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MULTI-HAZARD VULNERABILITY ASSESSMENT OF AN URBAN AREA: A CASE STUDY ON WARD 34 OF DHAKA SOUTH CITY CORPORATION

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Abstract

Multi-hazard assessment provides the scope to understand the vulnerability situation of any area based on different hazard context. This study was conducted in one ward of Dhaka city corporation area to examine its multi-hazard vulnerability. Three key potential hazards: fire, earthquake and water-logging were considered to implement the multi-hazard analysis framework. To perform the analysis entire study area was surveyed and examined applying Geographic Information System in terms of practicing planning rules and regulation of Government of Bangladesh. All the structures of the study area were assessed and categorized into four classes ranging from severe to none according to some vulnerability criteria defined by safety standards. Individual vulnerability analysis was performed to realize the hazard specific vulnerability context. Finally, single processed hazard maps were combined to examine the multi hazard vulnerability of this study area. These findings denote that there are a certain number of structures in very risk position which should receive immediate hazard mitigation measures.

Key words: Multi-hazard, GIS, Vulnerability, Urbanization, Planning Standard, Fire, Earthquake, Water-Logging

Introduction

Urbanization and rapid population growth lead to the concentration of population in hazard and risk prone urban areas, both in mega cities and in small and medium sized urban center although it is the size, number, functions and geographical distribution of medium to large and mega cities that create a major concern for disaster risk (Gencer 2013). The interconnection between natural and human influenced disasters has made the hazard assessment system more holistic that consider all the potential vulnerable factors than counting single events. Many hazards can be caused by the same events. Assessment and mitigation of the impact of catastrophic events in a given area require innovative approaches allowing a comparison of different risks and accounting for all the possible cascade events (Marzocchi *et al*. 2009). The multi hazard assessment (MHA) is an excellent tool to create awareness in mitigating multiple hazards. It becomes a comprehensive analytical tool for assessing vulnerability and risk to develop an integrated emergency preparedness response and recovery procedures (OAS 1991).

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The geographical setting of Bangladesh has made this country vulnerable to many natural hazards. Situation becomes worst when it merges with manmade disasters especially in the urban areas. With the advancement of urbanization cities are deliberately shifting towards vertical direction to cope with the extensive population pressure. The unplanned and uncontrolled construction of high rise buildings, paved roads and markets are emerging as risk factor for the urban dwellers. Many of those were constructed without following planning rules and regulations which cause needless human suffering and economic losses. This study intends to analyze this hazard situation of an urban setting from planning perspective considering all potential hazards experienced in previous years.

The study aims to analyze hazard specific vulnerability situation of the study area considering the potential hazards. Three main hazards of the study area: fire, earthquake and water logging were considered to conduct multi hazard assessment on the basis of different vulnerability criteria. Here, the vulnerability criteria have been chosen mainly from planning views.

Materials and Methods

Multi Hazard Assessment (MHA) becomes an influential tool to the decision makers for future planning initiatives because it can provide a composite hazard profile for the target area. To perform this assessment it is required to prepare individual hazard analysis that might cause risk to that region. In this study attempts were taken to analyze three hazards as fire, earthquake and water logging individually that ultimately provide the composite vulnerable situation of the study area. In compliance to authentic secondary information individual buildings were also surveyed to assess their vulnerability situation in accordance to several practicing planning rules of Bangladesh. Specific vulnerability criteria for each hazard were specified based on safety standard applicable for urban areas. Weightage and scoring methods were applied to analyze the vulnerability of structures which were finally described in hazard maps developed in ARCGIS. The individual hazard vulnerability was assessed in scale 0-3 (Table 1).

Table1. Hazard wise vulnerability score of fire/earthquake/water-logging.

Scale	Score
Severe	3
Moderate	2
Light	1
None	0

The individual results were then accumulated in one single map to get multi hazard picture. The interconnectivity between earthquake and consequent fire event influences to develop a hazard map for these two hazards. Finally, a multi hazard map describing vulnerable situation for these three major hazards was developed. This map has divided the area into four vulnerable zones as severe, moderate, light and none based on their vulnerable situation.

