

Megacities – megarisks

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Abstract We review the definitions, population trends, and characteristics of megacities. Characteristics of megacities are, apart from their size, their complexity in terms of administration, infrastructure, traffic, etc., and at the same time the speed of change. Vulnerabilities and risk potential are discussed using the examples of Mexico City and Mumbai. We present the experience accumulated in the 6 years work of the Earthquakes and Megacities Initiative (EMI, <http://www-megacities.physik.uni-karlsruhe.de/>) with more than 20 large cities around the world, mostly located in the developing world. On this background we analyze obstacles that keep megacities from developing an efficient approach towards disaster mitigation and define a strategy that might overcome these problems. The key element of this strategy is the development of a Disaster Risk Management Master Plan (DRMMP) for cities. Currently the Istanbul Earthquake Master Plan (IEMP) serves as best example for an appropriate strategy for disaster reduction in megacities.

Keywords Megacity · Urbanization · Vulnerability · Disaster mitigation · Risk management master plan

1 Trends in urbanization

The world has experienced rapid urbanization during the past few decades. While in the 1950s approximately 18% of the world's population was living in urban areas, this

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figure had jumped to 50% by the year 2001. Within the next 20 years the world is expected to add another 2 billion people (approximately the combined population of India and China) to its urban population. Most of the increase in urban population has occurred in developing countries, primarily due to collapse of sustainable rural economy and the consequent migration of rural population to urban areas in search of employment opportunities. In several cases, the rate of urbanization is several times greater than the rate of population growth. This global urbanization phenomenon has led to the emergence of megacities, densely populated urban centers with populations exceeding 8 million.

The pattern of urbanization shifted significantly since 1900. At that time no city in the world counted 10 million people. Around 15 cities housed more than 1 million residents. The 15 cities were: London, Paris, Manchester, Birmingham, Glasgow, Berlin, St. Petersburg, Moscow, New York, Chicago, Philadelphia, Boston, Calcutta, Peking, Tokyo. Only London, Paris, and New York were larger than 3 million, and only 2% of the world population lived in the 15 megacities of 1900. In 2000 we have 19 cities in excess of 10 million residents. By 2015 this number will increase to 23, with five of them larger than 20 million (Table 1). Today about 20% of the world population lives in megacities. This percentage will increase to 30 in 2020. Significant growth rates of megacities are restricted to the developing world. The four megacities of the developed world (Tokyo, New York, Los Angeles, Osaka) remain almost constant in population, whereas megacities in the developing world grow rapidly. Some cities are growing two or three times faster than the country's overall population, reflecting massive migration to cities (Gelbard et al. 1999). For example, Dhaka grew in population by an average of nearly 7% per year from 1975 to 2000 compared

Table 1 Cities with 10 million or more inhabitants, 1975, 2000, and 2015 (population in millions)

City—1975	Population	City—2000	Population	City—2015	Population
Tokyo	19.8	Tokyo	26.4	Tokyo	26.4
New York	15.9	Mexico City	18.1	Bombay	26.1
Shanghai	11.4	Bombay	18.1	Lagos	23.2
Mexico City	11.2	Sao Paulo	17.8	Dhaka	21.1
Sao Paulo	10.0	Shanghai	17.0	Sao Paulo	20.4
		New York	16.6	Karachi	19.2
		Lagos	13.4	Mexico City	19.2
		Los Angeles	13.1	Shanghai	19.1
		Calcutta	12.9	New York	17.4
		Buenos Aires	12.6	Jakarta	17.3
		Dhaka	12.3	Calcutta	17.3
		Karachi	11.8	Delhi	16.8
		Delhi	11.7	Metro Manila	14.8
		Jakarta	11.0	Los Angeles	14.1
		Osaka	11.0	Buenos Aires	14.1
		Metro Manila	10.9	Cairo	13.8
		Beijing	10.8	Istanbul	12.5
		Rio de Janeiro	10.6	Beijing	12.3
		Cairo	10.6	Rio de Janeiro	11.9
				Osaka	11.0
				Tianjin	10.7
				Hyderabad	10.5
				Bangkok	10.1

Source: UN Population Division, March 2000

with an annual average of 2.1% for Bangladesh as a whole. In the same period, the population of Lagos grew at an average of 5.6% per year compared with 3% for Nigeria as a whole (UN 2000).

