Enrollment No: 119997106005

Batch: 2011

Branch Name: Civil Engineering

Specialization: Civil Engineering

Name of Student: Nilesh S. Jha

Title of the thesis: Study of Multi-hazards on Urban Habitats of India: A Case Study of Ahmedabad City

Name of Supervisor: Dr. R. K. Gajjar

Principal, Vishwakarma Government Engineering College (VGEC),
Director, Gujarat Technological University (GTU)
Chandkheda

Name of Co-supervisor: Dr. Beena Sukumaran
Professor & Chair,
Civil & Environmental Engineering
Rowan University, Glassboro, NJ 08028, USA

Doctoral Progress Committee Members:

1. Prof. Dr. C. N. Ray, CEPT University

2. Prof. Dr. B. J. Shah, Principal, GEC Modasa

- **Title of Research Work**

"Study of Multihazard on Urban Habitats of India: A case study of Ahmedabad city".

- **Brief Description on *State of Art***

India is one of the world's most disaster prone countries. Most of the cities in the Indian subcontinent are in need of proper urban planning. It takes as long as a decade for formulation of such development plans. Hence these cities develop without any mapping of hazards to which they may be subjected. The city of Ahmedabad is vulnerable to hazards like earthquake, fire, urban floods due to short duration high intensity rainfall, blasts etc. The city of Ahmedabad was worst affected by the earthquake of Bhuj, 2001. This study is focused on the effect of Earthquake and Fire hazard considering the pipeline network of gas and water, on the habitats of Ahmedabad city. The said combination is considered, as fire generally occurs following earthquakes which subject buildings to significant shaking. It is a major problem in large metropolitan areas predominantly comprising of closely spaced buildings and localities with very high population density.

From among various types of public and private buildings in the city, this research is exclusively based on the study of the effect of earthquake on Government Multi Storied Buildings, as the data required for the research is available in the public domain. Data related to the various external parameters of earthquake like Soil Profile, Water Table, Shear Velocity, N – Value, Zoning Regulation, Fault line, Lineaments etc. are collected from various localities of Ahmedabad. This data is fed into Geographical Information System (GIS) and various maps are generated related to the parameters mentioned above. These parameters are applied on pre identified 76 Government multi storied buildings (study buildings) within the city in a GIS Environment. Only those (5) multi-storied government sample buildings that are found vulnerable to earthquake hazard are further analysed for hazard of fire. A fire hazard map is formulated based on various parameters like historic call record of fire in Ahmedabad city, gas pipeline details, road network, location of various major industrial units, water pipeline network, location of petrol pumps and CNG stations, zoning regulations of local development authority and population density of the locality. Locations of fire stations are also mapped for rescue operations. Details of Water pipelines and Gas pipelines within the ground level are also collected and studied as these affect the buildings during the hazard of earthquake and fire. All these data are digitised into a

Geographical Information System (GIS). Specific details of the buildings under study are also collected for the hazard of earthquake and fire by a survey. Based on experience and consultation with experts, professionals and academicians risk has been calculated for these parameters. Risk assessment is done and population at risk is calculated for all these sample buildings.

Finally guidelines are formulated based on the study of the existing practices of the local body (corporation) for construction of new multi-storied buildings. Maps formulated for earthquake and fire together with the guidelines (check list) will be very useful for local authorities from the safety point of view.

- **Literature Review**

Sr. No.	**Paper Title**	**Authors & Publication Details**	**Results & Conclusions Discussed**	**Review**
1.	Applied Risk Mapping of Natural Disasters for Impact Assessment	A Research Project coordinated by T6 Societa of European Union, Italy 2007, pp.32	New approach to produce integrated multi risk maps for more effective spatial planning by Decision Support System (DSS). The emphasis is on harmonizing the methodologies for various hazard and risk assessment, standardization of data collection, analysis and monitoring. Formulation of new guidelines for regional and local sites and synchronize various stake holders like city planners, municipality, public, fire brigade and political units of European Union	This type of research is missing in the Indian context which is the need of the day for urban habitats.
2.	Multi Hazard Mitigation Plan for Columbia County, Oregon	Kenneth A. Goettel, Natural Hazards Review, Vol. 7, 157 (2009)	Covers each of major hazards that pose risks. Objective is to reduce negative impacts due to disasters on community, save lives, minimize damage to buildings & infrastructure and economic losses. Consideration also laid upon community profile, Community involvement and public process in development of mitigation plan	It is a planning document and not a regulatory document.
3.	Disaster Prevention in Urban Environment	Henk Voogd, European Journal of Spatial Development ISSN 1650 – 9544, (2007), Vol.12	Formulates a disaster prevention policy, emphasis on implementation issues and gaps and failure of local and national authority's prevention policies. Parameters to be given prime importance are lifelines structures such as hospitals, medical facilities, structures containing toxic/explosive substances, public and institutional buildings and jails.	It highlights the failure of disaster prevention policies and inadequate enforcing component.

