URBAN MAPPING AND LAND USE CHARACTERISATION FOR RISK ASSESSMENT

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ABSTRACT:

Urban areas are subjected to many different types of hazards, which may be related to a variety of causes (geological, hydro-meteorological, biological, environmental, technological, etc). In order to assess the multi-hazard risk level of urban areas, and its spatial distribution, detailed information is required on the elements at risk, such as buildings, infrastructure, population, and economic activities. The use of detailed building information for the hazard risk assessment is essential. Very often this data is derived from existing building footprint maps, cadastral databases and population censuses. However, in many developing countries, such data sets are not available in digital format, or they are not compatible with other data or are restricted in their use. The lack of information about building footprints, linked to urban land use, is a major problem and its collection is further obstructed due to restrictions (financially and organisationally) on availability of high resolution data. This paper describes the process of preparing a database on elements at risk, for the Indian city of Ahmedabad, which is subjected to multi-hazards, specifically earthquakes, urban flooding, urban fires, and technological hazards. Urban land use is taken as the principal factor in determining the various parameters that define the degree of vulnerability and capacity in relation to the different types of hazards. This study envisages the evaluation of public documents, and the use of publicly available high resolution imagery from Google Earth in combination with a field survey to compile an efficient database of urban mapping units, which are characterized by homogeneous land use and building types. An analysis of the existing Development Plan for 2010 is carried out in order to reach to an optimal classification of urban land use classes. Such a land use classification will allow to estimate the population distribution both spatially and temporally, based on a stratified sampling scheme and existing population census information per ward. The land use classes are characterized by a number of parameters like the age, building density, building height, occupancy, etc. The whole city is reclassified according to the new land use classes and then a sample survey of each of the land use class is carried out to look at the building profile. As an end result, the whole city is divided into urban mapping units with similar building profiles. The resulting polygons will be assessed for a case scenario of the 2001 earthquake and the assumptions and interpretations indicated.

1. URBAN VULNERABILITY

Although many efforts are taken by international agencies, the toll of disasters still remains high, and is a major obstacle in achieving the Millenium Development Goals (MDG's) (United Nations, 2002). Disaster tolls are high both because there is an increase in hazardous events (mostly of hydro-meteorological origin) and due to increasing vulnerability of societies, especially in developing countries (MunichRe, 2004). Vulnerability is a rather vague term and has been defined in many different ways (Blaikie et al, 1994). It was defined by UNDP/UNDRO (1994) as "the extent to which a community, structure, service, or geographic area is likely to be damaged or disrupted by the impact of a particular disaster hazard, on account of their nature, construction, and proximity to hazardous terrain or a disaster-prone area". For quantification purposes, physical vulnerability is defined as the degree of loss to a given element at risk, or set of such elements, expected to result from the impact of a disaster hazard of a given magnitude. It is specific to a particular type of element at risk, and expressed on a scale of 0 (no damage) to 1 (total damage) (UNDRO, 1979). For socio-economic purposes and macro-level analyses, vulnerability is a less-strictly defined concept. It incorporates aspects such as capacity, resilience and coping mechanisms of communities and individuals to deal with emergency response and post-disaster recovery. These cannot be directly quantified, and are at best represented by semi-quantitative indicators. In many cases, it is sufficient to use a qualitative classification in terms of "high", "medium", and "low"; or explicit statements concerning the disruption likely to be suffered.

Physical vulnerability is a function of exposure of elements at risk to the different "hazard footprints" of the various hazards that might occur, each one characterized by its type of process (e.g. ground shaking, explosion, inundation), its spatial extent, and its intensity (e.g. Modified Mercalli Intensity, temperature, water depth, flow velocity, flood duration), and of the characteristics of the elements at risk (e.g. type of buildings, building height, number of population at a given moment). Large cities are characterised by extreme concentrations of people, values and infrastructure which might be at risk. There are large differences between these cities in terms of vulnerability (Mitchell, 1999). For example, the ten largest cities in terms of economic strength are all in industrial countries. If population is taken as the yardstick, however, seven of the ten most populous cities are in emerging and developing countries. Whether the risks are natural catastrophes, weather, environment, health or terrorism, *Megacities* are more vulnerable than rural areas (MunichRe 2004). Ahmedabad, with the population of 4.6 million is no exception. It has been exposed to various forms

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of disasters: earthquake, urban floods, fire, civil strife, and air pollution.

