 2005 Kashmir earthquake. The European Macroseismic Scale-98 (EMS-98) was used to define typical building types in Pakistan and their vulnerability by taking in to account local construction practices and material properties. Moreover, geostatistical extrapolation was carried out using the statistical data of the 1998 national census from the Government of Pakistan.

Recent floods in 2010 and 2011 were the most devastating floods in the history of Pakistan, and it emphasizes that although earthquakes are a major hazard in Pakistan, considering one hazard at a time for vulnerability calculations of the existing building stock is not sufficient. So, it is the need of the hour to use a multi hazard approach. Methodologies have been developed at the Earthquake Damage Analysis Center (EDAC) Bauhaus-Universität Weimar, Germany for conducting damage scenarios for both earthquake and flood hazards. These methodologies (see also Schwarz and Maiwald, 2012) will be used in an adaptive way for a multi-hazard approach for Pakistan considering both earthquakes and floods.

2. SINGLE-HAZARD ZONING MAPS OF PAKISTAN

2.1. Seismic zoning map of Pakistan

According to the Building Code of Pakistan (Seismic Provisions 2007), Pakistan is divided in-to five seismic zones (Zone 1, 2A, 2B, 3 and 4) considering the severity of seismic hazard. Fig. 2.1 shows the seismic zoning map of Pakistan. Zone 1 is the lowest seismic zone and zone 4 is the highest seismic zone. It is evident from the seismic zoning map that the northern parts of Pakistan as well as the north western parts of Baluchistan are situated in high seismic zones, whereas most parts of Punjab and Sindh provinces are situated in low seismic zones. The epicenters of some of the major earthquakes in Pakistan and the study area for this paper (district Dadu) are shown in Fig. 2.2.

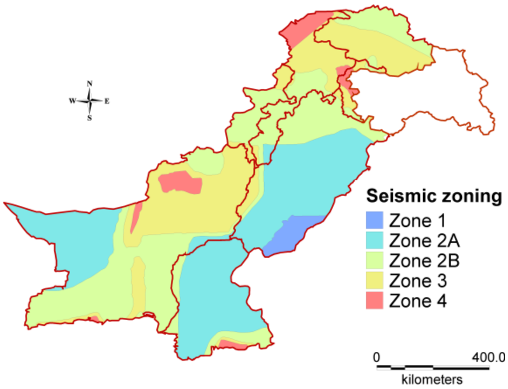

Figure 2.1. Seismic zoning map of Pakistan

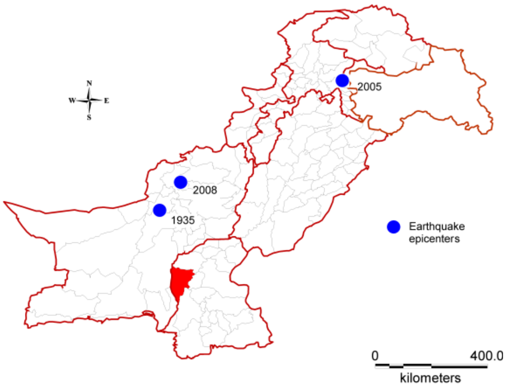

Figure 2.2. Location of Dadu district and epicenters of historically major earthquakes in Pakistan

2.2. Flood hazard maps of Pakistan

Pakistan has suffered from floods in past, but most recent floods in 2010 and 2011 were highly destructive. According to the National Disaster Management Authority (NDMA) website, 78 districts were flooded in the 2010 flood. Fig. 2.3 shows the map with locations of all the flood affected districts of Pakistan. It is clear from the map that severely affected districts are mostly located in Khyber Pakhtunkhwa, Punjab and Sindh provinces. During the 2011 flood, almost the whole Sindh province was flooded (see Fig. 2.4).