4.	Multi Hazard Risk Assessment using GIS in Urban areas: Case Study of Costa Rica	Cees Westen, Lorena, Luc Boerboom and Elena Badilla, Hazard mapping and risk assessment, Regional workshop on best practices in disaster mitigation, (2010).	Formulates digitized map based on historical information. GIS database is generated for mapping natural multi hazards and graph of Probability vs Potential damage is developed. It develops a tool to find suitable areas for further expansion, to relocate people in hazard prone zones and determine mitigation measures by Benefit Cost Analysis	Research relies on historical information, expert judgment and relationship between magnitude and return period of different events and no. of assumptions which varies from individual to individual
5.	Management/ Evaluation of Urban Disaster Risk	Norio Okada, IUPEA Conference, USA, (2008)	Methodologies of diagnosis for Urban Risk Management to provide information based on spatial GIS developed as a joint venture between Japan & China. Focuses on EQ and based on concept of Performance Evaluation, Economic Evaluation, Water Resource planning and management.	Long term and Short term effects of mitigation upon regional economy. In short run, Individuals and firms cannot change location but in long run it can do so.
6.	Knowledge-Enabled Decision Support System for Routing Urban Utilities	H. M. Osman and T. E. El-Diraby, Journal of Construction, Engineering and Management, vol. 137, Issue 3, ASCE 1943-7862, (2011)	Web based system for supporting selection of most suitable routes. System capable of : extracting attributes of each routing option, interaction/conflicts between route attributes, studying impacts of routes, referring users of best practices to enhance routes and develop objective methods for comparing different routes	GIS based system to help visualize route data and determine the best route. This type of research is missing in India.
7.	Multi Hazard Risk Assessment : A New Methodology	Eshrati, Mahmoudzadeh, Taghvaei (2015): Intern'l Journal of Health System and Disaster Management; Volume – 3, Issue – 2, pg: 79-88.	This study aims to give a new methodology for Multi-hazard risk assessment that makes easier the comparability analysis of vulnerability for different hazards and accounts for possible triggering effects.	The focus is on establishing a general overview of the emerging issues, and indicating how hazard relations can be considered in multi-hazard studies.

8.	Urban Hazard Mitigation: Creating Resilient Cities	David R. Godschalk, Natural Hazards Review, vol.4, Issue 3, ASCE 1527-6988, 136, (2008)	Comprehensive strategy of Urban Hazard mitigation able to withstand disasters. Reviews mitigation practice and considers relationship between resilience and terrorism.	Discusses why resilience is important and how to apply its principles to physical and social elements of cities
9.	Promoting Safer Building Construction	*V. Suresh*	The research lays emphasis on need for evolution of safer habitat which can respond and resist the loads, forces and effects due to natural disasters.	Only one hazard i.e. Earthquake has been considered

- **Research Gap**

  Literature review of the related topics clearly depicts that:

  1. In most of the developed and developing countries research has been conducted on hazard planning and authorities take into account the effect of multi hazards for planning of urban habitats.
  2. Research has generally been conducted on a particular hazard in isolation. But a hazard is always coupled with other systems failure which exacerbates the disaster. eg. Japan Earthquake, fire ignition and nuclear reactor rapture.
  3. Evacuation procedures, routes required and shutdown of other systems in case of multi-hazard for public buildings are not defined.
  4. Urban hazard mitigation is not accounted for during the planning stage. e.g. Ahmedabad earthquake, Mumbai bomb blasts, Surat floods.
  5. Earthquakes are followed by fires but the effect is not taken into account during the planning stage of multi-storied buildings in India. This effect of multi-hazard leads to premature failures and unnecessary loss of life and property.
  6. Zoning guidelines are not formulated to identify areas and localities within urban habitats which may be vulnerable to hazards like earthquake, fire, flooding and chemical hazards.

- **Research Question**

  Are the multi-storied buildings in India safe from the effect of multi-hazards such as earthquake and fire simultaneously?