2. AHMEDABAD CITY

2.1 Urban context

Physical setting: The Sabarmati River separates the city into two parts: the Eastern Walled City and Western Ahmedabad (Figure 1). Its midway location, with Rajputana and Malwa Plateau Region on one side and Saurashtra Peninsula and Bombay Metropolitan Region on other side has resulted in its development as an important trade centre. The city was once famous as the 'Manchester of India' on account of its textile industry.

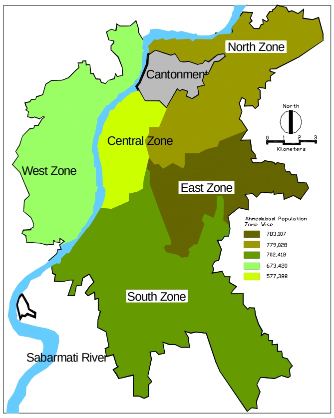

Figure 1: Administrative divisions of Ahmedabad

City growth: The present area of Ahmedabad city is 190.84 sq km, grown from an area of 5.72 sq km in 1858. Most of the area of the Ahmedabad Urban Agglomeration is under the administration of the Ahmedabad Municipal Corporation (AMC). In the year 2006, the city boundary was expanded and some additional areas were included (AMC, 2006). The urbanisation rate of Ahmedabad (35% growth per decade) is highest in the state. In 1981-91, owing to the inclusion of 92 sq.km area, the city experienced a record high growth rate of 40 per cent. Subsequently the growth rate reduced to 22 per cent. Figure 2 indicates the population growth over the last 45 years (AMC, 2005). The average population density for Ahmedabad city based on the 2001 census is 18420 persons per sq.km. The Ahmedabad Urban Agglomeration has a population of 4.5 millions (2001) of which 78 percent is residing within the municipal area. Ahmedabad is the main city of Gujarat, presently holding 23 percent of the state's urban population and the sixth largest Indian city in terms of population size (Census Bureau of India, 2001). Over the years, the rapid urbanization has led to spillover of population outside the city limits, and intensification of development in the city area, resulting in tremendous pressure on the infrastructure facilities.

Economic base: The city has a well-developed industrial base housing (inter)nationally important industries, as well as a range of national research and educational institutions.

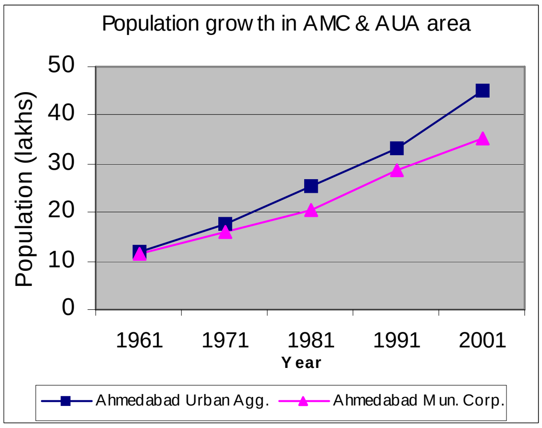

Figure 2: Population growth trends in Ahmedabad

2.2 Land use

Based on information from 1997 (Figure 3), more than one third (36%) of the total area is under residential use, followed by 15 percent of the area with industries. Large tracts of land (23.44%) are lying vacant, mostly in the newly acquired area of the AMC. Only 9.5 percent of the total area is under transportation network as against the norm of 15-18 per cent. as specified by UDPFI[1] norms.

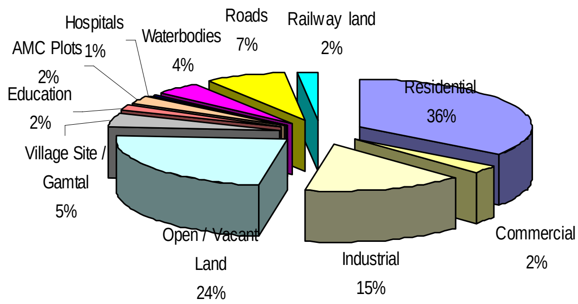

Figure 3: Land use distribution in Ahmedabad in 1997.