Study Area

Dhaka, the capital city of Bangladesh, is renowned not only because of its huge population, but also in terms of economy, trade, commerce and administrative facilities. Megacity Dhaka is an agglomeration of Dhaka South City Corporation (DSCC), Dhaka

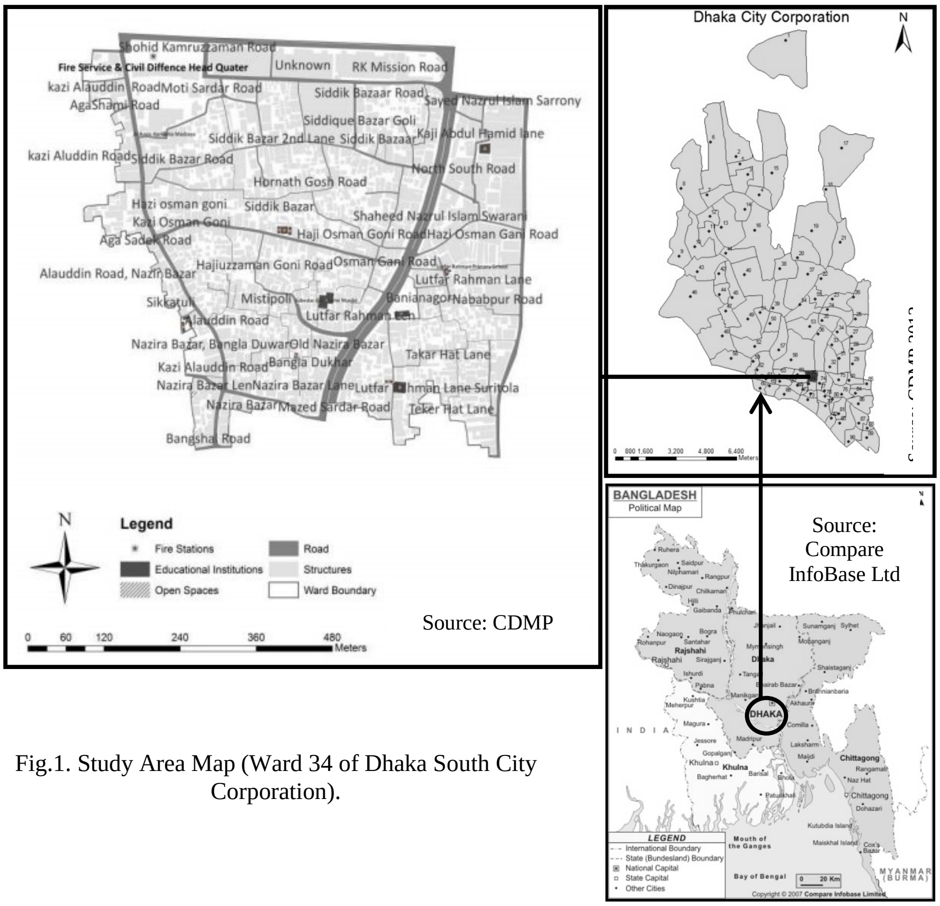

Fig.1. Study Area Map (Ward 34 of Dhaka South City Corporation).

North City Corporation (DNCC), four other municipalities (Narayanganj, Tongi, Gazipur and Savar), several cantonments and a large number of rural settlements, stretches of agricultural lands, wetlands, rivers, and even part of the Modhupur forest (Islam 1998). This study was conducted in ward no. 34 of Dhaka South City Corporation (DSCC) area (Fig. 1). The ward includes Siddique Bazar, Taker Hat Lane, Nowabpur Road, Hazi

Osman Goni Road, Nazira Bazar Lane, Lutfor Rahman Lane, Kazi Abdul Hamid Lane, Kazi Alauddin Road and Fulbaria Puraton Railway Station (Kotowali Part) (Fig. 1). Total area is about 0.37 sq km with a population of 50624 (BBS 2014). To keep pace with the increasing demand new buildings are emerging by demolishing old structures. This mixed used area is characterized by both old and new structures surrounding narrow and congested old roads (Khatun 2003). Most of the buildings are used for multipurpose including residential, industrial and market which poses great risk to live and livelihood. Violation of rules increases the vulnerability to fire and earthquake hazard. Moreover, unplanned urbanization results in water logging that makes the lives of the inhabitants miserable.

Results and Discussion

Hazard specific vulnerability criteria were fixed to analyze the potential hazard of the study area. Based on the result the multi-hazard vulnerability was assessed.

Fire Hazard Vulnerability: Fire is always ranked as top most vital hazard for any urban area. It poses devastating impacts on communities. Several factors like unplanned urbanization, high population density, lack of following safety codes, lack of proper monitoring and development strategy etc. causes fire event in an urban area. In Dhaka, fire is quite a predictable risk factor especially for high-rise buildings in mixed used areas that constructed violating safety codes (Islam and Adri 2008).