- **Objectives**
    1. To study the effect of multi hazards i.e. earthquake and fire on public multi-storied buildings and population affected in nearby locality due to these hazards.
    2. Development of multi layered maps for earthquake and fire using Geographic Information System (GIS)
    3. To study the existing practice (planning, design and construction) followed by local body like Municipal Corporation for earthquake and fire and formulate a check list for existing limitations and disparity in development for multi-storied buildings.
    4. Developing road map for setting safety standards for multi-storied buildings for hazards like earthquake and fire.

- **Scope of Research Work**
    1. Multi-storied public buildings of Ahmedabad city are taken as case study and are mapped in Geographic Information System (GIS) by finding locational details by Global Positioning System (GPS).
    2. GIS maps for earthquake hazard are created for multi-storied buildings considering various parameters like soil profile, N – value, shear velocity (Vs), fault lines, lineaments, ground water table and zoning guidelines.
    3. Fire hazard map for buildings are developed considering underground pipelines of water and gas, historic fire call records, household units, road networks, location of fire station and CNG stations, industrial estates and population details.
    4. Effect of earthquake is studied on multi-storied buildings and only those buildings that are vulnerable to earthquake are further analyzed for hazard of fire.
    5. Mitigation strategies existing in US, Canada and Europe for the hazard of earthquake and fire specifically for multi-storied buildings are studied.
    6. Existing practices adopted by local authority like Municipal Corporation and urban authority for the hazard of earthquake and fire for buildings.
    7. Study and comment on design features for earthquake resistance and fire safety measures of selected buildings.

- **Methodology of Research**

Details of multi-storied buildings in city limits like location, number of buildings, age and number of storeys are collected from the Property Tax Department of Ahmedabad Municipal Corporation (AMC). From these multi-storied buildings, government buildings are identified based on ownership rights. The parameters of earthquake hazard affecting multi-storied buildings like faults maps and lineaments are collected from Geological Survey of India (GSI) and Land use map of city is collected from Ahmedabad Urban Development Authority (AUDA). These maps are scanned and geo-referenced in ArcGIS software. Other earthquake parameters affecting buildings like soil profile, ground water table, standard penetration value, shear velocity are collected for various borehole locations from soil testing laboratories. These details are further mapped in GIS. ArcGIS software does not read any qualitative information. Qualitative information is converted into quantitative values for further risk assessment. The city of Ahmedabad extends over an area of 460 sq. km. The borehole data is collected from 82 locations within the city. All intermediate values are found using inverse weighted distance method of interpolation in ArcGIS software [51]. Figure 3.1 shows the flowchart of the procedure adopted, to assess vulnerability of buildings to the hazard of earthquake.