Characteristics of megacities are their size, the complexity in terms of administration, infrastructure, traffic, etc., and at the same time the speed of change. City growth renders figures on population and inventory of buildings, data on social and administrative structures become very quickly outdated. Megacities are of crucial importance to their countries and regions. They are often the economic drivers for their countries and influence economic and political activities. In addition, the intellectual, corporate, and political leaders are often located in the megacities. Therefore, disruption of normal activities in a megacity due to a natural disaster has the potential to upset the social, economic, and political fabric of the country or surrounding region.

2 Vulnerability and risk for megacities

The potential for large-scale urban disasters has been demonstrated during the last decade by several earthquakes. In 1995 the Kobe earthquake (magnitude 6.9) resulted in 6,000 fatalities and more than US\$ 100 billion direct economic losses. On August 17 a magnitude 7.6 event struck the heavily populated and industrialised area of Izmit in Turkey causing 20,000 fatalities and 6.5 billion US\$ loss. Studies of a repeat of the 1923 Great Kanto (Tokyo) earthquake indicate losses in excess of US\$ 2,000 billion and 30,000–60,000 fatalities. The Kobe earthquake was not a big one, and the projections for a Tokyo 1923 repeat refer to a city in a highly affluent country. Systematic studies of earthquake risk in terms of fatalities have been provided by Bilham (1988, 1995, 2004). The earthquake of July 28, 1976 near Tangshan represents one of the largest urban disasters of the 20th century with almost the entire city destroyed, its residential buildings as well as its industrial facilities (Yong et al. 1988). Official estimates of fatalities are quoted as 246,000, but unofficial data point to 500,000 rather.

The vulnerabilities of megacities are much greater in the developing world where the average number of victims is 150 times larger than in the developed world, and the economic loss (as a percent of GNP) is 20 times greater. In developing countries, precious investment funds get regularly diverted towards paying for the costs of disasters causing economic recessions, setting back development, and increasing poverty. Various factors contribute to the increase of megacities vulnerability including:

- High population exposure due to concentration of housing in below standard construction
- Complex and ageing infrastructure
- Dependence of population welfare on proper functionality of lifeline systems such as transportation, power, water, and communication
- Lack of robustness of critical facilities such as public health, public safety, and educational facilities
- Weaknesses of preparedness programs and response and relief capabilities.

Each city is highly dependent on the functionality of its infrastructure. In fact a working infrastructure contributes to a city's attractiveness. However, at the same

time this infrastructure constitutes a major component of the vulnerability of a city if disasters strike. Water supply can break down widely for a variety of reasons: ground shaking can destroy supply pipelines and service lines, tanks, and reservoirs. Subsurface supply lines are often damaged by liquefaction of soil. Lack of electricity will hamper the necessary pressure generation by pumps. People might be cut off from water for many days and restoration of water supply can last weeks. Similar considerations apply to waste water and sewage. Transportation to and within cities are always disrupted by an earthquake. Bridges collapse either by ground shaking or by liquefaction that destabilises the abutments. Railways and roads are blocked by debris and landslides, damaged by liquefaction, or cut off by faulting. Electric power is usually lost by an earthquake when substations are damaged or overhead lines knocked down (Telford 1995).

Gas and petroleum storage facilities and pipelines pose another threat to a city when damaged. Lack of supply is one issue, pollution by oil spills, fire in refineries ignited at service line connections to buildings another one. A key parameter to vulnerability is usually the age of construction. Telephones and other communication facilities are quite robust, however, mostly non-functional for days due to overload. Performance of critical facilities of a city (hospitals, fire stations, police stations) is mandatory for rapid response and rescue operations. Yet many hospitals do not withstand ground motion. For instance, the 1985 Mexico earthquake destroyed 30% of the city's hospital capacities (Puente 1999) with very adverse impact on the medical supply for victims. Vulnerability of schools is still a major issue in cities with too little efforts done for mitigation.