The building owners of Bangladesh are bound to follow the building construction rules amended in 1996. This rule imposes conditions on setbacks, site coverage, plot usage etc. that ensures building safety during different hazards. Set back defines the optimum distance that a structure should maintain from adjacent road and other structures to offend spreading hazard effect. In case of fire event this distance plays a very crucial role. The shorter the distance the structures are more vulnerable to catch up with fire from nearby sources. According to building construction rule 1996 at least 1.80 m (to some cases it can be 2.00 m or more based on plot size) have to be unoccupied to keep buildings safe. So, buildings were identified into five cases based on buffer distance as 0.5 m, 1.00 m, 1.50 m, 2.00 m and more than 2.00 m to measure potential vulnerability of the study area in terms of susceptibility to spread fire event. The study found about 87.67% structures have space less than or equal to 1.5 m space that does not follow the minimum standard defined by GoB.

To asses fire hazard vulnerability access to road is always considered as one of the important factors. Death tolls goes higher if fails to control at the right moment where access roads provides the opportunity to get escape as well as access to rescuers. In the study area a good percentage of structures has limited and even no access to roads (Field Survey 2013). The residents of this area use man made walkway or even balcony and courtyard of adjacent structures to access their living place. It increases the vulnerability of losses due to fire hazard. Previous experience of fire hazard in older part of Dhaka city proves this statement (Islam and Adri 2008 and Roy 2011). Many people get trapped within their structures during fire event. Moreover, fire control equipment cannot reach to them only because of lack of access road. The field observation states that structures having access road at least 10 m distance provide them the opportunity to get escape from their place but only presence of access road does not represent low fire hazard vulnerability. According to Building Construction Rules, 1996 every site has to be accessible to road having width minimum 3.65 m which can be 3.00 m width in case of private own land that ensure easy access to people and vehicle. According to fire service and civil defense (FSCD), in Bangladesh at least 3.05 m (10 ft) road width is needed to access fire control car. Thus structures were identified as having access to road with 3m width or not. The field survey states that the main roads have width more than or equal to 3 m but inner roads hardly meets the requirements. The study revealed that about 25.43% of the roads having width only 1 m. Some places were even found where people cannot bring their furniture within their home due to narrow road width. They bring raw wood and make furniture within their living space. From this scenario the condition of ward no 34 in DSCC can be realized. If fire hazard occurs in these places it is quite impossible for fire control car to reach. In this case fire control pipe or pump is used which needs more time to control fire event and thus existence of narrow roads certainly increases vulnerability to fire.

Ward no 34 in DSCC is basically a residential area but intrusion of various kind of usage has transformed the area as a mixed-up one. A single structure is used for different purposes like residence and retail, residence and industries, garments and hospital etc. which increase fire hazard vulnerability. Study revealed that only 50% of the structures are solely used for residential purpose and the rest are accounted for commercial, educational and even industrial activities and many of them handle highly flammable ingredients as raw materials. The primary information collected from Fire Service and Civil Defense (FSCD) provides the data for fire events that happened in last year in the study area. According to their information most of the fire events ignites from chemical, leather and shoe factories due to using chemical and glue which are highly sensitive to fire. Besides, the previous experience states that the hazardous structures used as garments, workshop and storage are also vulnerable for fire hazard in terms of both source and spreading perspective (Roy 2011). The highly flammable material used for these activities can easily spread fire. Buildings located nearby to these sources are considered as highly vulnerable to fire events.

Beside these vulnerable structures electricity supply sources may also appear as potential fire source if not follow safety rules. According to Electricity Rules, 1937 every conductor of an aerial line shall be inaccessible either from ground or from any building or structure, whether permanent or temporary except by the aid of a ladder or other special appliance (Electricity Rules 1937). That means, a safe distance has to be kept from electric pole to avoid fire incidence. Buildings were surveyed based on distance maintained between structure and electric pole and vulnerability score were given.

The vulnerability situation for fire hazard was then analyzed by applying some score (Table 2) as given below:

Table 2. Fire hazard vulnerability score.