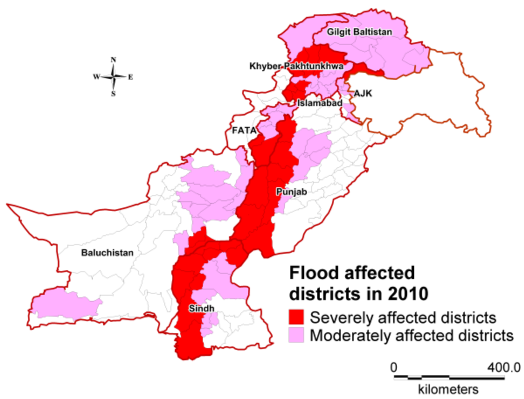

Figure 2.3. Flood affected districts in 2010

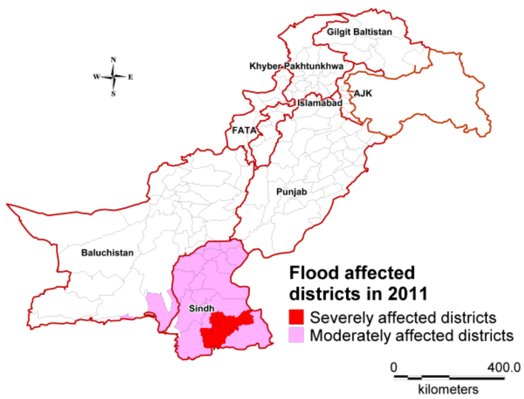

Figure 2.4. Flood affected districts in 2011

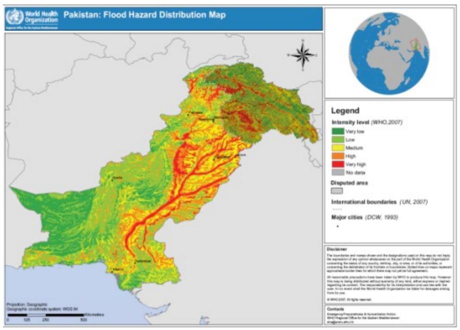

Figure 2.5. Flood hazard distribution map (http://reliefweb.int/node/17289)

Fig. 2.5 shows the flood hazard distribution map according to the World Health Organization. It shows five intensity levels of the flood hazard all over Pakistan. The 2010 flood was triggered due to heavy monsoon rainfalls in the northern parts of Pakistan. The eastern rivers in Punjab province were mainly unaffected in 2010 and 2011, but historically there have been huge floods in these rivers too. During the 1992 monsoon season there were heavy rain falls, which resulted in huge flooding in most of Pakistan.

3. MULTI-HAZARD ZONING MAP OF PAKISTAN

3.1. Procedure

An effort is made to generate a new zoning map of Pakistan combining the earthquake and flood hazards. Fig. 3.1 shows the flow chart of a multi-hazard zoning map. There are five well-defined zones for earthquake hazard in the seismic zoning map of Pakistan. A flood hazard distribution map prepared by the World Health Organization (WHO) indicates five intensity levels for flood. For simplification purposes, only three zones for flood are chosen which are: low, medium and high. Then a correlation is developed of these zones with the information from the latest floods in 2010 and 2011. The districts which were severely affected by flood are categorized as zone 3 (high zone), the moderately affected districts are categorized as zone 2 (medium zone) and similarly the districts not affected by flood are categorized as zone 1 (low zone, see Table 3.1). A combined flood hazard map is generated, merging the two event based flood hazard maps (flood in 2010 and 2011) and a general flood hazard map from the World Health Organization (see also Fig. 3.2). From earthquake hazard point of view, five zones are there which are joined with combined flood hazard zones. This leads to a multi-hazard zoning map of 15 possible zones (see also Fig. 3.3).

Two types of hazards are defined namely "flood" and "earthquake" (abbreviated as F and E respectively), along with three intensity levels for flood as: low, medium and high (abbreviated as l, m and h respectively) and five intensity levels for earthquake as: very low, low, medium, high and very high (abbreviated as vl, l , m , h and vh).

Table 3.1. Legend and classification of multi-hazard zoning map

<table>
<tr><td colspan="2" rowspan="2">Flood
Earthquake</td><td>Low</td><td>Medium</td><td>High</td><td>Low</td><td>Medium</td><td>High</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Hazard</td><td>Zones</td><td colspan="3">Multi-hazard map zoning</td><td colspan="3">Classification</td></tr>
<tr><td>Very low</td><td>1</td><td>FlEvl</td><td>FmEvl</td><td>FhEvl</td><td rowspan="2">NHDA</td><td colspan="2" rowspan="2">FHDA</td></tr>
<tr><td>Low</td><td>2A</td><td>FlEl</td><td>FmEl</td><td>FhEl</td></tr>
<tr><td>Medium</td><td>2B</td><td>FlEm</td><td>FmEm</td><td>FhEm</td><td rowspan="3">EHDA</td><td colspan="2" rowspan="3">CHDA</td></tr>
<tr><td>High</td><td>3</td><td>FlEh</td><td>FmEh</td><td>FhEh</td></tr>
<tr><td>Very high</td><td>4</td><td>FlEvh</td><td>FmEvh</td><td>FhEvh</td></tr>
</table>