Mexico City can serve as an interesting example for the growing vulnerability of a megacity. The city swept across the Federal District (Distrito Federal DF) a boundary that contains the administrative Mexico City in the 1960s when the total population was at a level of 5 million. Since then growth in the DF remained limited, but growth continued in the suburban around the DF up to more than 20 million in the 1990s. Today the Mexico City Metropolitan Zone (MCMZ) covers six states with Mexico as the largest state. Geographically the MCMZ grows in the Central Mexican Basin. The DF is socially stable, inhabited by higher-income groups and dominated by service industry. The suburban around the DF is rapidly growing by inner city migration and rural inflow. It is less affluent and socially rather unstable. The city faces a wide range of hazards. Natural hazards include earthquakes both from the Pacific plate boundary and adjacent continental tectonics, volcanic eruptions from Popocatepetl, and geologic subsidence, which is partially man-made and caused by ground water extraction. Hydrometeorological hazards are floods and almost more severe droughts. The latter was the ultimate cause for the Aztecs to leave the Mexican Basin. Man-made hazards include the afore-mentioned subsidence, extreme air pollution and technological emergencies such as natural gas tank explosions. The development pattern of the city reflects the economic and migration history. The center is multi-storeyed, well equipped with infrastructure and services, whereas the suburban is sprawling in low-rise buildings with little infrastructure (Puente 1999).

Mumbai is India's most populous conurbation and the sixth most populous agglomeration in the world. According to the 2001 census, the population of Mumbai has increased from 9.93 million in 1991 to 11.91 million in 2001. However, city officials estimate that an additional 2–3 million 'floating population' also resides in Mumbai. The official population density (about 27,209 people per km²) is one of the highest in the world. Roughly 60% of the population resides in informal settlements

and the number of structures including residential, commercial, and industrial comprise 2,768,910 (1991 census). Mumbai is located on a peninsula on the island of Salcette and spread linearly along the Arabian Sea coast. It consisted originally of seven islands which were joined together by land reclamation projects through the years. The Mumbai Metropolitan Region Development Authority Act, 1974 further treated Greater Mumbai with its rapidly growing hinterland as one region for development purposes under the name ‘Mumbai Metropolitan Region (MMR)’. The region adds 3,887 km² to the Greater Mumbai area of 468 km², while only adds 5.90 million inhabitants to its 11.91 million population (2001 statistics).

Mumbai lies, according to the Bureau of Indian Standards (BIS), in Seismic Zone III. Its most severe historical earthquakes appear on Table 2. Jaiswal et al. (2004) have studied the probabilistic seismic hazard of Mumbai. Using different attenuation models they estimate depending on the return-period (T) PGA-values of 0.03 g ($T = 100$ years), 0.08–0.1 g ($T = 475$ years), and 0.16–0.20 g ($T = 2000$ years). These values correspond to intensities (MMI) of smaller than V ($T = 100$ years), VI ($T = 475$ years), VII ($T = 2000$ years). Soil conditions have been assumed as stiff soil to hard rock. The instrumental intensity that corresponds to MMI is determined by a method proposed by Chernov and Sokolov (1999) and further developed by Sokolov (2002). The method is based on the assumption that Fourier Spectral Amplitudes (FAS) at representative frequencies and the intensity of an earthquake are directly connected, so that the latter can be calculated from the FAS. Variations in intensities by soil conditions (site effects) can be high in Mumbai because of the soft ground that constitutes the filled land. During the recent Bhuj (2001) earthquake intensities have been observed in Mumbai ranging between VI and VII MMI (Hough et al. 2002). The role of site effects is systematically studied in the frame of UNESCO–IUGS–IGCP project 414 ‘Realistic Modelling of Seismic Input for Megacities and Large Urban Areas’ at the Abdus Salam International Centre for Theoretical Physics in Trieste (Italy). Results of this project covering many large cities of the world have been recently published (Panza et al. 2004) but do not include Mumbai. Sinha and Adrash (1999) provide the following fatality figures for three different earthquakes in the Mumbai region (Table 3).