Criteria	Weightage	Sub-criteria	Score
Distance from Hazardous Building (HB)	6	Hazardous Structure	3
		Structure within 15m from Hazardous Structure	2
		Other Structure	1
Space between Structures (ST)	5	Space less than or equal to 0.5 m	5
		Space more than 0.5 m to/equal to 1.00 m	4
		Space more than 1.00 m to/equal to 1.50 m	3
		Space more than 1.50 m to/equal to 2.00 m	2
		More than 2 m	1
Distance from Electric Pole (EP)	4	Structures within 1m	4
		Structures within 2m	3
		Structures within 3m	2
		Structures within 4m	1
		Distance more than 4m	0
Proximity to Roads (PR)	3	Roads within 10m	1
		Roads within 15m	2
		Roads within 20m	3
		Distance more than 20m	4
Width of Access Road (WR)	2	Accessible	1
		Not Accessible	2

Here, the weightage score was assigned based on their significance to ignite and increase the intensity of fire events. Expert opinion was also considered while assigning this value. In this analysis scale was chosen as 1 equals to low and 6 equals to high value. A rank value for sub-criteria was also assigned to understand the vulnerability situation of each structure that ranges from 0 to 5 where zero means the building is not vulnerable to fire hazard whereas 5 indicates the high susceptibility to fire. Based on weightage and ranking value Fire Hazard Vulnerability (FHV) Score was calculated as:

FHV= (6 x Score of HB) + (5 x Score of ST) + (4 x Score of EP) + (3 x Score of PR) + (2 x Score of WR)

Finally, all the structures were categorized as severe, moderate and light vulnerable in terms of fire hazards. None of the buildings was found which show zero vulnerability. According to the analysis only 2.03% of the structures are at great danger. Certainly, it is good for the area that the proportion of severe vulnerable categories is less significant. However, approximately 60.44% and 37.53% structures were also identified as moderately and lightly vulnerable respectively. The situation can be well described from Fig. 2.

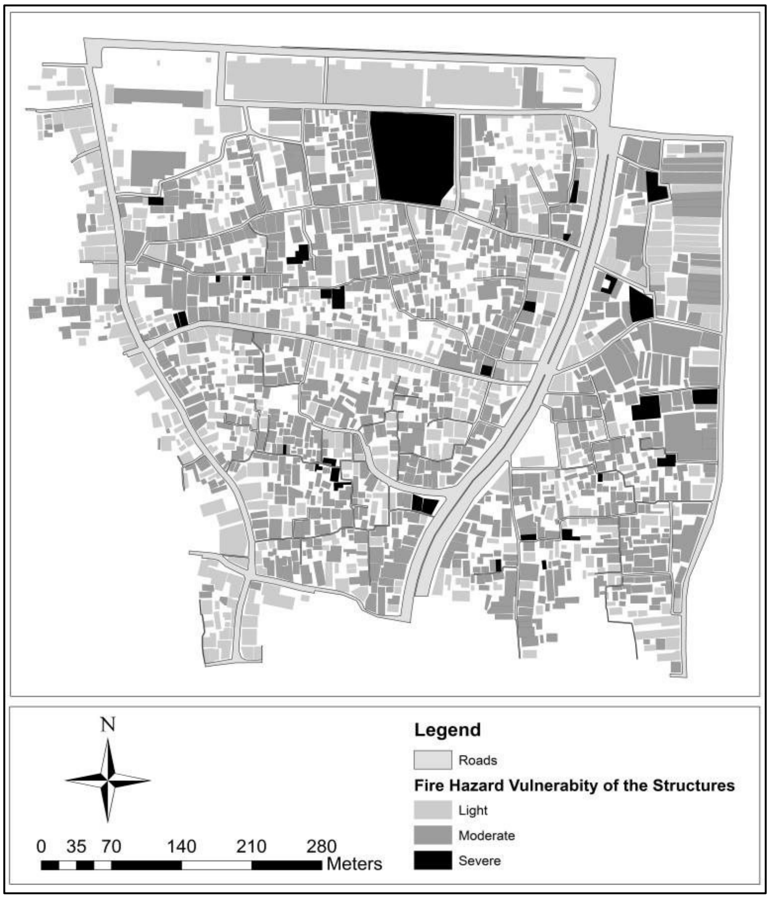

Fig.2. Fire Hazard Vulnerability Assessment (Source: Field Survey 2013).

Earthquake Hazard Vulnerability: The geographical and topographical setting of Dhaka makes it vulnerable to earthquake hazard. Unplanned urbanization with high population density can turn the situation to its worst. A study conducted by Cardona *et al*. (2001) ranked Dhaka city as one of the highest values of earthquake disaster risk index (EDRI) among other twenty cities in the world mainly due to its inherent vulnerability of building infrastructure.

The total number of floors above the ground level is one of the most important factors to measure earthquake vulnerability. From the previous earthquake experiences it has been estimated that the proportion of severely damaged structures increases steadily with building height which follow negative trend for the low rise structures. Here, age of building also describes the vulnerability situation of any structure. As time passes buildings start to decline its strength and fail to resist any earthquake force which is significantly important for high-rise structures. In this area, about 4.73% structures were built before 1960 having height 1-6 stories which are extremely vulnerable to earthquake hazard. There are still some (1.57%) buildings which are more than 90 years in age. Among those about 0.14% structures have 4 stories which indeed show high vulnerability to earthquake.

