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Initiatives for earthquake disaster risk management in the Kathmandu Valley

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Abstract Situated over the Himalayan tectonic zone, Kathmandu Valley as a lake in geological past has a long history of destructive earthquakes. In recent years, the earthquake risk of the valley has significantly increased due mainly to uncontrolled development, poor construction practices with no earthquake safety consideration, and lack of awareness among the general public and government authorities. Implementation of land use plan and building codes, strengthening of design and construction regulations, relocation of communities in risky areas, and conduction of public awareness programs are suitable means of earthquake disaster risk management practice. Kathmandu, the capital of Nepal, is still lacking earthquake disaster risk management plans. So, this paper highlights some initiatives adopted by both governmental and nongovernmental organizations of Nepal to manage earthquake disaster risk in the Kathmandu Valley. It provides some comprehensive information on recent initiatives of earthquake disaster risk management in the valley and also highlights the outcomes and challenges.

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1 Introduction

Nepal lies in a very high seismic region and has a history of devastating earthquakes. The major source of earthquakes in Nepal and the Himalayan region is the subduction of the Indian plate underneath the Eurasian plate, which causes contraction and stress concentration. Seismicity is considered to be high in this region based on the frequency and intensity of the past earthquakes. Seismicity of the Himalayan region has been studied in terms of its relationship with known geological faults (Fig. 1) and tectonic activities (Rai et al. 2004). During the past 100 years, three great earthquakes (Table 1) occurred along the Himalayan front (Seeber and Armbruster 1981; Wyss 2005). From east to west, they includes the 1905 Kangra Earthquake (M_s ~7.8), the 1934 Bihar–Nepal Earthquake ($M_w = 8.1$), and the 1950 Assam Earthquake (M_w ~8.6) (Pandey and Molnar 1988; Ambraseys and Bilham 2000; Bilham 2001). Although none of these earthquakes is reported to have produced primary surface rupture (Seeber and Armbruster 1981), it is generally assumed on the basis of isoseismal map and location of damage that these earthquakes are the result of slip on the main frontal thrust (MFT). Lack of primary surface rupture during the major historical earthquakes in the Himalaya region has often led previous researchers to attribute the earthquake occurrences to a blind thrust, whereby the strain release is expressed as anticline growth rather than primary surface rupture or co-seismic surface rupture (Chander 1989; Stein and Yeats 1989; Yeats et al. 1992; Yeats and Thakur 1998). However, Avouac et al. (2001) have mentioned that these earthquake events have produced a rupture of 250–300 km in the Himalayan arc together with a co-seismic slip of estimated average length of 5 km.

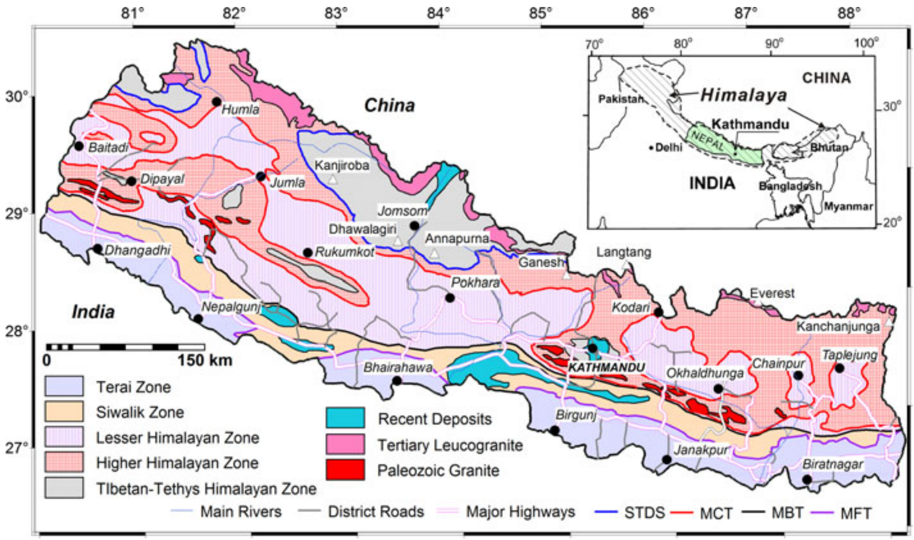

Fig. 1 A generalized geological map of Nepal with major thrust lines (modified after Dahal and Hasegawa 2008)

Table 1 Magnitude–frequency data on earthquakes in Nepal and the surrounding region in the period of 1911–1991 (modified after BCDP 1994)

Earthquakes of magnitudes in Richter scale	5–6	6–7	7–7.5	7.5–8	>8
No. of events	41	17	10	2	1
Approximate recurrence interval (years)	2	5	8	40	81

The recurrence time for these great earthquakes is determined on the basis of the rate of slip of the Indian plate underneath the Eurasian continental mass, while these slip rates are estimated on the basis of global plate motions (DeMets et al. 1990), from seismic productivity and from the advance sediments on the northern Ganges plain (Bilham et al. 1997). In this endeavor, various global positioning system (GPS)-based geodetic survey has been carried out in Nepal since 1991 so as to measure the rate of plate movement as a part of collaboration between the Department of Mines and Geology (DGM) of Nepal and various international organization/institutions, such as IRES (Colorodo University, USA) and French Laboratories under the Centre National de la Recherche Scientifique. Plate motion models and GPS measurements indicate that India-Eurasia convergence continues today at a rate of about 40–50 mm per year (Demets et al. 1994), while the rate of contraction across the Himalaya is estimated to be only 17.52 ± 2 mm per year (Bilham et al. 1997). Armijo et al. (1986, 1989) and Avouac and Tapponnier (1993) mention that the difference in these rates is absorbed by a combination of thrusting, crystal extension, and strike-slip motion within the Eurasian plate.

As a Himalayan nation, Nepal has had a long history of destructive earthquakes. In last one century alone, over 11,000 people were killed in four major earthquakes. A study of the seismic record of the region suggests that earthquakes producing a shaking of MMI-IX or more occur approximately every 75 years, while smaller earthquakes occur more frequently. Earthquakes are thus a relatively frequent and disastrous natural event in Nepal, and a major earthquake is likely in near future (Ambraseys and Bilham 2000; Bilham et al. 1997). The earthquake disaster risk of urban areas in Nepal, especially the capital area of Kathmandu Valley, is ever increasing alarmingly due to rapid urbanization, poor construction practice, and lack of disaster preparedness. In spite of the knowledge of historical seismicity and earthquake disasters, public awareness on earthquake hazard and risk was negligible until a few years ago. Many institutions apparently responsible for disaster emergency response are largely focused on relief management. It was only after the massive destruction and loss of 721 human lives in an earthquake in 1988 in the eastern Nepal that a need of an organized approach toward earthquake risk management was realized, and it led to the beginning of several innovative initiatives on earthquake risk management in Nepal.

In the Kathmandu Valley, the increased earthquake disaster risk is mainly attributed to uncontrolled and unplanned development, inadequate or no use of building code, lack of earthquake safety considerations, and lack of awareness among the general public as well as authorities. Implementation of land use and building codes, design and construction regulations, relocation of communities from risky area, and use of public awareness programs are suitable means of earthquake risk management, but Kathmandu is still lacking the programs intended for earthquake risk management.