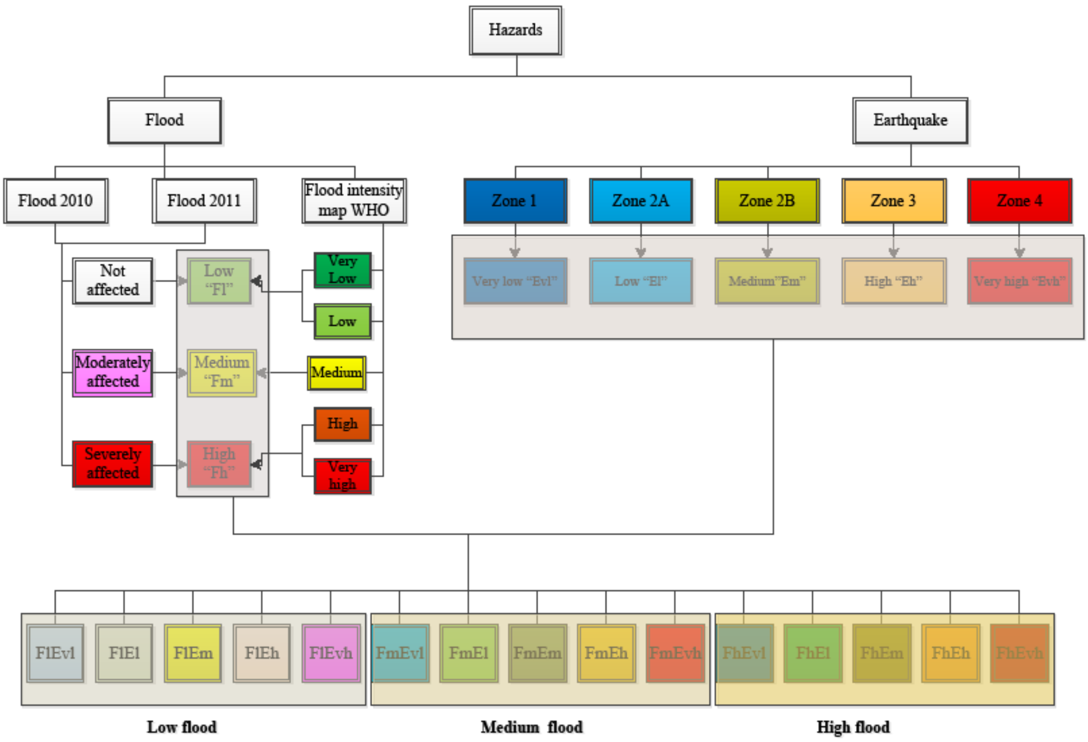

Figure 3.1. Flow chart of multi hazard zoning

To make a combined hazards zoning map (shown in Fig 3.3), a raster having a grid spacing of 10 km is selected. Each grid element is assigned the appropriate multi-hazard zone. Due to use of a square mesh of 10 km size, there are small errors in defining boundaries of the districts and boundaries of different seismic zones. These errors can be reduced by selecting a smaller grid size.

3.2. Classification of multi-hazard zoning map

The multi hazard zoning map is further classified in to four groups, Earthquake Hazard Dominated Areas (EHDA), Flood Hazard Dominated Areas (FHDA), Combined Hazard Dominated Areas (CHDA) and No Hazard Dominated Areas (NHDA) (see Table 3.1). These classifications show that flood hazard is dominated in Punjab and Sindh province, whereas Khyber pakhunkhwa, Gilgit baltistan, FATA and AJK provinces are prone to both hazards. Earthquake hazard is dominant in most of Baluchistan province; also no hazard dominated area is located in Baluchistan province. Fig. 3.4 shows the complete map with all the classifications and Fig. 3.5 to 3.8 show each category separately.