2.3 Hazards in Ahmedabad

The vulnerability atlas for India prepared by BMTPC (1997) has delineated the city into medium earthquake risk zone, characterized by earthquake intensity (MSK scale) of VII, which might result in very high damage. It is also in the risk zone from wind and cyclones (50m/s). Recent experiences of localised flooding, caused by high intensity rainstorms made it clear that parts of Ahmedabad are vulnerable to flooding as well. The presence of extensive chemical and petro-chemical industries, partly surrounded by residential buildings, make the city prone industrial/technological disasters as well.

The earthquake of 2001 in Gujarat had highlighted the importance of strict building regulations and better construction practices. In the city a total of 96 multi-storeyed buildings (varying between 2-5 floors) and 2 high-rise (more than 5floors) collapsed causing 751 deaths and 1742 injured people (AMC, 2001). AMC was one of the instrumental agencies that had worked on reconstruction and rehabilitation.

In a study sponsored by the Ahmedabad Municipal Corporation (AMC) and the Ahmedabad Urban Development

[1] Urban Development Plan Formulation and Implementation (UDPFI) Guidelines, Ministry of Urban Affairs and Employment

(AUDA), the Centre for Environmental Planning and Technology (CEPT) carried out an earthquake damage assessment study after the 2001 Gujarat earthquake (CEPT, 2001). This study shows the detailed damage pattern in various parts of the city. Most of the buildings designed by professionals have survived with minor damage to infill partition walls. There were shear cracks in beams and columns of approximately 2350 buildings (Goyal et al 2001). In the city, only minor damage was observed in single, or two story short- period structures. Most of the damage was limited to G+4 and G+10 storey buildings having "soft storey" at the ground floor. These buildings have not been designed for lateral loads as required by IS 1893 (Zone III).

3. METHODOLOGY

This paper is a part of a research being carried out from ITC, the Netherlands and CEPT, India, titled, "Decision Support System for Urban Risk Management". The study will define hazard footprint for the Indian city of Ahmedabad using GIS and RS tools; identify elements at risk, and assess the risk; define risk mitigation measures and eventually develop a methodology to evaluate and prioritize them in a Spatial Decision Support System.

As a part of one of the objectives to assess the risk we need to have information on the buildings and population. However, as mentioned earlier, Ahmedabad does not have an existing digital building footprint map. This research aims to develop a methodology for generating 'usable' building profile information for risk assessment, using GIS and Remote Sensing. The process adopted in the methodology is presented in Figure 4.

3.1 Defining appropriate urban land use classes

The land use map forms the basis for many urban planning, management and development activities. For example on the basis of the urban land use the building regulations are defined keeping in view the volume of the buildings and the width of road, etc. that can be allowed. The building volume (i.e. building height, plot coverage, etc) in turn influences the no. of people that are occupying the building in different periods of time and the infrastructural requirements, etc. In order to assess the vulnerability a city is posed to, we need to analyse the potential combinations of land use with building types. Ideally building risk assessment should be carried out at building level. However, in most cases this level of information is too difficult to collect and time consuming to evaluate vulnerability of individual buildings. Also for implementing remedial measures, some level of aggregation is required.