Earthquakes have been found to cause fewer deaths but greater economic loss or heavy fatal loss but little economic damage based on the development index of a nation (Chatelain et al. 1999; Erdik and Durukal 2008). The 1987 Loma Prieta Earthquake (USA) caused only 62 deaths in and around San Francisco but the economic loss was estimated to be \$4.7 billion, while a similar scale earthquake in Spitak (Armenia) killed over 20,000 people but the economic loss was only \$570 million (Chatelain et al. 1999). So as an underdeveloped nation, earthquake damage data in Nepal will be more terrible than Armenia.

In this context, this paper highlights some of the initiatives taken by both governmental and nongovernmental organizations of Nepal to mitigate earthquake disaster risk of the Kathmandu Valley and also provides information on the achievements made out of the earthquake disaster risk management initiatives in the valley.

2 Kathmandu Valley

2.1 Location and importance

Kathmandu Valley is situated almost in the middle of Nepal and is constituted of three administrative districts, namely Kathmandu, Lalitpur (partly), and Bhaktapur (Fig. 1). There are five municipalities in the valley: Kathmandu Metropolitan City (KMC), Lalitpur Sub-metropolitan City (LSMC), Bhaktapur Municipality (BM), Madhyapur (Thimi) Municipality (MM), and Kirtipur Municipality (KM). Additionally, there are 98 Village Development Committees (VDC) in the valley, which are basically nonurban areas consisting of several rural settlements (Fig. 2).

Urban services including water supply, telephony, electricity, and so on in whole Nepal are usually managed by the central authorities, not by the municipalities or local authorities. On the other hand, urbanization is rapid throughout the valley, and all valley urban settlements exhibit rapid growth around their periphery. Because of inadequate coordination between the central and local authorities, the above urban services are not well managed, which has increased the risk of their failure during earthquake disasters.

While KMC is the largest municipality and hosts most of the central government offices, the entire Kathmandu Valley is considered the capital of Nepal. Therefore, the term "Kathmandu" in this paper is supposed to represent the entire valley. Not only as the administrative and economic capital, but Kathmandu also serves as a cultural asset of the nation. Numerous historical monuments, national and international heritages including 8 World Heritage Sites are located in the valley.

2.2 Geology and earthquake damage risk

The Kathmandu Valley is an ancient lake filled up in recent geological times by the sediments derived from rapid erosion of the surrounding hills and mountains. The lake-bed sediments are up to 350 m thick (Sakai et al. 2001) and they consist mainly of soft and weak organic silts and clays. The lake-bed also consists of fine sand, which is susceptible to liquefaction. The thick, soft valley sediments are considered to have higher earthquake wave amplification capacity, and this phenomenon could be accentuated by potential basin-effect because the valley is roughly circular in shape with about 25 km diameter, and the Bagmati River system exhibits a remarkable centripetal drainage pattern.

The valley was hit by numerous earthquakes in the last 100 years including four major earthquakes of magnitude greater than M8.0 (Seeber et al. 1981; Molnar 1984). Categorically, major earthquake damages in the Kathmandu Valley were reported to have taken place in the years 1255, 1408, 1681, 1803, 1810, 1833, and 1866 (Bilham et al. 1995;

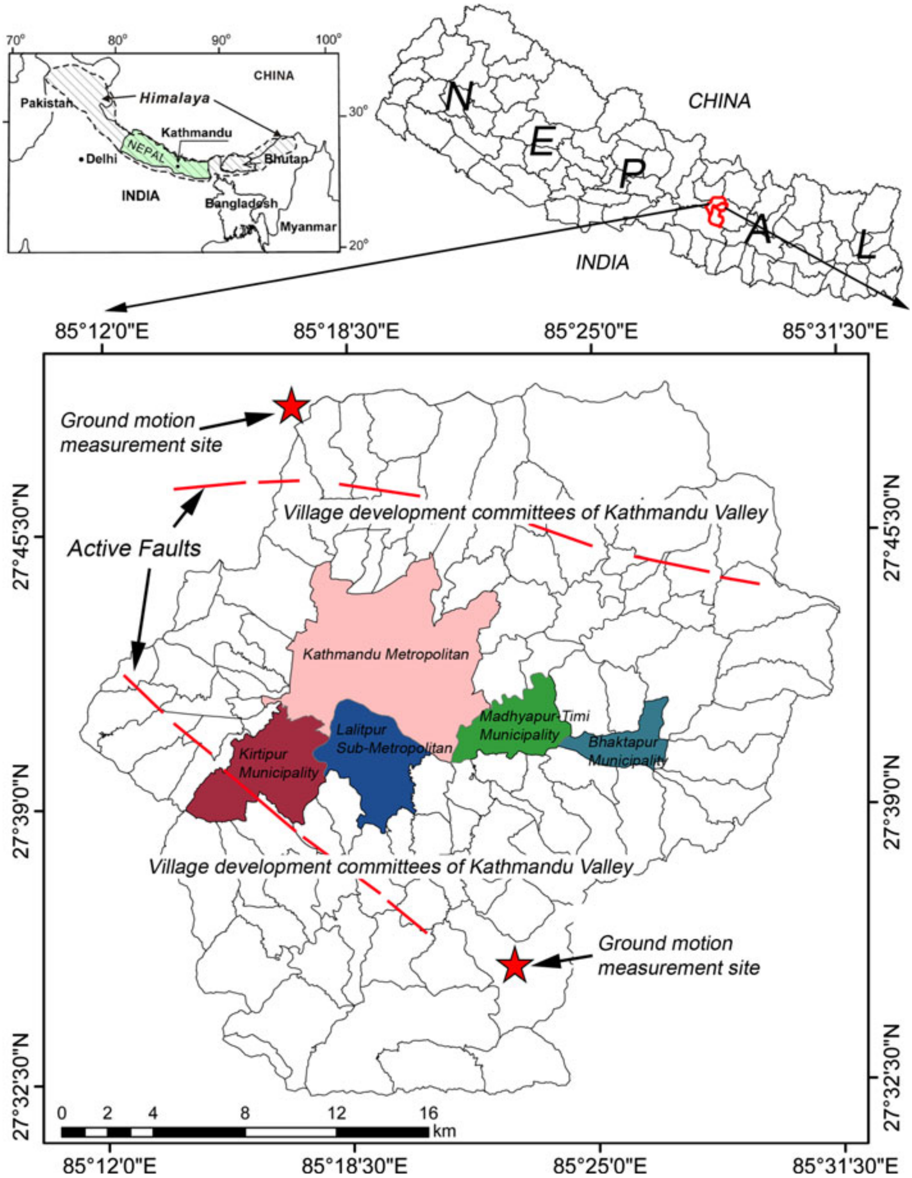

Fig. 2 Location map of Kathmandu Valley and municipalities as well as surrounding village development committees. Tentative location of active faults and ground motion measurement sites are also shown in the map

Chitrakar and Pandey 1986; Gupta 1988; Pandey et al. 1995). The oldest recorded earthquake event of 1255, which had an estimated intensity of at least MMI-X, was reported to have damaged the valley very badly. In this earthquake, one-third of the Kathmandu population (i.e., several thousands in number), including King Abhaya Malla, were killed (ibid). The latest great earthquakes that significantly affected Nepal and the Kathmandu Valley were 1833 Kathmandu Earthquake and 1934 Bihar–Nepal Earthquake.

The 1980 Chainpur Earthquake ($M_L = 6.6$) and the 1988 Eastern Nepal (Udayapur) Earthquake ($M_L = 6.5$) also killed hundreds of people and extended a great infrastructural loss in the epicenter areas. More recently, an earthquake in Sikkim–Nepal border ($M_L = 6.9$), which occurred on September 18, 2011, caused heavy damage in terms of rural house collapses and partial destruction including landslides and rock slope failures at numerous locations along the major road network in the eastern part of Nepal. Although only 6 people were reported to have been killed in this earthquake, the total number of completely or partially destroyed nonengineered houses was about 21,000.