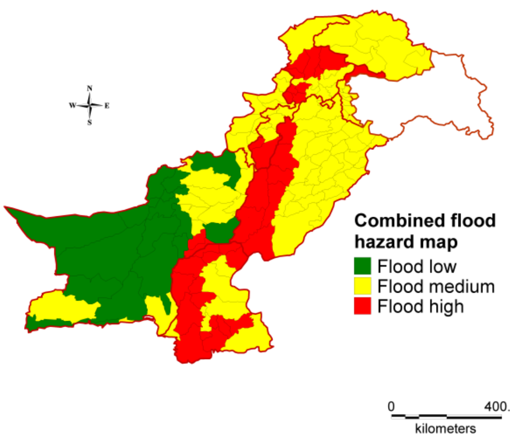

Figure 3.2. Combined flood hazard map

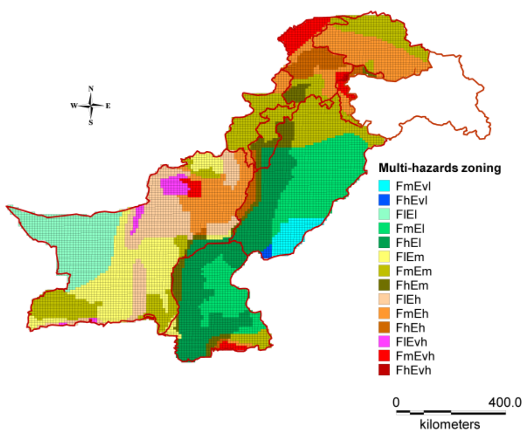

Figure 3.3. Multi hazards zoning map of Pakistan

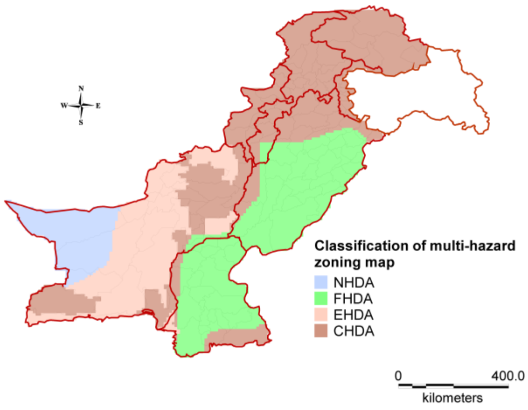

Figure 3.4. Classification of multi-hazard zoning map

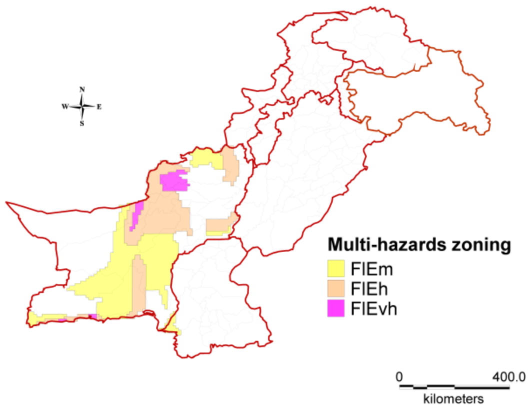

Figure 3.5. Earthquake Hazard Dominated Areas (EHDA)

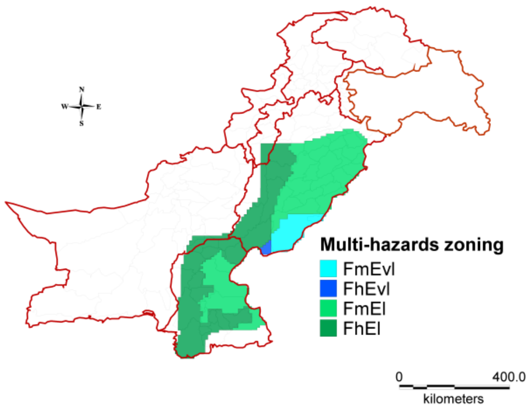

Figure 3.6. Flood Hazard Dominated Areas (FHDA)