One of the most vulnerable elements exposed in Mumbai is its building stock, which certainly contributes to increasing risk of its population. The Mumbai region is 100% urban and the building stock exhibits a rich mix of several different building technologies. The most commonly used building categories are: (1) reinforced-con-

Table 2 Historical earthquakes in Mumbai region MMI > V; M > 4

Year	Month	Intensity (MMI)/Magnitude
1618	May	IX ^a
1832	October	VI
1906	March	VI
1929	February	V
1933	July	V
1951	April	VIII
1966	May	V
1967	April	4.5
1967	June	4.2

Source: Compiled by Sinha and Adrash (1999) from catalogues of IMD, NGRI, EPRI, and MER

^a There is some uncertainty about this damage being caused due to an earthquake

Table 3 Estimated number of fatalities in Mumbai

Time	MSK VI	MSK VII	MSK VIII
Midnight	11,200	42,600	100,100
6 A.M.	9,000	34,000	80,000
12 Noon	6,700	25,500	60,100

crete frame buildings with partition walls; (2) brick masonry buildings with reinforced concrete roofs and using cement mortar; (3) informal brick masonry buildings (which may or may not use cement mortar); (4) buildings made of other materials such as tin sheets, thatch, and other light-weight elements. The first two categories typically constitute engineered constructions in which the assistance of qualified engineers are usually taken at each stage. The last two categories are non-engineered constructions, wherein the services of skilled engineers may not have been employed. In Mumbai, however, it has been observed that several reinforced concrete and brick masonry buildings have been constructed without the assistance of qualified engineers. Due to this reason, these buildings are also not engineered since they may be improperly designed or constructed resulting in lower strength.

Whereas European cities had often centuries to grow to their current size, cities in the developing world grew within a few decades after World War II by migration of rural population without adequate development of infrastructure and social structure (Husa and Wohlschlägl 1999). This circumstance forms the key to the high vulnerability of those megacities.

3 Obstacles for disaster mitigation in megacities

Presently in most megacities, disaster management is focused on post-disaster response. While planning for post-disaster response is an important function in disaster management, a disaster management policy based on post-response planning alone is flawed. Focusing solely on post-disaster response does little to reduce the inherent risks. Redistributing resources towards mitigation creates better protection of assets, reduces the losses, and ensures faster recovery. For megacities where there is a high concentration of human exposure and physical assets, the shift towards mitigation could be highly cost-effective. However, for policy makers mitigation often appears as an option with no clear political and financial advantages, and consequently the shift of policy towards pro-active mitigation has proven very difficult.

The Earthquake and Megacities Initiative (EMI, <http://www-megacities.physik.uni-karlsruhe.de/>) works since 1998, under the umbrella of UNESCO, with more than 20 large cities around the world. Numerous meetings in city clusters and three international workshops provided the insight into the key impediments for disaster reduction in megacities and how this understanding can be transformed into responsible policy and practice:

- Effective governance structures;
- Multi-sectoral, inter-disciplinary work culture;
- Efficient use of resources;
- Awareness and informed knowledge of risk; and
- High professional standards and ethics.

In order for mitigation efforts to be successful, many sectors of the society must work in cooperation with one another. In particular, mitigation requires efficient and transparent communication between government agencies (public works, housing, public safety, environment, land-use, public health, and welfare, etc.) at every level (central, provincial and local). In most developing countries, government structures are rigidly centralized around individuals who exercise significant personal control of power and information, and who often are reluctant to institute reforms that would allow better communication and flow of information within and between agencies. Institutions are weak, and bureaucracies have little incentive to change them.

Contrary to response planning, which can be placed at the level of a single government organization (e.g., civil protection), mitigation requires coordinated action from many branches of government (construction, urban planning, public work, public health, social services, education, etc.) Further, mitigation requires integration of expertise from many disciplines and close cooperation between professionals from varying fields that generally operate separately in daily practice (e.g., urban planning and social welfare). Developing countries are often characterized by a lack of multi-disciplinary and inter-sectoral work cultures. The process of planning, design, and delivery of construction of buildings is one of the principal vulnerability factors in developing countries. This is often not an issue of lack of knowledge. In most developing countries, knowledge exists on how to build structures so that they do not collapse during an earthquake. However, that knowledge lies in the hands of relatively few researchers and specialists and is not widespread among practitioners or building inspectors.

Key professions such as social services, urban planning, engineering, architecture, and construction need to be better structured and organized in developing countries. Professional organizations can play an important role in improving professional standards and ethics, and in elevating the importance of these professions with society. Introducing licensing and accreditation procedures would have a significant effect on the construction industry. In many megacities, credentials are not now required for planning, designing and constructing buildings, and infrastructure. Such practices compromise construction quality and increase urban vulnerability. Similarly, many civil society organizations failed to gain the trust of their communities and are sometimes seen as opportunistic entities looking to benefit the few. At the same time, regulatory oversight is plagued by lack of expert knowledge, resources and most often corruptive practices.