Among the major earthquakes with recorded history, the Great Bihar–Nepal Earthquake of 1934 (Ambraseys and Douglas 2004; Hough and Bilham 2008) with a maximum intensity of X-MMI caused an extensive damage in the Kathmandu Valley (Dunn et al. 1939; Pandey and Molnar 1988). Of the total number of deaths in whole Nepal at 8,519 (Fig. 3), which was more than the number of deaths in Bihar (i.e., 7,188 deaths), 4,296 people died in the valley alone (Rana 1935; Pandey and Molnar 1988). This earthquake reportedly destroyed about 19 % and damaged about 38 % of the valley buildings (Pandey and Molnar 1988; Rana 1935). The level of destruction particularly in Bhaktapur City in the eastern part of the valley and neighboring areas was found to be the highest (Pandey and Molnar 1988; Rana 1935). Many historical temples and monuments also collapsed or sustained severe damage (Tables 2, 3).

The time series record of earthquake generation points in the Nepal Himalaya indicates that the strain energy in its central part has not been released for a long time. This state of stress build-up in the area, which is often known as a seismic gap, indicates that it is the most potential location for the next great earthquake in the Himalayas (Pandey et al. 1995; Bilham et al. 1997). Although the historical record is inadequate to make an accurate prediction of the recurrence period of great earthquakes in Nepal, the available data indicate that an earthquake greater than M8.0 occurs at a 100-year interval. As it is already about 80 years since the 1934 Bihar–Nepal Earthquake, the threat of a major earthquake in the region, particularly in the Nepal Himalaya, is sharply increasing day by day.

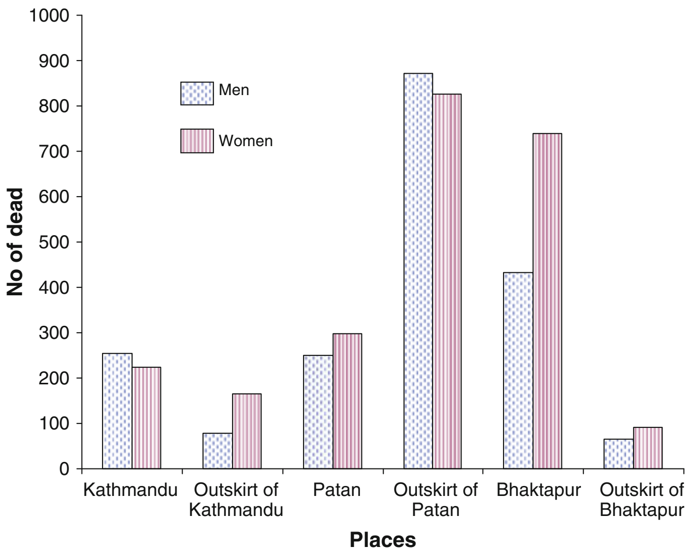

Fig. 3 Casualties in the Kathmandu Valley due to the 1934 Bihar-Nepal Earthquake

Table 2 Past earthquakes and damage records (modified after BCDP 1994; JICA 2002)

Years	Epicenter	Magnitude	Deaths	Houses destroyed
1255	–	–	One-third of the population of Kathmandu, including King Abhaya Malla, were killed	A lot of damage to residential buildings and temples
1260	–	–	Many people died, famine after the earthquake	A lot of damages to residential buildings and temples
1408	–	–	Many people died	A lot of damages to residential buildings and temples, fissures developed in the ground
1681	–	–	Many people died	A lot of damage to residential buildings
1767	–	–	No record of death	No records of damage
1810	–	–	Some people died particularly in Bhaktapur	A lot of damage to residential buildings and temples
1823	–	–	No record of death	Some damage to houses
1833	–	7.7 (M_L)	414 people died in the vicinity of the Kathmandu Valley	About 4,000 houses destroyed in Kathmandu, Bhaktapur, and Patan in the valley and adjoining Banepa and a total of 18,000 buildings damaged in the whole country
1834	–	–	No good record available	Many buildings collapsed
1837	–	–	No good record available	No damage in Nepal recorded but greatly affected Patna and other parts of Bihar, India
1869	–	–	No good record available	No good record available
1897	–	–	No good record available	No good record available
1917 (1918?)	–	–	No good record available	No good record available
1934	East Nepal	8.1 (M_W)	8,519 people died out of which 4,296 died in Kathmandu Valley alone	Over 200,000 buildings and temples, etc., damaged out of which nearly 81,000 completely destroyed in the country. About 55,000 buildings affected in Kathmandu Valley (12,397 completely destroyed)
1936	Annapurna	7.0 (M_L)	No good record available	No good record available
1954	Kaski	6.4 (M_L)	No good record available	No good record available
1965	Taplejung	6.1 (M_L)	No good record available	No good record available
1966	Bajhang	6.0 (M_L)	24	6,544 houses damaged (1,300 collapsed)
1980	Chainpur	6.5 (M_L)	103	25,086 buildings damaged (12,817 completely destroyed)
1988	Udayapur	6.5 (M_L)	721	66,382 buildings damaged
2011	Sikkim/ Nepal border	6.9 (M_L)	6 died and 30 injury (2 died in Kathmandu Valley alone)	14,544 house damaged (6,435 completely destroyed)

M_L Richter magnitude, M_W moment magnitude

Table 3 Houses destroyed within the valley due to 1934 Bihar-Nepal Earthquake

Region	Completely destroyed	Much fractured	Slightly fractured	Total
Kathmandu	725	3,735	4,146	8,606
Outskirt of Kathmandu	2,892	4,062	4,267	11,221
Patan	1,000	4,170	3,860	9,030
Outskirt of Patan	3,977	9,492	1,598	15,067
Bhaktapur	2,359	2,263	1,425	6,047
Outskirt of Bhaktapur	1,444	1,986	2,388	5,818
Total	12,397	25,708	17,684	55,789

Like many other urban areas particularly in developing nations, the earthquake disaster risk of Kathmandu Valley has increased significantly since the last major earthquake. The valley has a burgeoning population of almost 5 million, which goes in parallel with uncontrolled development activities and poor construction practices. Practically, all construction work goes without much input from an engineer and without considering the seismic forces. Earthquake risk-related technical information in the Kathmandu Valley is also incomplete and scattered among several governmental agencies. However, a more important contributor to the region's lack of earthquake preparedness was that the available technical information was synthesized, was not applied to infrastructure planning and design of the modern day Kathmandu Valley, and was not presented in a form the public and government officials could accept.

Urbanization of outer parts of the compact historical city core area began in the nineteenth century, mainly during the Rana regime when large palace complexes were built away from the city core, while a rapid urban growth started only after political changes of 1950. During this time, the city started to grow in the east, northeast, and north over easily accessible well-drained highlands along the major arterial roads. The growth accelerated further during the 1970s and 1980s, and especially after the construction of a circumferential road, known today as the Ring Road, more and more areas in the neighborhood of this road were made accessible. The urban growth in the Kathmandu Valley today covers most of the municipal areas including the low-lying flood plains.