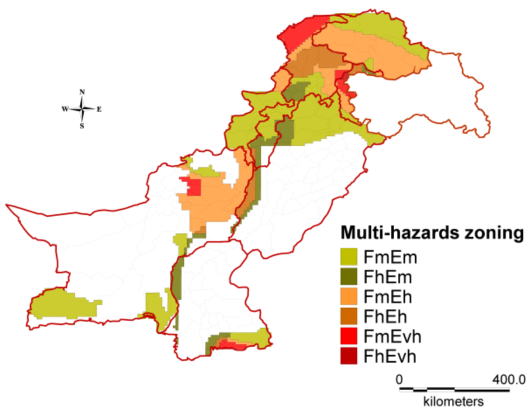

Figure 3.7. Combined Hazard Dominated Areas (CHDA)

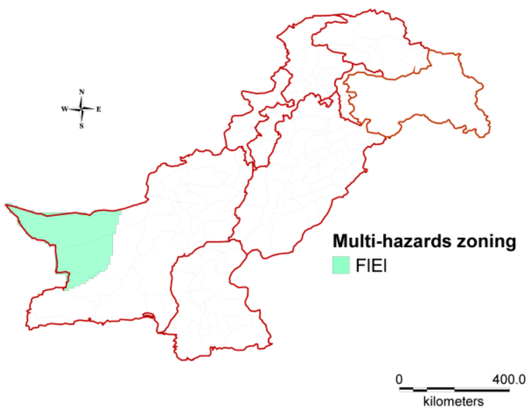

Figure 3.8. No Hazard Dominated Areas (NHDA)

3.3. Typical building types in Pakistan and their vulnerability classes

Maqsood and Schwarz (2008a) defined typical building types in Pakistan and their vulnerability classes. It includes adobe, stone masonry, unconfined concrete block masonry, confined concrete block masonry, unconfined brick masonry, confined brick masonry, reinforced concrete frames and timber structures. After the 2005 Kashmir earthquake, confined concrete block masonry and confined brick masonry has become popular. Maqsood and Schwarz (2008b) also extracted Mean Vulnerability

Table 3.2. Vulnerability classes of typical building types in Pakistan

Building Type	Hazard type	Hazard Vulnerability Class					
		A	B	C	D	E	F
Adobe	Earthquake	○					
	Flood	○					
Stone Masonry	Earthquake	—	○				
	Flood	···	○	—			
Unconfined Concrete Block Masonry	Earthquake	—	○				
	Flood	—	○	—			
Confined Concrete Block Masonry	Earthquake		—	○	···		
	Flood		—	○			
Unconfined Brick Masonry	Earthquake		—	○			
	Flood	···	—	○	···		
Confined Brick Masonry	Earthquake		—	○	···		
	Flood		—	○	···		
Reinforced Concrete Frames	Earthquake	···	—	○	···		
	Flood			···	○		
Timber Structures	Earthquake		···	—	○		
	Flood		···	○	—		
Earthquake resistant designed buildings	Earthquake					—	○
	Flood			···	○		
Flood resistant design buildings	Earthquake		···	—	○	—	
	Flood				—	○	

Index (MVI) from EMS-98. For calculating the MVI, a number from 1 to 6 was assigned for each vulnerability class from A to F, and then taking the mean over the different percentages of each vulnerability class, gives the mean vulnerability index for a certain building stock. Figure 3.9 shows Mean Vulnerability Index (MVI) at tehsil level (3rd administrative level) for Pakistan.

Schwarz and Maiwald (2008) defined vulnerability classes for building types in Germany for flood hazard. There were five vulnerability classes defined (A to E). There were six building types defined: clay, prefabricated, frame work, masonry, reinforced concrete buildings and flood resistant buildings.

The concepts of vulnerability class assignment for earthquake and flood are utilized to produce vulnerability classes of typical building types in Pakistan considering both hazards (see Table 3.2). The most likely vulnerability class is shown with a circle, and a solid line shows the probable range of the vulnerability class and a dotted line shows the less probable range of vulnerability class. Although both hazards are shown simultaneously in Table 3.2, it is noteworthy to mention here that vulnerability class definitions are different for both hazards. Another difference is that, for earthquake hazard there are vulnerability classes from A to F but for flood hazard only from A to E (see also Schwarz and Maiwald, 2012).