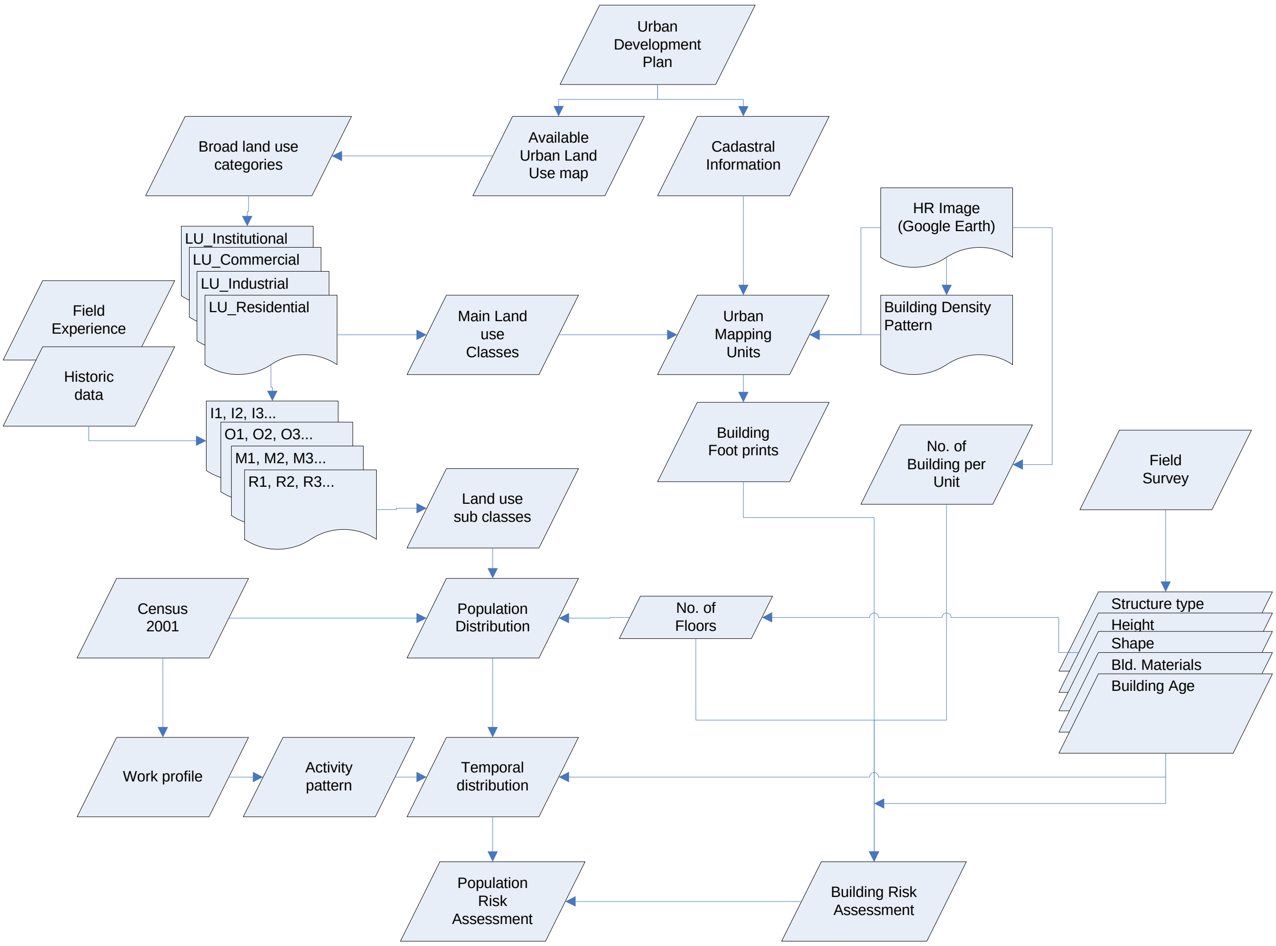

Figure 4: Methodology adopted in the study

Therefore, we base the risk study on so-called urban mapping units, which consists of a series of buildings, with more or less the same land use pattern.

The buildings range from shanty huts to high rise buildings of more than 10 floors. Generally these ranges occur in the residential land use, which are more valuable for the risk managers. The understanding the interactions of land use with building types is the main purpose of this paper.