3 Estimation of earthquake losses

The Seismological Center of the Department of Mines and Geology (DMG), Government of Nepal monitors seismic activities in Nepal through its network of 21 seismograph stations. The center has a capability of continuous recording of earthquakes equal to or greater than M2.0 throughout Nepal and M5.0 worldwide. However, there are only two strong ground motion recording stations in the country so far. One of them is located in Kathmandu, while the other is placed in the northern periphery of the valley at the top of the valley watershed.

In 1994, the National Building Code Development Project (BCDP 1994) carried out an assessment of primary seismic hazard for the country and has prepared a consolidated earthquake catalogue. The project also analyzed the identified active faults within Nepal and its surroundings and derived the earthquake hazard spectra based on this knowledge as well as using the commonly accepted seismotectonic model and attenuation relationships.

While it is necessary to continue conducting researches for detailing the geological, seismic, and seismotectonic models, the existing knowledge was used for deriving the design seismic forces required for seismic analysis of the structures. This analysis was used by BCDP (1994) for the formulation of the Nepal National Building Code. BCDP (1994) also prepared susceptibility maps for collateral seismic hazards such as landslides, liquefaction, and fault rupture hazard for the Kathmandu Valley. The liquefaction hazard map of the valley was prepared in combination with the intensity distribution map of the Bihar–Nepal Earthquake of 1934 to estimate potential losses due to future earthquakes that could result in MMI-IX level of shaking as was observed during the 1934 earthquake. During the estimation of damage in this study, the location and vulnerability of the valley infrastructures were determined through interviews with about thirty institutions. The information collected through these interviews was combined with previously conducted studies. It was accepted that these readily available models produced useful, conservative results at a sensible cost, considering that the main aim of the project was to promote mitigation action rather than to conduct a detailed scientific or technical research. Loss estimates were conducted for the road system, water system, electricity system, telephone system, and typical building structures. In addition, possible death and injury figures were determined by looking at the statistics from previous comparable earthquakes from around the world.

To understand possible earthquake losses in Kathmandu, a study was carried out and a systematic assessment of earthquake disaster risk was conducted with the help of a few data on buildings and experts opinions on building vulnerability. These data were used in the empirical processing proposed by the Applied Technology Council (ATC 1984, 1985) for the estimation of potential earthquake losses. In this paper, the probable worst scenario earthquake, that is, level of shaking equal to or greater than intensity MMI-IX, was selected to assess earthquake losses in Kathmandu. The estimated losses are summarized in the following subheadings.

3.1 Possible damage in building and casualties

A rough estimation of damage to buildings was conducted using information about typical construction types found in the Kathmandu Valley, which was collected and analyzed while developing the Nepalese Building Code. As many as 60 % of the buildings in the valley are likely to be damaged heavily and many beyond repair, Bhaktapur, which also suffered the worst damage in the 1934 earthquake, has historically suffered more than the rest of the valley in earthquakes, possibly because of its ground conditions, so as many as 75 % of the buildings in Bhaktapur are likely to be damaged heavily.

Death and injury expectations are equally shocking. Simply applying the percentage of the population killed or injured in the 1934 earthquake to the population of the valley today, it results in an estimate of 22,000 deaths and 25,000 injuries requiring hospitalization, while applying more recent earthquake casualty figures from cities comparable to the Kathmandu Valley, it results in an estimate of 40,000 deaths and 95,000 injuries during the next major earthquake in the Kathmandu Valley.

Additionally, estimated 600,000–900,000 residents of the Kathmandu Valley are expected to be left homeless due to damaged buildings or a fear of being in their homes. The existing government medical facilities in Kathmandu have a total of 2,200 beds, most of which are full under nonemergency conditions. An additional 3,500 patients could be accommodated on floors or outside space around the hospitals. In California and Japan, an earthquake shaking of MMI-IX generally makes at least 50 % hospital beds unusable due to structural problems (e.g., building collapse) or nonstructural problems (e.g., fallen bookshelves or loss of electrical power). So, it is for sure that there will be a major shortage of space for medical treatment in the Kathmandu Valley.

3.2 Urban building stock

The damage analysis of building stock in the Kathmandu Valley was based on a set of data obtained from an inventory of 1,200 buildings. Buildings for the inventory were carefully selected based primarily on a visual assessment of the typology distribution combined with an inventory of critical facilities. The data set was then used in the analysis of damage to building stock, public facilities, lifeline networks, and human casualty for different scenario earthquakes hitting or affecting the Kathmandu Valley in a comprehensive earthquake disaster risk assessment project supported by Japan International Cooperation Agency (JICA 2002). The main purpose of this project was to develop an earthquake disaster mitigation plan in the Kathmandu Valley.

A subjective estimation was made during the development of the valley building damage scenario, and it was found that 60 % of the buildings in the valley would collapse in case of a scenario earthquake with shaking equal to what happened during the 1934 Bihar–Nepal Earthquake. The prevalence of large stock of old masonry buildings and practice of unsafe building construction without considering seismic requirements was the reason behind such estimation. It was also concluded that 54 % of the buildings would be heavily damaged in a case of recurrence of the 1934 earthquake. About 1,200 buildings from 69 sample sites were surveyed for over 100 items including details on owners, location, age, usage, repair and extension history, past experiences of cracks, construction materials and type of structure, number of stories, shape, layout, soil and topography.

3.3 Public school buildings

To understand issues behind earthquake disaster risk mitigation in the Kathmandu Valley, school earthquake safety assessment was carried out during this study. The purpose of this assessment was not to identify individual schools as vulnerable, but to quantify the risk faced by the entire system. For this purpose, a questionnaire form was prepared and sent to the target school principals for their responses. The questionnaire items were size of buildings, density of students, year(s) of construction, whether or not an engineer was involved in the building design or construction, and so on. Additionally, simple questions about structural characteristics presented through illustrations and descriptions were also asked. Altogether, 17 seminars were conducted with the school principals from about 65 % of a total 643 public schools in the valley to teach them about earthquake disaster risk and necessity of planning for earthquakes at their schools and at the same time to instruct them how to fill out the questionnaire form. From the results of the questionnaire survey and responses from a total of 430 schools, conclusions were extrapolated to the entire building stock of the existing public schools of the Kathmandu Valley. The results of vulnerability analysis are presented in Table 4.

3.4 Transportation system

The Kathmandu Valley is connected with other parts of the nation through two main road systems, one leading to southern neighbor India and other to northern neighbor China.

Table 4 Seismic vulnerability of public school buildings in Kathmandu Valley

Particulars	Details	Percentage
Total number of public schools/buildings	643/1,100	64.3
Typology of traditional school buildings	Adobe (sun-dried bricks) or earthen buildings (mud cake buildings)	5
	Stone/brick masonry in mud mortar	56
	Rectangular block (brick or hollow concrete block or semi-dressed stone in cement mortar)	28
	Reinforced concrete frame (RC frame)	11
Existing condition (with extrapolation for 643 schools)	Hazardous for use at present (pull-down and reconstruct)	10–15
	Can be saved (with structural intervention, retrofit, repair, and maintain)	25
	Good for vertical load (but not for lateral shaking), need retrofitting	65
Vulnerability assessment (for intensities IX)	Collapsed grade	66
	Severe damage or partial collapse (not repairable/not usable after shaking)	11
	Repairable damage	23

More recently, the third but comparatively narrow road has been opened to traffic, which also leads to India though eastern part of the valley. As all these road systems pass through landslide-prone mountain slopes, there are enough chances that the road traffic through these routes is disrupted for days and weeks leading to acute shortage of daily commodities in the valley. Emergency international relief may also be delayed because of disrupted operation of the Tribhuvan International Airport (TIA), the only international access to Nepal. A closer look at seismic performance of the TIA has revealed that it will be potentially dysfunctional after a big earthquake. The ground conditions of the airport area including the runway indicate that there are possibilities of soil liquefaction and landsliding during an earthquake. The airport area largely consists of sandy deposits, and the ground water table below the runway, taxiways, and other airport facilities is close to critical level from the surface. This confirms that there are greater possibilities of soil liquefaction during an earthquake. In addition to liquefaction, loose and unsupported slopes of the TIA's slightly elevated runway ground and apron area are prone to liquefaction-induced sliding failure. The TIA area is surrounded by two river systems in the valley, Bagmati and Manohara, both of which have highly liquefiable banks according to the liquefaction map prepared in 1994 during the Seismic Hazard Mapping and Risk Assessment study by UNDP/UNCHS. If these low land areas subside due to liquefaction, there are high chances of failure of marginal slopes in the TIA area. Therefore, a detailed geotechnical investigation in the TIA area may be a primary concern of all stakeholders so as to accurately assess the liquefaction and landslide potential in this area.