In recent time, people are interested to go for vertical expansion which may also bring danger if proper rules are not followed during planning and construction. Many buildings of ward no 34 in DSCC were found to have heavy overhang, short column and soft story. In earthquake engineering these irregular shapes are considered undesirable because they cause an inappropriate dynamic behavior when subjected to horizontal earthquake ground motion (CDMP 2009 and Sucuoglu and Yazgan 2009). Limited building space insists people to ensure the maximum use of their land which results in heavy overhang part of their structure. Besides, some architectural design allows overhang to increase the aesthetic appearance. In the study area there are about 559 (33.35%) structures found having overhang section. Generally, commercial places keep some vacant places at ground level for the easy movement of people which is covered from second floor through heavy overhang. In case of residential structures people use this part as balcony, open space, small room and some other purposes. Some buildings were found to have their overhang part far beyond the plot boundary which is totally illegal from planning perspective and restricted by law. Similar to heavy overhang section short column is also a common practice in ward 34 in DSCC. About 26.68% structures observed having short column that attract several times larger earthquake force and suffer more damages compared to taller ones. There are also about 32.68% structures found with soft story. Soft story usually exists in a building when the ground story has less stiffness and strength compared to the upper stories. Many buildings with soft stories were observed to collapse in the past earthquakes all over the world (CDMP 2009, Sucuoglu and Yazgan 2009 and Sadat *et al*. 2010).

The lack of sufficient clearance between adjacent buildings allows them to pound together due to different vibration periods and consequent non-synchronized vibration amplitudes of earthquake. The foundation of building moves back and forth with the ground when experiences earthquake vibrations and the upper edges of the building swing from a few mm to many inches depending on their height size and mass. This may happen for buildings of all height but higher stories pose more damage (NZSEE 2006). In the study area there are about 38.54% structures show less than 0.5 m distance from adjacent buildings which may have the great potentially to have pounding effect during earthquake.

There is also a close relationship between apparent building quality and building damage. In most of the cases poor quality buildings show poor performance during earthquake. Quality building material and proper maintenance system determine the apparent building quality of any structure. For this study buildings were classified as good (have good strength and look lucrative), moderate (have moderate strength and maintenance works perform occasionally) and poor (have weak strength and no/seldom performs maintenance/repairing works). Following this criteria there are about 35.44%, 46.48% and 18.08% structures in good, moderate and poor quality respectively.

Ground motion intensity may increase on top of hills due to topographic amplification during earthquake. The methods used in this study consider buildings as vulnerable which are located on steep slope (steeper than 30 degrees). Structures located on steep slope are incapable of distributing the ground distortions evenly to structural member above and in consequence the potentiality if building collapse in seismic wave. A study conducted by CDMP in 2009 states that the slope in Dhaka City Corporation (DCC)ranges from 0-15 degree which means topographic effect create negligible impact for most part of DCC. Earthquake intensity also depends on soil characteristics. The mechanical properties of the rock and soil, such as incompressibility, rigidity and density play an important role in the speed, shape and duration of earthquake waves. The CDMP study also shows that soil properties of the ward no. 34 in DSCC consists of very dense soil and soft rock which reduces the intensity of earthquake wave.

From this information the vulnerability score for Reinforced Cement Concrete (RCC) structure were calculated using the method followed by Japan International Cooperation Agency (JICA) and Comprehensive Disaster Management Program (CDMP). This method is applicable for RCC structures with a height limit of 7 stories but in most of cases damage level of taller buildings can also be calculated following the similar methods (Alam *et al*. 2008).

Performance score for each building was then calculated based on the value assigned for vulnerability parameters (Table. 3), initial score and vulnerability score. The equation was:

PS = Initial Score – [(Vulnerability Parameter) x (Vulnerability Score)]

According to Peak Ground Velocity the study area is located under Zone II (CDMP 2009 and Sadat *et al*. 2010). Finally, the damage level (vulnerability) of buildings can be classified into three categories based on their PS value as Light, Moderate and Severe/collapse. There are about 14.51% structures found have the vulnerability to severe damage to total collapse during earthquake.