The development plan of Ahmedabad which has been prepared for 2011 has predominantly the following 8 broad land use classes (AMC, 2005):

1. Residential (three categories and old walled city)
2. Commercial zone (two categories based on activity pattern expected)
3. Industrial (three categories based on type of industry)
4. Educational
5. Health facilities
6. Transport nodes
7. Recreational zones
8. Agricultural zone

These land use classes are used for the purpose of restricting the land use, but they cannot give additional information in terms of the actual land use of individual buildings or the number of people that might occupy a building. Even though the land use document defines the activity that is permitted in a zone, some deviation in land use practice is observed. Another short coming of the development plans is that components of hazard susceptibility are not considered pro-actively. This is mainly because of lack of the technical support at the local level. So considering these broad land use classes for the vulnerability and risk assessment will yield very coarse results. Land use classes have to be divided into more relevant classes. For example, residential land use can be further divided based on structural type, construction techniques, character of the building materials, shape, height (different heights shake at different frequencies), building use, proximity to other buildings and age of the building, configuration of the building units (attached / detached / semi-attached), number of people that are going to occupy the building. Having these sub categories in each of the land use groups will help the vulnerability assessment, as the population that might be affected and the building behaviour in case of an event can be predicted more accurately to some extent. Therefore a more detailed land use classification is made which is presented in Table 1. When we consider the building density and the building materials, the residential land use groups can be further divided into eight categories, *make-shift/squatter units; small, single low class houses; mix of low class houses with (work) shops; row houses; row houses with shops/offices in ground floor; apartment buildings; single large houses with garden/open space around; and group houses like hostels/student homes/dormitories*. These classes were made considering the occupation pattern as main factor, but can also be differentiated on the basis of *building materials, configuration, building height,* etc. Similarly other land use groups were also subdivided depending on the nature of the uses.

3.3 Defining Urban Mapping Units

In this study only two types of elements at risk are taken into account: buildings and population. Building information could be obtained from existing cadastral databases, and population data from census databases. A sample of cadastral data available from the Ahmedabad Municipal Corporation is shown in Figure 5.

Figure 5: Sample of the cadastral map of Ahmedabad

These cadastral maps show individual plots with different revenue numbers. However, risk assessment cannot be carried out at this scale for the whole city as detailed plot level/building level information is lacking for each individual building. The cadastral maps are used to define and characterize the basic units for the urban risk assessment. These mapping units were delineated by looking at the urban fabric. Mainly these are the urban blocks of uniform land use and which are bound by roads wider than 4 meters. In some cases even if the dividing road is not wider than 4mt, if the density pattern as observed in the high resolution image is varying drastically, the mapping units are made separately.

The urban mapping units are best delineated on the basis of high resolution images. Acquiring high resolution imagery for the single purpose of risk assessment is often financially not viable. Nowadays, with the increasing availability of high resolution imagery in the freely available map servers, such as Google Earth, such urban mapping might be carried out without acquiring a new image. A sample image used is presented in Figure 6. High resolution imagery of the same area is compared with the existing cadastral information and the mapping units are marked on it. The imagery can also be used to update the information from the cadastral maps, as the imagery is more recent. However, there are some limitations in using the images for larger areas. The high resolution images cannot be properly exported and overlaid with the cadastral maps in a GIS.

Figure 1 High resolution image of same area used for building height estimation (© Google Earth)