3.5 Other life line damages

In addition to the building damage, it was estimated that almost half of the bridges in the valley could be impassable and that 10 % of the paved roads would sustain moderate damage, such as deep cracks or subsidence. Moreover, many narrow streets in the valley would be blocked by the debris of collapsed buildings. The city of Bhaktapur may not be accessible from Kathmandu or Lalitpur because of the road and bridge damages. The bridges connecting Kathmandu and Lalitpur are also at risk of liquefaction-induced damage. Tribhuvan International Airport is also surrounded by liquefaction prone areas, which means that the airport may also be cut off from access limiting emergency aid from outside.

Also, approximately 95 % of the water pipes and 50 % of other water system components (such as pumping stations, treatment plants) could be damaged seriously. Almost all telephone exchange buildings and 60 % of the telephone lines are likely to be damaged, requiring significant to moderate repair to make them operational. Likewise, approximately 40 % of the electric lines and all electric substations are likely to be damaged. It may take as long as 1 month to repair the electricity and telephone utilities and make them fully operational. Water system facilities, however, will require much more time to repair. It was estimated that most areas of the valley would be cut off from piped water supply for several months while many of them may lose the service for more than a year.

A study for the assessment of seismic vulnerability of the drinking water supply system of Kathmandu city was also undertaken in view of high level of earthquake risk. A practical methodology for assessing the seismic vulnerability of the pipeline network system, its components and institutional capacity was developed by adopting the Applied Technology Council ATC-25-1 (ATC 1992) tool with appropriate adjustment for Kathmandu. The assessment results in a form of network system damage for the scenario earthquake were presented using geographical information system (GIS). Based on possible maximum enhancement of the present intuitional capacity and spatial distribution of the possible damage extent, optimum routes for speedy restoration of the water supply services to meet a minimum level were identified under two different scenarios, that is, in its present state and in an improved system. It was found that a large number of pipeline breakages would take place mainly due to ground shaking. Very old stock of the pipeline without adequate maintenance and almost no incorporation of earthquake disaster risk in design and construction of water supply system are the main causes for such consequences.

3.6 Health facility damage

Considering high seismic damage risk of the Kathmandu Valley estimated at more than 40,000 human casualties and about 100,000 serious injuries requiring hospitalization for a scenario earthquake of maximum intensity of MMI-IX, high concerns are induced over the health facilities. Despite being situated in a seismically active region, Nepal is yet to practice effective application of earthquake-resistant construction standards and no special guidelines have been considered for hospital facilities. Only two hospitals, Tribhuvan University Teaching Hospital and Patan Hospital, are designed against seismic events. For this reason, there are higher possibilities that many hospital buildings will not be functional during a large seismic event.

Under such situations, two studies were undertaken; one to evaluate seismic performance of 14 hospitals in the valley and other to assess quantitatively the state of one main city hospital, known as Bir Hospital. The main purpose of these studies was to develop/apply an appropriate methodology for the evaluation of earthquake vulnerability of the medical facilities in general and to understand the actual situation of the reliability of the medical facilities in the Kathmandu Valley in particular. After this assessment study, an overall scenario of reliability of medical system in the Kathmandu Valley was revealed. The result of this study that only 10 % of the hospitals will be functional after an MMI-IX intensity earthquake reveals an urgent need of improving the earthquake resiliency of existing medical facilities in the valley. The overall performance of the hospitals in different scenario earthquakes is presented in the chart of Fig. 4.

Moreover, the results show that about 80 % of the hospitals fall in unacceptable performance category, while remaining 20 % are at life safety to collapse prevention performance level. So, phase-wise priority recommendations were made for improving the seismic performance of the different valley hospitals. In the first phase, securing of all equipment and contents, strengthening of critical systems, training programs for hospital personnel, and provisions of backup in critical systems were proposed for implementation, while in the second phase, seismic retrofitting of hospital buildings, further strengthening of critical systems, and provision of extra backup systems were proposed. Considering the opportunity of immediate implementation of nonstructural measures of risk mitigation, some examples of mitigation options were also developed during the study.

4 Initiatives for earthquake risk reduction

Action plans for earthquake risk management have been developed for Kathmandu Valley in order to address the earthquake risk estimated from the earthquake scenario development exercise under the different programs. The following subsections describe the current level of action plan development and implementation.

4.1 Kathmandu Valley earthquake risk management action plan

This action plan was created through active participation of about 82 concerned institutions of the Kathmandu Valley, including the main emergency response institutions and

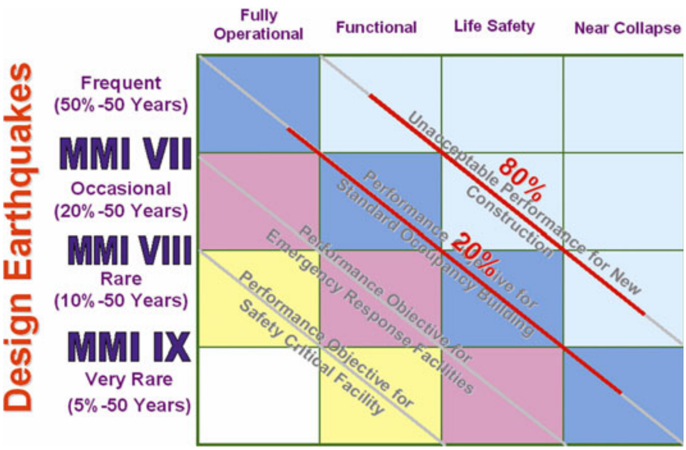

Fig. 4 Overall performance of hospitals in different earthquakes in Kathmandu (risk matrix modified after SEAOC 1995)

agencies. It was initiated for a process of systematically reducing the seismic risk over the time. The action plan process was a logical continuation of the earthquake hazard evaluation and risk assessment component (earthquake damage scenario development). Officially, the action plan was endorsed in the month of January in 1999, and the purpose was to assist the Government of Nepal, concerned agencies, and the municipalities in Kathmandu Valley to reduce the valley earthquake risk over the time through coordination among the agencies and focused risk management activities. Ten specific initiatives were defined as high priority jobs. During the planning process, notably, (a) implementing school earthquake safety program, (b) improving the safety of existing buildings by propagating nonstructural vulnerability measures, and (c) awareness raising and assisting the municipalities to implement seismic code for new buildings were considered as three major plans.