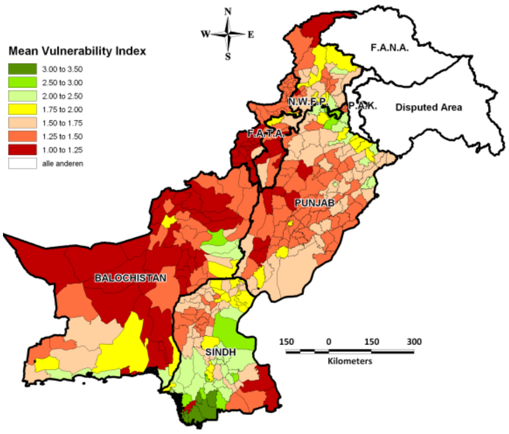

Figure 3.9. Mean Vulnerability Index (MVI) (Maqsood and Schwarz 2008a)

4. DAMAGE SCENARIOS

Dadu district from Sindh province is chosen for a detailed study because in Sindh province this district was most severely affected in 2010 flood (with over 168,000 houses damaged or completely destroyed). Damage scenarios are performed for both earthquake and flood. There are 47 union councils (4th administrative level in Pakistan) in Dadu district. Damage information is provided at union council level.

4.1. Damage scenarios for earthquake hazard

Adobe is predominantly the major building type in Dadu district, with most of the union councils having more than 80 % adobe buildings (see Fig. 4.1). Apart from adobe there are about 13 % timber structures (according to calculations made from 1998 census) and the rest are categorized as “others”. Fig. 4.2 shows the Mean Vulnerability Index (MVI) for the union councils in Dadu district. For the damage scenario, two earthquakes are taken, the 1935 Quetta earthquake and the 2008 Baluchistan earthquake. The reason for choosing these earthquakes is that they are near to the study area. Fig. 2.2 shows the epicenters of these earthquakes and highlighted district Dadu. For the damage scenario, an assumed epicentral Intensity I_0 = XI is chosen for both earthquakes, because using an intensity less than that the damage scenarios indicate very little to no damage in Dadu district. Mean Damage Grade (D_m) is calculated using the model developed at the Earthquake Damage Analysis Center (EDAC) Bauhaus-Universität Weimar, Germany. Fig. 4.3 shows that in the case of the 1935 Quetta earthquake and even a devastating intensity (I_0 = XI) will cause a mean damage grade of less than 2 in most parts of the district. Fig. 4.4 shows that in the case of the 2008 Baluchistan earthquake with a devastating intensity (I_0 = XI) will only cause a mean damage grade of less than 1.5. This shows that although MVI is very low (high vulnerability) in the district, seismic hazard is not dominant there.

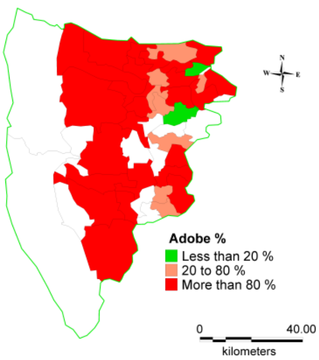

Figure 4.1. Percentage of adobe buildings in Dadu

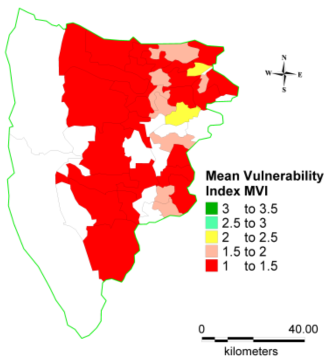

Figure 4.2. Mean Vulnerability Index (MVI)

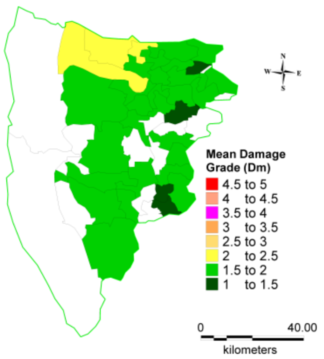

Figure 4.3. Mean Damage Grade (D_m) for an assumed I_0=XI, 1935 Quetta earthquake