Land use class		Explanation	Building Types	Population density	
				Daytime	Night time
Residential					
R1	Make-shift,/ squatter dwelling	Slums, temporary housing, unplanned	W / BM / S	High	Very High
R2	Small, single, low class houses	Individually constructed, unplanned	BM	High	Very High
R3	Mix low class houses & (work)shops		BM ,	Very High	Very High
R4	Row housing		Moderate / High	Moderate	Very High
R5	Row housing, shops/offices in ground floor		low	Very High	Very High
R6	Apartment buildings	Planned buildings	RCC	Moderate	Very High
R7	Single large houses in open space	including ground floor office, etc	RCC	Low	Low
R8	Hostel, student homes, dormitories		Variable	Very Low	High
Institutional					
I1	Government offices closed to public	Corporation / ward / zone offices	RCC Framed CRM	Moderate	Very Low
I2	Government office open to public	Post office,	RCC Framed CRM	Moderate	Very Low
I3	Police station	Essential for emergency response	RCC	Very Low	Very Low
I4	Fire brigade	Essential for emergency response	RCC	Very Low	Very Low
I5	Ambulance service	Essential for emergency response	RCC	Very Low	Very Low
I6	VS Hospital	Essential for emergency response	RCC	Very High	High
I7	Civil Hospital	Essential for emergency response	RCC	Very High	High
I8	Medical care space	Doctor's clinic, single room units, …	RCC	High	Low
I9	Dispensary, clinic, nursing home	Nursing Home, Maternity home etc-	RCC,	High	High
I10	Military buildings/ Cantonment area	Potential for emergency response	RCC	Low	Low
Educational					
E1	School (primary, kindergarten)	Aanganwadi / balwadi, pre-school, …	Variable	High	Very Low
E2	School (secondary)	excludes student hostels	RCC Framed CRM	High	Very Low
E3	School (university, college)	excludes hostels, staff quarters	RCC Framed CRM	High	Very Low
Cultural /Recreational / Religious					
C1	Covered space for cultural activities	Theatre, cinema, museum, library	RCC	Very Low	Occ. High
C2	Trade fair, conference center, hall	Sports hall, trade fair	RCC	Occ. High	Occ. High
C3	Community center	Meeting places	Variable	Occ. High	Occ. High
C4	Religious buildings	Temple, church, mosque etc.	Variable	Occ. High	Occ. High
C5	Garden / parks / sports field	Party plots, marriage plots	none	Low – Mod	Very Low
C6	Cemetery, cremation space				
Commercial					
O1	Mix of shops, offices, workshops	No substantial residential components	BM , RCC	High	Very Low
O2	Market area	Market stalls, in open air	none	Very High	Very Low
O3	Shopping malls	department stores, super markets,	RCC Framed CRM	Very High	Very Low
O4	Hotel, motel, resort,	with indication of Nr of rooms	Variable	Variable	Variable
O5	Office Buildings	Multi-storey office buildings	RCC Framed CRM	Moderate	Very Low
Industrial					
M1	Mix of various small industrial activities	Type of activities might be hazardous	Poor quality	Low- Mod	Low- Mod
M2	Light industrial zone	Workshops, small factories,	Variable	Low- Mod	Low- Mod
M3	General Industry	Service industries, not hazardous	Variable	Low- Mod	Low- Mod
M4	Hazardous Industry	Possible explosion, fires, toxic release	Variable	Low	Low
M5	Storage of flammable goods	includes LPG, CNG, petrol, diesel, …	Variable	None	None
M6	Storage of toxic goods	Type should be mentioned	Variable	None	None
M7	Water treatment plant	Critical facility	Variable	None	None
M8	Sewage treatment plant	Critical facility	Variable	None	None
M9	Power Plant	Critical facility	Variable	None	None
M10	Electricity Distribution Station	Critical facility	Variable	None	None
Transportation					
T1	Public transport terminal	Railway station, bus station	RCC	Very High	Low
T2	Service station, petrol filling station	Possible explosion, fires	Variable	Low- Mod.	Low
T3	Parking area, open spaces	Possible evacuation area	none	Variable	Variable
T4	Street		none	Variable	Variable
T5	Main street		none	Variable	Variable
T6	Highway		none	Variable	Variable
T7	Square		none	Variable	Variable
T8	Railway		none	Variable	Variable
Miscellaneous					
V1	Unused space		None	None	None
V2	Agricultural area		None	Very Low	Very Low
V3	Actual use unknown	Inaccessible, secret, invisible	Unknown	Unknown	Unknown

Table 1: Detailed urban land use classification for Ahmedabad, designed for multi-hazard risk assessment

Therefore visual comparison is done using two computers, one for viewing the high resolution images and one for screen digitizing the urban mapping units.
These units are classified based on the land use sub-classes mentioned in Table 1. An example is given in Figure 7.

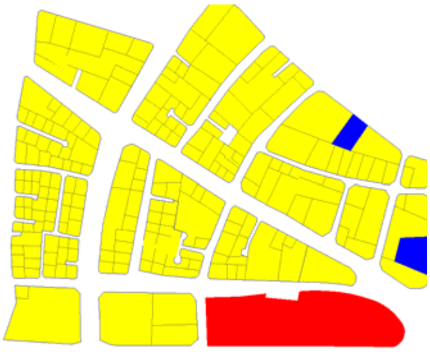

Figure 7: Map showing interpreted urban mapping units and land use

The no. of mapping units for whole city might be very high. So often a generalisation of these units will be made based on the homogeneity of the building stock. For specific parts of the city, building footprint maps will be available on paper. These will be digitized in order to estimate the typical building size and building density related to the various detailed urban land use classes (See Figure 8).