The detailed study on earthquake disaster management in the Kathmandu Valley has helped to generate implementation plan for earthquake disaster reduction at different levels of the government. It was understood that individual disaster management plans should be prepared at each level of government organizations and institutions through a method of full participatory planning by all stakeholders. For that purpose, a framework of the disaster management plan was prepared, as shown in Fig. 5. Main components of the earthquake disaster management study in the Kathmandu Valley were earthquake loss estimation for different earthquake scenarios, a social structure survey, vulnerability assessment of representative buildings, study on legal and policy aspects, and so on. The study also proposed earthquake disaster plans at different levels of government suggesting individual disaster management plans prepared at each level of government and institutions should be developed by the method of participatory planning of all stakeholders. Thus, the earthquake disaster management plans at each level of government fit together as elements of a single overall system, operating in a coordinated fashion.

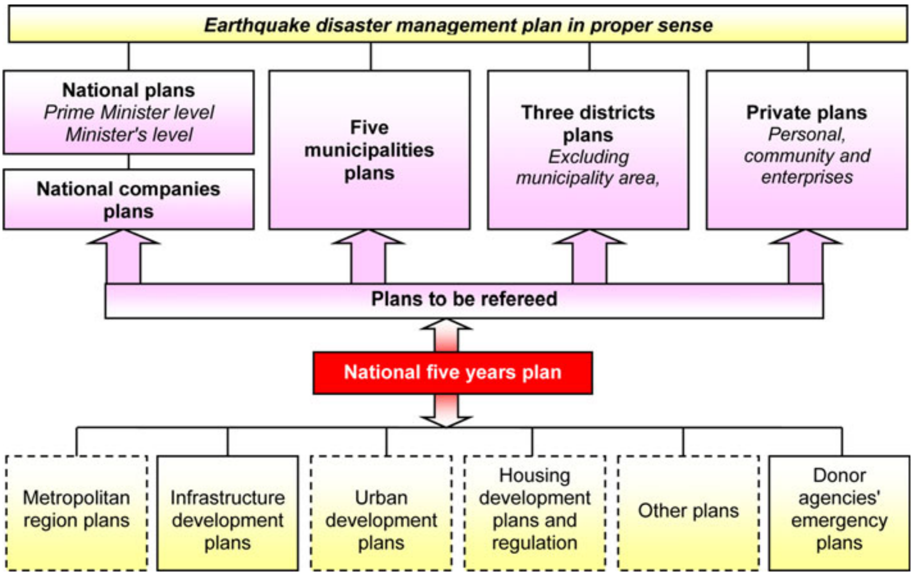

Fig. 5 Framework of disaster management plan

As a consequence of the above plan, it is encouraging today to see that earthquake vulnerability reduction (EVR) measures such as building code implementation, school earthquake safety program, trainings for mason and petty-contractors for earthquake-resistant construction, and awareness raising are common priority items in the action plans of all municipalities of the valley.

Main objectives of Kathmandu Valley earthquake risk management plan were as follows: (1) evaluating the earthquake disaster risk of the Kathmandu Valley and prescribing an action plan for managing the risk; (2) reducing the earthquake vulnerability of public schools; (3) raising awareness among the public, government officials, international community in the Kathmandu Valley, and international organizations; and (4) building local institutions that can sustain the work which were included in the action plan.

The plan included a wide variety of activities aimed at beginning a self-sustaining earthquake disaster risk management program for the Kathmandu Valley. The program components were as follows: (1) development of an earthquake scenario and an action plan for earthquake disaster risk management in the Kathmandu Valley, (2) a school earthquake safety program, and (3) awareness raising and institutional strengthening.

The project was implemented through strong participation of national government agencies, municipal authorities, professional societies, academic institutions, schools, and international agencies in the Kathmandu Valley. These organizations serve the program through their presence in advisory committees, various workshops, seminars, interviews, and joint programs. The major accomplishment of the project is development of an earthquake damage scenario and an action plan for reducing the earthquake disaster risk of the valley. The action plan is a consensus document depicting roles and responsibilities of all concerned institutions in managing the earthquake disaster risk of Kathmandu. School Earthquake Safety Program was another major accomplishment, which established technical and social feasibility and affordability for seismic improvement of school buildings. It has now been a well-established program, which not only helps to build the school buildings stronger, but also serves as an awareness-raising tool that ultimately makes the entire community safer against earthquakes. Training of masons in earthquake-safe construction and disseminating the earthquake safety information to children, teachers, parents, and community at large are the strongest parts of the School Earthquake Safety Program, which is found as beginning of a self-replicating process. The Kathmandu Valley earthquake risk management plan also helped institutionalize the earthquake safety consideration with several policy shifts.

4.2 Preparedness programs

4.2.1 School earthquake safety programs

As the centers of social life, schools play a vital role in communities of a developing country like Nepal. They can play an important role in raising awareness because any type of message can reach the parents, their relatives, and the entire community through the pupils and the teachers. Schools can also play a crucial role in helping a community to get back on its feet after an earthquake. However, in Nepal, both the school buildings and their occupants face extreme risk of earthquake disasters. A study was carried out in the Kathmandu Valley, which revealed that more than 60 % of the buildings are highly vulnerable to earthquakes even in normal conditions. Therefore, vulnerability reduction programs in schools were prompted with the following primary objectives.

(a) Seismic retrofitting or earthquake-resistant reconstruction of school buildings.
(b) Training of teachers, students, and parents on earthquake disaster risk mitigation and preparedness.
(c) Training of local masons on earthquake-resistant building construction technology.

The program has been found successful in encouraging community participation in raising earthquake awareness significantly. Masons trained in the program have now successfully spread the technology of earthquake-resistant construction in their communities by replicating it while constructing new buildings as well as providing hands-on training to other masons. Effectiveness of the program as well as its sustainability has been demonstrated. The experiences gained during the implementation of this program have been translated into a technical manual for designers and builders with an aim to assist them with designing and implementing earthquake-resistant school building construction practice. Furthermore, the approach and methodology of this program is in process of being adopted by the Ministry of Education and other educational institutions in their regular plans and programs.

4.2.2 Community-based risk management programs

Common people started to have an increased interest in earthquake issues and raised questions shortly after the implementation of Kathmandu Valley Earthquake Risk Management Project (KVERMP). Many requests for conducting awareness-raising trainings have also started to appear from many community-based organizations. In Nepal, for administrative or political purposes, municipalities and VDCs are divided into number of small districts called as "Wards." The initiatives are being carried out through the Ward Level Disaster Management Committee with the support of the KVERMP along with other local, national, and international institutions. Scope and effectiveness of the efforts have increased with the participation of a wide range of society. Various disaster risk management activities have been initiated in the valley, especially under the KVERMP. Annual programs have been prepared for conducting household-level survey in municipality wards, implementation of training programs for the ward residents, awareness-raising activities and mobilization and training of young volunteers in earthquake disaster management issues and other activities. Till date, several trainings, community meetings, and awareness-raising activities are organized annually. Although a systematic survey is yet to be carried out to assess the impacts, there are many positive signs that indicate a positive impact of the community-based programs. Some of the indicators of the positive impact are as follows:

- The participants and volunteers interested and committed to work for disaster risk reduction have significantly increased.
- Some wards of the KMC have been already replicating the approaches and activities carried out in pilot program area in their wards and requesting the pilot program area to assist in organizing community-level trainings.
- The experiences have been shared with the similar initiatives carried out in other municipalities and districts.