4 The strategy of developing a Disaster Risk Management Master Plan

Given this understanding of impediments for disaster management key elements of EMI's disaster reduction strategy are:

- (1) Creation of coalitions of stakeholders around local government policy makers: the mainstreaming of disaster risk reduction needs to start at the local level because cities are in charge of basic services such as land-use planning, management of urban growth, construction planning and control, public works, and social welfare. The goal is to integrate the disaster risk management agenda within each of the city functions, and to strengthen institutions so that the process is sustainable on the long-term.

- (2) Engaging local governments in the implementation of pro-active disaster risk reduction actions (Fig. 1): we propose disaster risk management as another key city-wide planning function of megacities. City administrations are familiar with the notion of city-wide planning (e.g., planning for transportation or for urban growth), and hence strategically, if cities engage in a similar planning process, disaster risk management could be transformed into an institutional local function. In essence, the association of disaster management with a city-wide planning function represents the starting point of the mainstreaming process.

A model is proposed to help cities understand the context of their exposure to risk, develop knowledge on the spatial, social and functional distribution of the risk, and address risk management in a holistic manner by which the components of disaster preparedness, disaster mitigation, disaster response planning, and knowledge development are examined within a realistic legal and institutional framework. This model is referred to as Disaster Risk Management Master Plan (DRMMP, Fig. 2). DRMMP stresses the development of a process for long-term planning and action that is specific to each city; it enables the understanding of gaps and constraints, provides the parameters for policy-making and supports the development of options for disaster risk mitigation. The knowledge produced by the DRMMP provides a city administration with the elements for putting together a city-wide disaster management plan, for making informed decisions about disaster management action, and for supporting public policy.

Disaster assessment and use of information and communication technology (ICT) stay as the engine for the development of the knowledge on risk that supports the implementation of the DRMMP. ICT is used in many aspects of managing megacities,



Fig. 1 Mainstreaming disaster risk management at the local level—the integration of central government policies with local level implementation and stakeholders’ participation

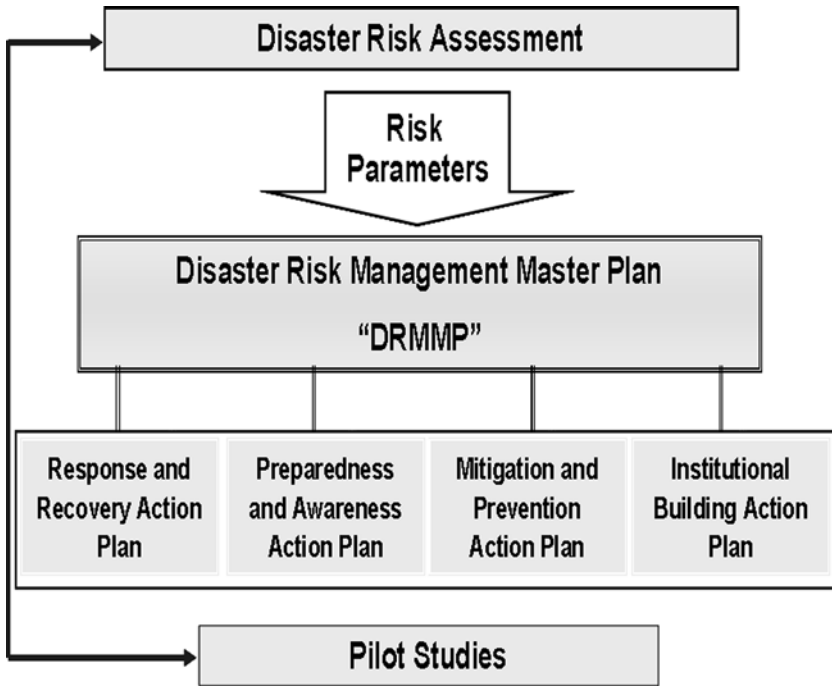


Fig. 2 Concept and components of a Disaster Risk Management Master Plan Model

and can be efficiently extended to perform risk assessment studies. Institutions and communities who understand their risk parameters also understand the options for disaster risk reduction and the trade-offs associated with these options. Moreover, the quantification of disaster risk also permits realistic estimation of mitigation cost, and monitors change in disaster risk over time.