Figure 8: Map showing building foot prints superimposed on land use

Stratified sampling will be used to select the mapping units across the city and a series of attributes will be collected with the help of Mobile GIS.

3.3 Attributes that influence building vulnerability

The population vulnerability depends on building vulnerability and socio-economic attributes of the population (age, gender, education, social network etc). The most important attributes that define building vulnerability to different types of hazards are shown in Table 2. From the building attributes indicated only a few are feasible to collect over larger areas for the urban mapping units, which are used in the multi-hazard risk assessment. Structural type is important as it is directly related to the available vulnerability curves for earthquake damage (BMTPC 1997; IITR 2001, FEMA, 2003). Building height is also very important, as it also determines the floor space and therefore also the number of person per building. Building height can be obtained automatically, if Lidar information is available (Zhan et al., 2002), or using photogrammetrical techniques (Montoya 2002; Willneff 2005). Otherwise this will have to be estimated from the interpretation high-resolution images and fieldwork.

Building attributes	Earth quake	Urban Flood	Urban Fire	Wind Storm
Structural type	++	+	+	++
Height	++	++	+	++
Shape	++	+	-	+
Wall materials	++	+	+	+
Roof materials	++	-	++	++
Foundation type	+	-	-	-
Age & Quality	+	+	+	+
Distance from other object	+	+		++
Openings	-	++	+	+
Cooking method	+	-	++	-
Water tank	++	+	+	+
Protecting walls	-	++	+	+

Table 2: Importance of building characteristics for determining building vulnerability for several types of hazards
(++ = very important, + = Important, - = Not important).

This study aims at collecting information on the most important attributes for building vulnerability assessment, without the need to carry out a complete building survey of the city, which would not be feasible economically and logistically. For the population vulnerability assessment, economic attributes will be considered, related to the basic urban mapping units, and the population distribution for different periods of the day/year. Population information is available for a census in 2001, but is linked to wards, which are too general to be used in the risk assessment. The urban mapping units will be used to redistribute the ward population. This method of distributing the population can accumulate some errors, but given the purpose of the study is still considered acceptable. For collecting the physical attributes, we use image interpretation techniques combined with stratified sampling using Mobile GIS.

3.4 Attributes for population vulnerability estimation

For the estimation of number of people present in each of the identified urban mapping units at a given moment in time, the following attributes are important:

- Urban land use type
- Number of buildings per mapping unit
- Building footprint area for each individual building
- Number of floors
- Time scenario

The population information is based primarily on available census information. However, this type of information is only available at the ward level, and will be redistributed on the basis of the urban mapping units, based on the estimated floor space within the mapping unit and the land use class. The floor space is determined from the building density, average building footprint area, and the number of floors.
Representative mapping units within the land use types of Table 1 will be selected across the city, in order to sample the number of people per hectare floorspace taking into account both daytime and nighttime scenarios. Also some more demographic parameters need to be evaluated such ase the family size, cultural/traditional households (usually associated with larger family size), etc. that may be specific for the situation in Ahmedabad.

4. Conclusions

Urban multi-hazard risk assessment is a procedure that requires a large amount of data (Davidson, 1997; Granger et al. 1999). Part of this data can be used from existing sources. However, both in terms of the spatially optimal units for the risk assessment, as well as for the collecting of relevant attributes for building and population loss estimation, specific data needs to be collected. However, in order to make this process economically feasible, the collection of new data should be kept to a minimum. New developments in the availability of high resolution images, such as those made available in Google Earth might be an important new tool in this data collection, although it still has some main disadvantages, related to the direct comparison of data sets. A further integration these freely available data with GPS and Mobile GIS is expected to happen in the near future and will offer further opportunities in improving urban vulnerability assessment.

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