4.2.3 Institutional strengthening programs for seismic code implementation

Toward promoting safer building construction, a partnering approach with other organizations and stakeholders is stated in municipality level. Experts are supporting programs for the integration of seismic resistance into the process of new construction, improving seismic performance of the existing buildings, and in increasing the experts' knowledge of the earthquake phenomenon, vulnerability, consequences, and mitigation techniques. In collaboration with various organizations, metropolis provide regular orientation programs to house owners.

The LSMC started compulsory implementation of the provisions of Nepal National Building Code, which includes earthquake-resistant design and construction practices. Figure 6 shows the framework of building code implementation in LSMC. Now, the KMC and other municipalities are doing preparatory works for implementing the building code in their byelaws.

4.3 Awareness programs

Raising earthquake awareness is a strong component of the initiatives of Kathmandu Valley earthquake risk management programs. Various awareness activities have been started in both government and nongovernment level. All these activities are designed to raise the awareness of different target groups, such as government officials, media, international agencies, that is, all sections of the society from officials and decision-makers at the central government through the municipal and ward-level authorities and elected representatives to the communities in the villages. However, the objectives of awareness-raising activities are different for different target groups. For example, for politicians and high profile government officials, the objective is to convince them of the necessity to look at disaster risk reduction as a national development issue; for general public, it is to enable them with a capacity to understand risk and identify possible measures of reducing the vulnerability on an incremental basis. Moreover, the awareness-raising programs are designed in such a way that they not only mean knowledge and information transfer but also internalization of knowledge, and ultimately its ownership and use, as much as possible, in day-to-day life of common people. Some of the major awareness-raising activities is described in the following subsections.

4.3.1 Earthquake Safety Day

The Government of Nepal has designated January 15 as the Earthquake Safety Day in recognition of the occurrence of the latest big earthquake that hit the Kathmandu Valley on January 15, 1934 (Fig. 7).

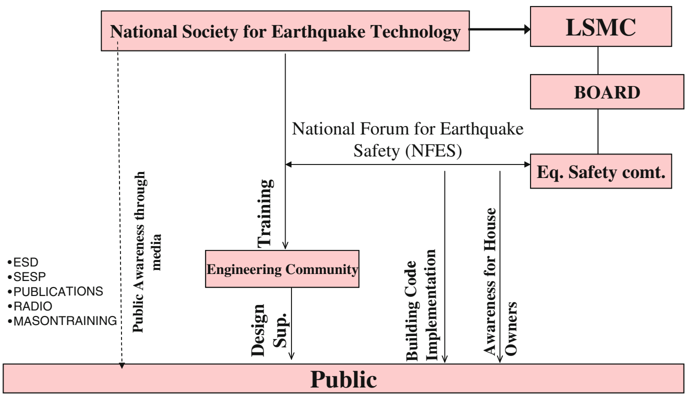

Fig. 6 Building code implementation framework in the LSMC

The Earthquake Safety Day has been designed to include two main activities, that is, Earthquake Safety Exhibition and Symposium. Other associated events include public broadcast of earthquake safety message by the Prime Minister, awareness rally in the streets, national meeting with government ministers, shake-table demonstration of traditional building models with and without seismic safety elements, children's essay/painting competition, street drama on earthquake safety, and so on. Moreover, numerous publications such as information leaflets, calendars and earthquake-resistant construction posters are distributed to the public.

4.3.2 Radio/TV programs

Several local radio and TV stations air earthquake safety and preparedness messages on a regular basis using various earthquake-related publications as a basic guide for mass education. Local FM radios in major cities of Nepal air weekly 30-min programs on earthquake safety. The Kathmandu Municipality has also provided adequate time slot per week on the nation-owned Nepal Television to broadcast a program series on earthquake safety and earthquake-resistant construction targeting mainly the house owners.

4.3.3 Public talk programs and orientation programs

A number of public talk programs on earthquake safety have been organized in different community gatherings, such as regular meetings of Rotary Clubs, Scout Jamborees and trade association meetings. The number and regularity of such talk programs have significantly increased, especially after the Nepalese professionals participated in study and reconstruction activities after the Gujarat Earthquake of 2001. The experiences of Gujarat have not only informed the public about the Kathmandu Valley's earthquake risk, but have also given important feedback on the concerns and perceptions of the public, which have subsequently helped to tailor the public awareness campaigns. Likewise, in different occasions of meetings of professional organizations, such as Nepal Engineers Associations,

Fig. 7 Celebration of Earthquake Safety Day on January 15. This has extensively helped to raise awareness for earthquake safety among the valley citizens

Society of Nepalese Architects and Nepal Geological Society, earthquake-related lectures are frequently incorporated.

Similarly, some nongovernmental organizations have also started to organize free-of-cost weekly orientation programs on retrofitting and earthquake-resistant construction targeting the house owners. Similar programs are now also regularly conducted for the contractors and builders, focusing mainly on the aspects of earthquake-resistant construction methods. It has been found that a walkover through the municipal areas of the Kathmandu Valley with the builders involved in major constructions and analysis of the structural details together with them are an effective method to convince them of the commonly practiced mistakes in construction method.

4.4 Improvement in policy

The awareness and preparedness program has now created an environment of influence on the policy makers toward earthquake disaster risk mitigation in Nepal. Subsequently, several policy improvement initiatives have also been formulated and implemented in the country. These policies help create conducive environment for achieving disaster risk reduction and emergency response. Some of the efforts and achievements in these areas are described in the following subsections.

4.4.1 Mandatory implementation of building code

The Bureau of Standards and Metrology of Nepal has initiated a process to recognize the draft building code as Nepal Standard. Several of the 22 documents that were prepared as the National Building Code focusing primarily on seismic safety of building structures has been accepted as Nepal Standard. Recently, the Council of Ministers has decreed that the stipulations of the National Building Code should be made obligatory for the construction of all government-owned buildings. It has also directed the municipal authorities to strengthen the current building permit process so that code compliance becomes mandatory for all new constructions in the urban areas of the Kathmandu Valley.

4.4.2 Disaster mitigation policy in National Plan

For the first time in Nepal, the document on the tenth year development plan incorporates natural disaster management as one of the objectives of the government in order to contribute toward making the national infrastructures durable, sustainable, and capable of providing the intended service. Thus, the development plan of the country now encourages prevention and mitigation as important activities toward disaster management. The policy statement in the plan includes preparation of long-term disaster management action plan, incorporation of disaster risk in infrastructure construction projects, conduction of public awareness programs on disaster, establishment of central disaster management department and earthquake hazard mapping. In the same spirit, the government has also allocated a nominal amount for building code implementation under a separate heading in the national budget.

4.4.3 Local governance acts and policies

The recently promulgated Local Self Governance Act 1999 gives a fresh momentum to the process of decentralization and devolution of authority. It empowers the local governments to undertake disaster management activities. Techno-legal aspects of mitigation actions are now considered within the jurisdiction of local governments. A separate act, notably, KMC Act, is being formulated in order to provide a comprehensive legal and policy framework for an effective governance of the capital city in the Kathmandu Valley.

5 Outcomes

The following are some of the important achievements of the earthquake risk management plan in the Kathmandu Valley.

- There has been a remarkable change in terms of policies, especially in the area of building code development and implementation.
- The level of public earthquake awareness has remarkably enhanced, especially in areas where people and agencies were active in the past one decade. It indicates a very high potential of bringing in changes in other parts of the country too.
- The demand for earthquake-resistant construction method is growing. House owners have started to influence the municipal authorities for including seismic safety measures in the building permit process. The importance of such change in peoples' attitude toward earthquake safety becomes obvious when one considers that it is taking place at a time when there has been no significant devastating earthquake in Kathmandu in the past several decades.
- Nowadays, more and more institutions are implementing earthquake risk management action as their regular agenda.