5 Istanbul Earthquake Master Plan

Currently the best example for a master plan is the Istanbul Earthquake Master Plan (IEMP) that has been developed by four leading Turkish universities upon request of the Istanbul Metropolitan Municipality (IMM). Following the 1999 Marmara earthquake, IMM embarked on improving its earthquake response and readiness capabilities in order to eventually support its population and institutions and to ensure rapid resumption of vital services to the city during and immediately after an earthquake event. More importantly, IMM in conjunction with other Turkish institutions, and fully aware of the earthquake risk to the city resolved to reducing the risk to Istanbul through the development of mitigation programs. Following the 1999 Marmara earthquake, EMI lent its support to IMM in the development of a comprehensive strategy for earthquake risk management and reduction. EMI worked closely with IMM officials in improving the internal understanding of the risk to the city, developing options for risk mitigation, enhancing internal and external resources for implementation, fostering an environment of cooperation between IMM and the Turkish academia, offering opportunities for capacity enhancement, gaining access to

international experience and expertise, and adding credibility and recognition to IMM efforts.

IMM benefited also from the support of several other national and international organizations, such as the Japanese Agency for International Cooperation (JICA), the American Red Cross, which supported researchers at Bogazici University in developing a risk evaluation of the city that provided more insight and data on the earthquake impact on population, building, infrastructure, and essential services. The IEMP study was procured by IMM in November 2002 and completed in July 2003. Two teams of research universities, Middle East Technical University (METU) and Istanbul Technical University (ITU) on one hand, and Bogazici University (BU) and Yildiz Technical University (YTU) on the other hand were hired by IMM to undertake the study.

Components of IEMP are:

- Analysis of the “current situation” that summarizes the previous studies and provides a comprehensive summary of the risk parameters to the population, buildings, transportation systems, and lifelines as well as to the potential impact on essential facilities, services, and emergency response.
- Seismic assessment, evaluation, and strengthening of existing inventory of buildings with suggestions for several methods for the evaluation of the buildings.
- Integration of risk reduction in urban planning and urban renovation of Istanbul including legal issues, administration, and finance
- Software, hardware, and data structures related to information management.
- Educational and social issues, including various earthquake preparedness programs, with an emphasis on community education and social networking.
- Basis principles of disaster management, including a framework for emergency management for Turkey that provides a role to the provincial and local governments.

The Master Plan is not a short-term set of measures. Rather it must be viewed as road map for disaster risk management including all relevant components. Currently the municipality conducts a large-scale study in a part of Istanbul (Zeytinburnu), including risk assessment, reconstruction and renovation, and civil participation in order to develop experience in incorporating risk reduction in city development. At the same time the World Bank has launched a 1 billion dollar program for Istanbul, mostly devoted to retrofitting vulnerable building stock.

6 Summary

Although the key to disaster reduction is political action, this can be substantially supported by science. Hazard and risk assessment can be significantly improved and communicated much better to stakeholders than done so far. It is often academic without attempt to integrate and generate understandable statements beyond technical terms. The dynamics and complexity of megacities are poorly understood in all their interrelations with and their impact on the natural environment (huge water consumption and waste-water generation, air pollution, micro climates, etc.) in addition to social complexity and complexity in infrastructure. Looking at a megacity as an object of rapid change and high complexity includes looking at new challenges for quantitative hazard and risk assessments: they cannot be viewed any more as static

results of an analysis performed at a certain time. Hazard and risk monitoring must follow assessment in order to match the speed of change of many cities. Some quantitative research was performed in this direction. We have developed a database of best practices, adapted a socio-economic risk evaluation scheme, which is currently tested in Manila, run an Internet-based tool for risk evaluation etc. (results of the studies are to be published).

Megacities' problems can be addressed only with a multidisciplinary agenda and pose in this respect a significant challenge for science ranging from social sciences, engineering to natural sciences such as geosciences and meteorology. Finally science projects in cities of the developing world offer the opportunity to help building local capacity, without which no sustainable development is conceivable.

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