Beside RCC structure there are also some Unreinforced Masonry (URM) and *kutcha* house (bamboo and other materials) found in the ward no 34 in DSCC. It is generally assumed that URM structures show poor performance during earthquake. They have limited capacity to deform once the strength of their elements has been exceeded, leading to abrupt failures. These buildings were analyzed based on their age, no. of stories and apparent building quality that counted 11% of these structures as highly vulnerable. One the other hand, *kutcha* houses mostly show less susceptibility to earthquake damage from both physical and economic perspective.

Table 3. Earthquake vulnerability assessment parameters.

Parameters	Value	
Presence of Heavy Overhang	Yes	1
	No	0
Presence of Short Column	Yes	1
	No	0
Presence of Soft Story	Yes	1
	No	0
Apparent Building Quality	Good	0
	Moderate	1
	Poor	2
Pounding between Adjacent Buildings	Yes	1
	No	0
Topographic Effect	Yes	1
	No	0

Source: Sucuoglu and Yazgan 2003, CDMP 2009 and Sadat *et al*. 2010.

All the vulnerability score for each structure was then accumulated into a single map to show their potentiality to damage during earthquake. According to the analysis, only 38.48% structures can be termed as safe in terms of earthquake damage but the rest 61.52% structures have the potentiality to damage from light to severe scale. The earthquake vulnerability is presented in Fig. 3.

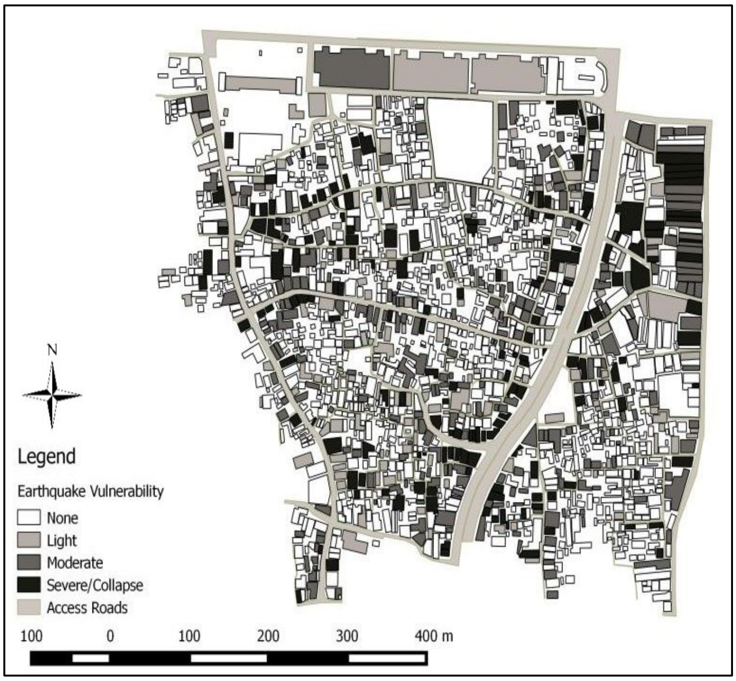

Fig. 3. Earthquake Hazard Vulnerability Assessment (Source: Field Survey 2013).

Water Logging Hazard Vulnerability: Although, ward no. 34 in DSCC is protected by flood control embankment short term water logging is prevalent here during the rainy season. In addition to improper management of pumping system, non-functionality of sluice gates and presence of hydraulic leakage with increasing rate of urbanization also impairs water logging situation in this protected area. Many water bodies were also subject to encroachment due to earth filling, deposition of city garbage and construction of building. The increasing development activities damage natural landscaping and destroy the natural drainage system. Topography is another important feature for city wide drainage function. Water moves from high to low land areas to meet the river. Topographically the area lies within 4.76 m to 6.00 m slope which is surrounded by both high and low land. Water from surrounding high land areas is discharged within this ward boundary towards river. If this water gets any obstacle on its way to drain water logging occurs. Local level water logging is also quite common in this area during rainfall (normal to heavy) when drainage system fails to remove excess rain water. Besides, nonfunctional sewerage system is also liable for the existence of waste water on the road. Some areas were even found where daily usage water overflows and always remain ankle to knee deep water on the road. The depth of water logging in ward no 34 in DSCC ranges from 1.5-2 ft. based on rainfall intensity and local topographic level. In the high land areas water stays comparatively shorter duration than the low land areas. Based on rainfall amount water logging may exist from 2 hour to 1 day. In some parts of the ward water logging is observed even for 2-3 days.

Based on the above analysis four parameters have been chosen to calculate vulnerability score for water logging as topography, average water height, presence of water logging and duration. Vulnerability score for each building was given from 0-3 based on intensity. All the structures were then categorized as severe, moderate and light considering the water logging vulnerability context (Fig. 4). Based on this analysis about one third of the study area fall under “severe” category in terms of water logging.