While these changes are very positive, they are still in beginning stage. A lot more needs to be done and a number of challenges are yet to be met. Twenty years ago, the concerned professionals and agencies were at their wit's end, especially after the 1988 Udayapur Earthquake, but now, the same people and agencies know how things can be improved, so they have implemented various programs that include disaster mitigation.

6 Challenges and further improvements

The achievements made by Nepal in the past 15 years in terms of successful implementation of earthquake risk reduction actions could be considered as a matter of pride and satisfaction by those who are directly or indirectly involved in the process. The success made is surprising, especially if one considers the fact that Nepal is one of the weakest economies and it has not made any significant investment in disaster risk reduction, and that the seismic risk of the country is one of the highest in the world if one considers earthquake lethality as an indicator.

Such situation puts forward two main challenges to the concerned professionals and agencies: (a) continue the work done so far to ensure continuity of the dividends from the investments made so far and (b) assist the local institutions, central and local governments, and nongovernmental organizations, to take up new and ever-widening responsibilities. One has to understand that raising earthquake awareness of the community reduces the risk significantly, but it also tremendously increases the demand for more and better knowledge, technologies, management tools, institutional capabilities, and improved policy and legal environment. Coping with such natural, expected, and desired outcome may become a maddening trance for a disaster activist, especially if he/she or the institution fails to receive necessary support or even a moral support.

In several occasions, the available methodologies of assessment as well as mitigation may not be suitable in the context of the local environment, largely because of the difference in typologies of construction resulting from the preference of certain construction materials by the local community. Appropriate methodologies need to be developed and tested so that the local problems could be addressed properly. An example could be assessing the available seismic resistance of typical Nepali buildings built in brick with mud mortar, such as numerous historical monuments, old temples, and even residential buildings that were constructed centuries ago. A careful understanding of the seismic resistance of the traditional architectural styles needs to be developed so that there is unison approach while trying to improve the seismic performance of existing traditional buildings.

With these successful activities, however, the challenge now is to continue the momentum so that the lessons learned could be utilized on a larger scale so as to improve earthquake performance in many more number of urban and urbanizing settlements in Nepal and adjacent areas. The problem is enormous given the rapid growth of the urbanizing settlements in the country. In the existing settlements, such as the core areas of Kathmandu, the problem appears to be almost hopeless. However, successful cases of effective awareness-raising programs and achievement of positive changes in the mindset of people provide certain level of optimism on the possibility of vulnerability reduction even in old cities like Kathmandu. With these understandings, the following suggestions are made for further improvements.

6.1 Improve formal and informal communication

People tend to shy away from earthquake risk reduction concepts because of the general unfamiliarity with the phenomenon. This results generally in a lack of proper interest and low level of buy-in. Communication with the stakeholders could be effective under such situation only if the communication is frequent, repeated, persistent, and accompanied by successful demonstrations. Focusing on implementation of earthquake risk reduction activities, howsoever small, is therefore necessary.

6.2 Need a drastic improvement in capacity

The Nepalese institutions responsible for the disaster risk reduction and emergency response do not generally have required capacity. Even the qualified civil engineers and geoscientists in several occasions do not have enough exposure to elements of earthquake engineering because many of them might have studied overseas where the earthquake problems are insignificant. On the other hand, many municipal agencies do not even have an adequate number of engineers and architects to ensure improved seismic safety of buildings and institutions. A chronic problem is lack of adequate number of trained building inspectors with the municipal corporations.

The following are seen as the major tasks that need to be addressed in the near future:

(A) Scale-up activities: Time is running out because the next expected big earthquake is considered to be just a few steps behind the doorstep. It is therefore necessary to scale-up implementation of methodologies and programs that have proven to be replicable, in as wide geographical area as possible. Some of these successful programs include hazard/risk assessment, action planning of earthquake risk management, implementation of school earthquake safety program, mason training, earthquake awareness, and so on.

(B) Make the approach comprehensive: Success in earthquake risk management cannot be achieved on a piecemeal basis. The efforts should be comprehensive; it should tell a common person how to construct a safer house, how to maintain it, how to convince his/her neighbor on the benefits of earthquake vulnerability reduction, what to do before, during, and after an earthquake, how to demand earthquake safety from the state, etc.

(C) Emphasis on action-oriented implementation: It is clear at this stage that the School Earthquake Safety Program has demonstrated that it works wonderfully in developing countries. So, implementing similar initiatives immediately is imperative.

(D) Emphasis on grassroot-level works: The most vulnerable are the people at grassroot level, and the most willing to implement earthquake vulnerability reduction are also people at grassroot level.

(E) Publicize success stories: Given the low level of awareness and the complexity of earthquake risk reduction measures, success stories should be publicized widely.

6.3 Methodologies for assessment and mitigation suitable for local problems

In many occasions, available methodologies of assessment and mitigation are not suitable in local environment. So, appropriate methodologies need to be developed and tested so that the local problems could be addressed properly. For example, there are several historical buildings, monuments, and temples built of brick in mud mortar technology. Many of these structures in the Kathmandu Valley have been standing for 100 of years and are still in use. Obviously, they are strong enough to have resisted several of the devastating earthquakes in Kathmandu and parts of Nepal.

7 Concluding remarks

As a moderately earthquake-threatened region, Nepal has suffered from a large number of devastating earthquakes in the past. As such, the disaster record does not clearly indicate any massive loss in historical earthquakes, but the latest great earthquake of 1934, which hit Bihar state of India and the whole Nepal, has been comparatively well recorded as one of the devastating earthquakes in Nepal. This earthquake extended a tremendous loss, mainly in the capital area of Kathmandu Valley, which as a soft lake deposit is comparatively vulnerable to earthquake damages. The recorded earthquake history of Nepal roughly indicates that an earthquake of 1934 scale is generated in about 100-year interval, so on the basis of experts' predictions, Nepal expects a big earthquake in next few decades. Up until early 1980s, no one was worried much about mitigating the risk of earthquake disasters in Nepal, but after the 1988 East Nepal Earthquake, the perception of earthquake disaster risk in Nepal, especially in the Kathmandu Valley, started to change, which in about two decades have encouragingly influenced the national policy and public awareness level on earthquake disaster risk of the nation and the capital.

A large number of activities have been started for assessment and mitigation of the earthquake disaster risk in the Kathmandu Valley. This paper has provided a comprehensive information about most of the activities and initiatives taken by the governmental and nongovernmental organizations in Nepal for earthquake disaster risk management in the Kathmandu Valley. Most of these activities are related to the assessment of risk, awareness programs, institutional strengthening, and public participation; however, the impact of initiatives and programs is worth mentioning and it creates drastic change in the government and public attitude toward earthquake disaster in the valley. As a result, a broader base of support for earthquake disaster risk management activities is already consolidated. Similarly, through institutionalizing multiple organizations to manage earthquake risk initiatives and earthquake risk management in the Kathmandu Valley is planting the seeds for a locally driven and sustainable disaster risk management process in the south Asian regions.

Acknowledgments This paper is an outcome of the last 20 years of work experience in the field of earthquake risk management in the Kathmandu Valley, and it is largely based on the work done by National Society for Earthquake Technology Nepal (NSET, Nepal). All research staffs of NSET are sincerely acknowledged for their technical support during the preparation of this paper. Also, the comments provided by three anonymous reviewers have greatly enhanced the quality of this paper.

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