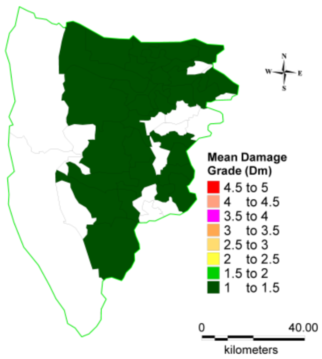

Figure 4.4. Mean Damage Grade (D_m) for an assumed I_0=XI 2008 Baluchistan earthquake

4.2. Damage scenarios for flood hazard

Mean Damage Grade (D_m) for an individual building subjected to flood can be calculated from Eqn. 4.1 proposed by Maiwald and Schwarz (2011).

$$D_m = 2 \cdot \tanh(A \cdot x + B) + 3 \qquad (4.1)$$

Here, A and B are regression variables that depend upon the type of building, whereas x is the flood height above ground level or specific energy height. The characteristic values of A and B used in Eqn.4.1 are taken from the flood model for Germany developed by Maiwald and Schwarz (2011). The damage scenarios are performed for flood heights of 0.5m, 1m, 2m and 3m. The Mean Damage Grades for individual buildings for these scenarios are shown in Table 4.1.

Table 4.1. Mean Damage Grade (D_m) for typical building types in Dadu district

Building type	A	B	Mean damage grade Dm			
			x=0.5 m	x=1.0 m	x=2.0 m	x=3.0 m
Adobe	0.683	-0.495	2.7	3.4	4.4	4.8
Timber	0.381	-0.495	2.4	2.8	3.5	4.1
Others	0.148	-0.495	2.2	2.3	2.6	2.9

For meso scale (at union council level) damage grade calculations, the total number of buildings of each building type is estimated and the Mean Damage Grade in Union Council (MD_m) can be calculated by using the model from Maiwald and Schwarz (2011). Let, total number of adobe buildings = x, total number of timber buildings= y, total number of other buildings= z. Also $(D_m)_a$, $(D_m)_t$ and $(D_m)_o$ represent the Mean Damage Grade (D_m) for adobe, timber and others respectively (see Table 4.1), then using Eqn. 4.2 Mean Damage Grade in Union Council (MD_m) at meso scale can be calculated as:

$$MD_m = \frac{x(D_m)_a + y(D_m)_t + z(D_m)_o}{x + y + z} \qquad (4.2)$$

Fig. 4.5 shows the main river profile (including link canals) in Dadu district with dark blue color, and the hatched area shows the flood extent in the 2010 flood. Fig. 4.6 shows the total number of houses destroyed in each union council (data obtained from the Provincial Disaster Management Authority (PDMA) Government of Sindh, website). Fig. 4.7 to 4.10 shows the results of the damage scenario performed assuming uniform flood heights throughout the district, for the above mentioned scenarios. The scenarios indicate a low damage in case of a 0.5m flood height, medium damage for a 1m flood height, medium to heavy damage for a 2m flood height and very heavy damage in most of the union councils of the district for a 3m flood height.