Table 4. Initial scores and vulnerability scores of concrete building.

	Initial Score			Vulnerability Score					
No. of Stories	Zone I 60<PGV<80	Zone II 40<PGV<60	Zone III 20<PGV<40	Soft Story	Heavy Overhang	Apparent Quality	Short Column	Pounding	Topographic Effect
1.2	90	125	160	0	-5	-5	-5	0	0
3	90	125	160	-10	-10	-10	-5	-2	0
4	80	100	130	-15	-10	-10	-5	-3	-2
5	80	90	115	-15	-15	-15	-5	-3	-2
6, 7	70	80	95	-20	-15	-15	-5	-3	-2

Source: CDMP 2009.

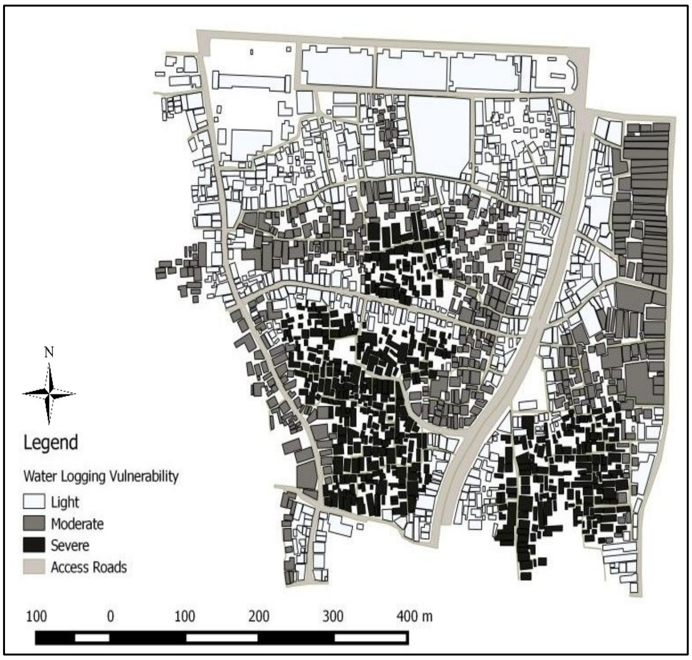

Fig. 4.Water Logging Vulnerability Assessment (Source: Field Survey 2013).

Multi Hazard Assessment: Multi hazard assessment is the way to understand the real vulnerability context of any area by considering all the potential hazards. To run this multi hazard analysis a matrix was adopted from the Federal Emergency Management Agency (FEMA) which was further modified in local context. The hazard specific vulnerability score as described in methodology section were inserted in this multi hazard index which categorized the vulnerability context into four criteria:

- Severe “A”: High-risk condition with highest priority for mitigation
- Moderate ‘B”: Moderate-to-high-risk condition with risk addressed by mitigation
- Light “C”: Risk condition is light but give consideration for further mitigation and planning
- Low “D”: No risk condition with additional mitigation

Here, structures in category “A” show the highest vulnerability. Severe vulnerability to both fire and earthquake certainly influence those structures to fall under category “A”. Buildings moderately vulnerable to either category but severely affected by any of the hazard i.e. fire or earthquake also fall the buildings under “A”. The rest of the values were assigned based on cumulative hazard vulnerability assessment result.

According to this analysis there are about 7%, 27.41% and 64.18% structures identified as severely, moderately and lightly vulnerable respectively. The buildings with severe vulnerable are mostly used as mixed use with hazardous structure. Moreover, the earthquake risk factor like overhang building part with short columns etc. makes these structures severely vulnerable. There are also 1.41% buildings found which shows zero vulnerability to both fire and earthquake hazard.

Similar approach was applied to get multi-hazard score for earthquake, fire and water logging. The score arrived from Table 5 was accumulated with water logging vulnerability score to calculate the final multi-hazard picture. According to this analysis about 11.12% structures were identified as severe whereas about 63.53% found as moderately vulnerable. Figs. 5 and 6 illustrate the graphical and spatial pattern of vulnerable structures for fire, earthquake and water logging.

Table 5. Earthquake and fire hazard matrix.

Earthquake / Fire	Severe	Moderate	Light	None
Severe	A	A	B	B
Moderate	A	B	B	C
Light	B	B	C	C
None	B	C	C	D

Source: Modified from Federal Emergency Management Agency (FEMA) 1993.

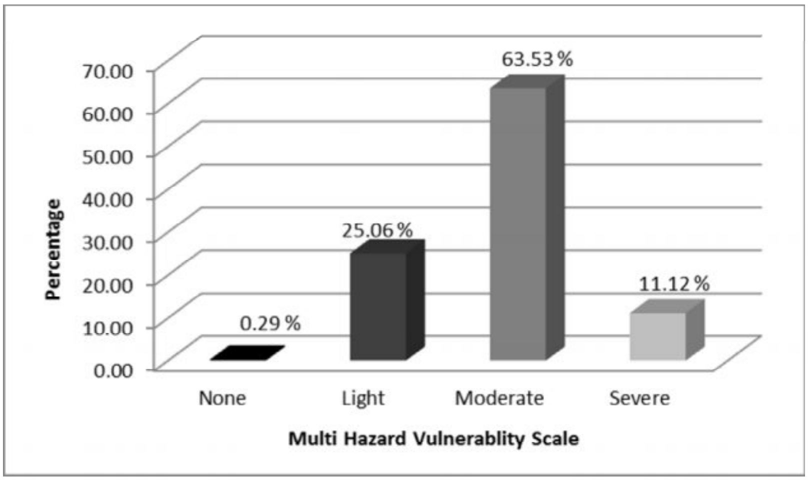

Fig. 5. Structures showing Multi Hazard Vulnerability (Source: Field Survey 2013).

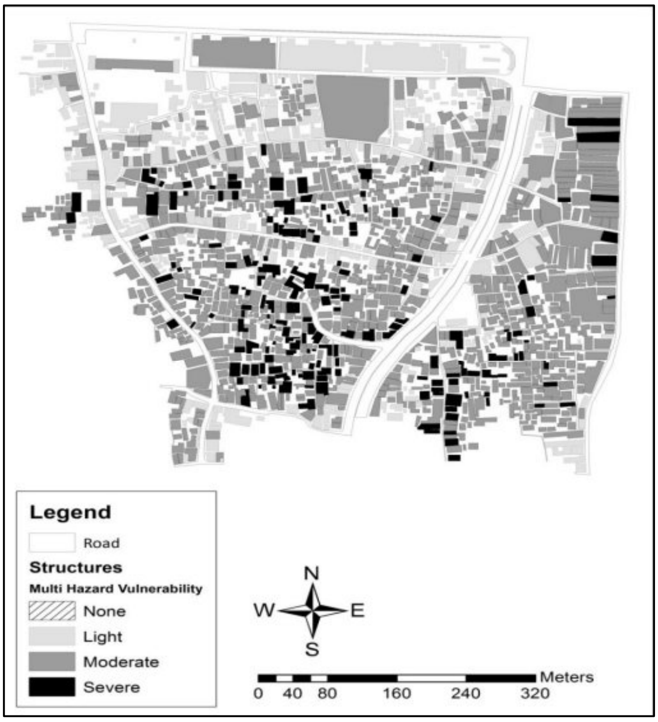

Fig.6.Multi Hazard Vulnerability Assessment (Source: Field Survey 2013).

The multi-hazard analysis performed in this study clearly states that the risks are not separated but strictly interconnected. Different threats can interfere among them and result in multi-hazard vulnerability. For example, while integrating fire and earthquake hazard are about 64.18% of the structures found as low vulnerable but the amount cut into only 25.06% while integrating water logging vulnerability in it. Water logging has changed the vulnerability context of the area. Thus, in a small area vulnerability situation may vary due to presence of several vulnerability parameters. Structures located adjacent to hazardous sources with limited access to roads were identified as vulnerable to fire. But those structures may not be vulnerable for earthquake due to nonexistence of soft story, heavy overhang and other vulnerability parameters. So, individual hazard analysis can give the vulnerability context of one hazard which incomplete as the area is susceptible to many hazards. There are many buildings located in water logged areas vulnerable to fire hazard. That means the buildings required mitigation and preparedness measure for both hazards. Single hazard mitigation will increase the susceptibility rather than improving the context.

The effective capacity of building resilience in large cities depends on a thorough knowledge of their exposure to risks. Almost each urban area, especially extended and highly populated cities, is exposed to a number of different risks. The whole set of risks should be taken into consideration in the urban planning process. Multi hazard approach thus helps planning authorities to look into separate angle of hazard context to ensure safety to future residents. Ignoring one hazard may results into failure of entire planning system. Micro level planning is hence required in this regard to consider the localized context as well as the general hazard condition. This helps to develop a disaster resilient safe city for its inhabitants.

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