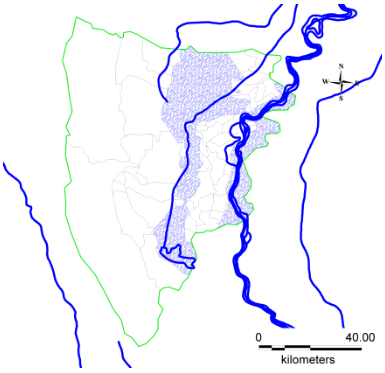

Figure 4.5. River profile and flood extent

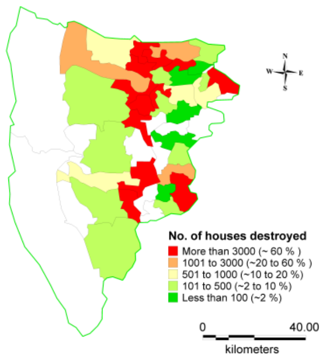

Figure 4.6. Number of houses destroyed in flood 2010

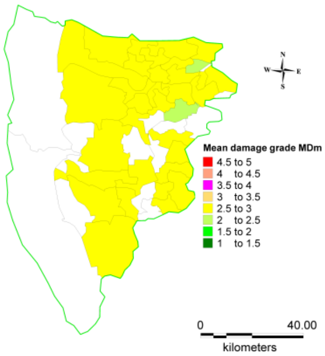

Figure 4.7. Damage scenario for 0.5 m flood height

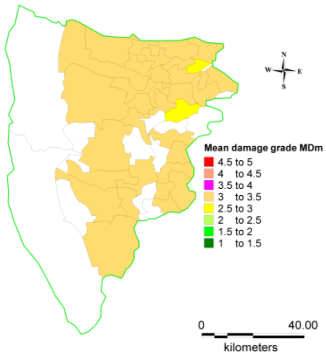

Figure 4.8. Damage scenario for 1 m flood height

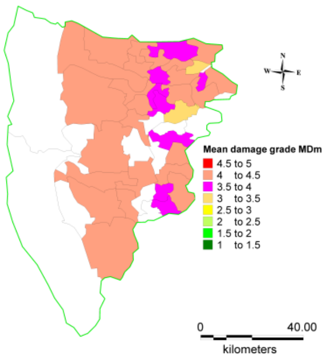

Figure 4.9. Damage scenario for 2 m flood height

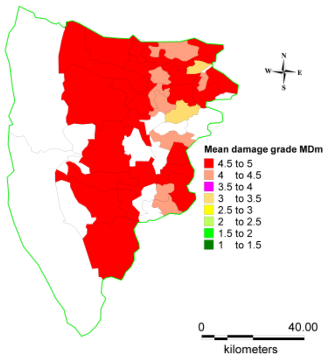

Figure 4.10. Damage scenario for 3 m flood height

Figure 4.11. Damaged brick masonry building

Figure 4.12. New brick masonry construction

In the union councils that were fully inundated (see Fig. 4.5), the observed damages (see Fig. 4.6) are in correlation with a damage scenario for a 3m flood height. Similarly in other parts of the district, which were either not fully inundated or flood height was low, the observed damages are in correlation with the damage scenario for a 0.5m flood height.

A damaged brick masonry building in Jakobabad district (Sindh province) in the 2010 flood is shown in Fig. 4.11 and a new construction approach is shown in Fig. 4.12. It is visible that these new constructions are built to perform well during flood (flood water is allowed to pass underneath the building) but the building may not perform well during earthquake, because the columns at corners will cause a soft story effect, which will lead to collapse of the building.

5. CONCLUSIONS

Pakistan has suffered from a couple of major natural disasters in last decade. Although earthquakes have been major threats in the region, huge damages caused by floods in 2010 and 2011 emphasize the fact that considering a single event for the vulnerability assessment of the building stock in Pakistan is not enough. So, it is need of the hour to use a multi-hazard approach. An effort has been made to develop a multi-hazard zoning map of Pakistan considering both earthquake and flood hazards. This multi-hazard map is further classified in-to four types based on the severity of flood or earthquake hazard in different parts of the country. This multi-hazard zoning map is time dependent and subjected to changes due to future events of floods or earthquakes.

Adobe buildings are the most vulnerable of all the building types in Pakistan and these are built in rural areas, where there is very little knowledge in local communities about hazards and their consequences. So, mostly it leads to huge damages in the case of any natural hazard. Confined brick masonry should be constructed in the future as a replacement for adobe construction because it will be good for both earthquakes and floods. More refined information of the building stock in Pakistan is required for the improvement in damage scenarios for both earthquake and floods. To safeguard against flood hazard buildings should preferably be built on higher grounds with cement plaster on the outer walls, at least up to mid height of first story. Damage scenarios are performed for earthquake and flood, the results of the damage scenarios are presented at union council level which shows that flood hazard is dominant in Dadu district. Buildings should be carefully designed, because a building good for flood hazard may not be good for earthquake hazard (as discussed in 4.2).

AKCNOWLEDGEMENTS
The first author is thankful to the colleagues from the Earthquake Damage Analysis Center (EDAC) Bauhaus-Universität Weimar, Germany, they were always very helpful. The first author greatly acknowledges the Higher Education Commission (HEC) Pakistan for providing him scholarship for PhD.

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http://floods2010.pakresponse.info/MapCenter/GISData.aspx

http://115.186.134.22:43038/Maps/Seismic Zoning and Flood Extend 2010 Map.pdf