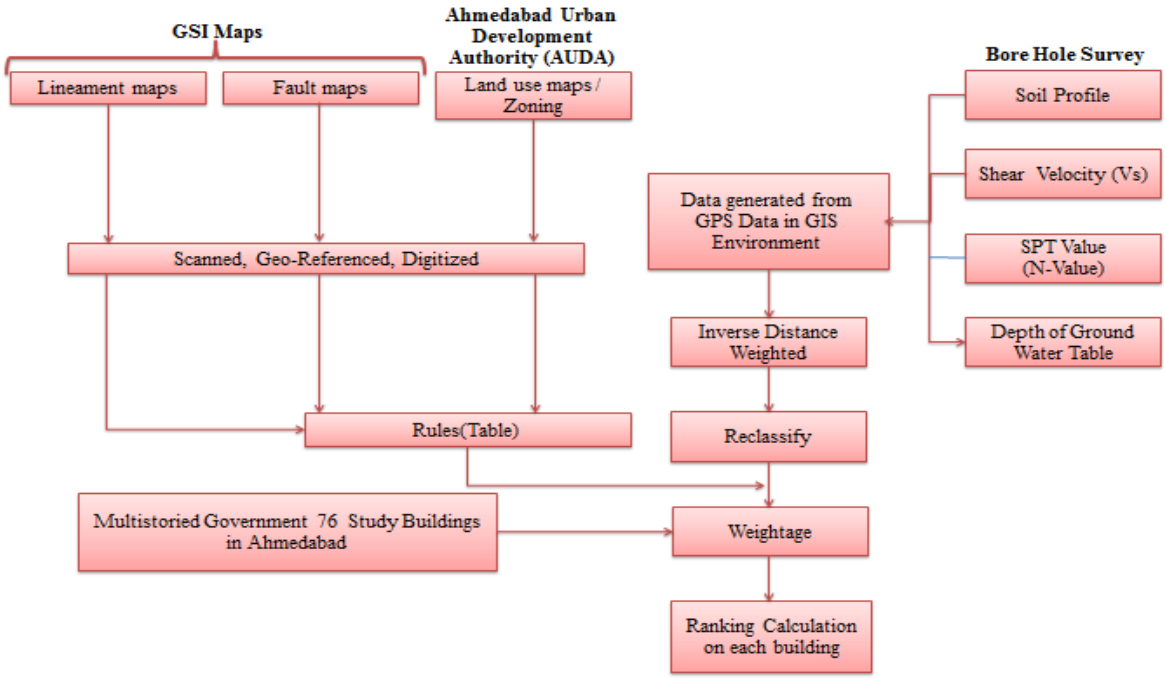


FIGURE – 3.1: Methodology adopted for preparation of map for EQ Hazard

The step by step methodology adopted for preparing map for hazard of earthquake and fire is;

1. A primary survey has been conducted within the city limits of Ahmedabad City wherein data is collected for desired parameters of Earthquake hazard.
2. Location details of the buildings under study are generated by GPS and fed in GIS.
3. Respective Maps for the hazard of earthquake is formulated in Geographical Information System (GIS) Environment (Figure – 3.1).
4. Qualitative information is converted into quantitative data based on experience and consultation with professionals, academicians and experts of the subject and a table weighted of values, is formulated.
5. Similar methodology as mentioned in steps 1 to 3 is adopted for generation of hazard map for fire (figure – 3.2).
6. The methodology adopted is not **experimental** and techniques adopted are both qualitative and quantitative.

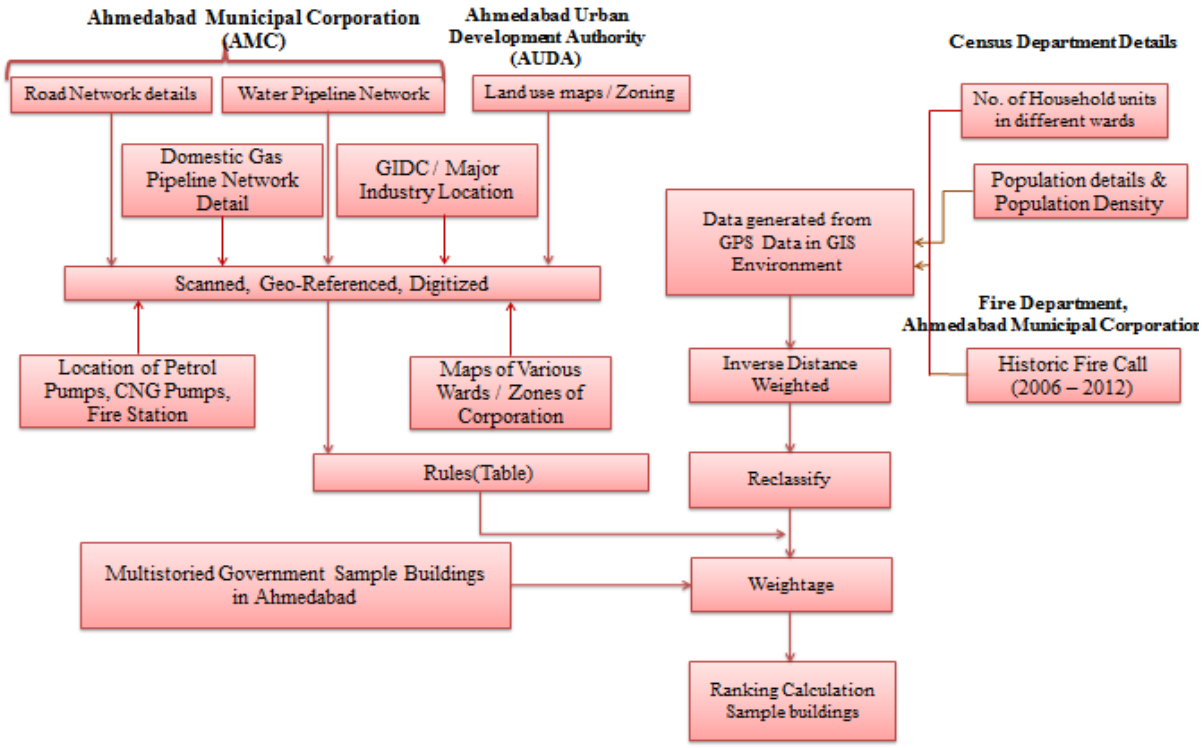


FIGURE – 3.2: Methodology adopted for preparation of map for Fire Hazard

- **Data Collection and Analysis**

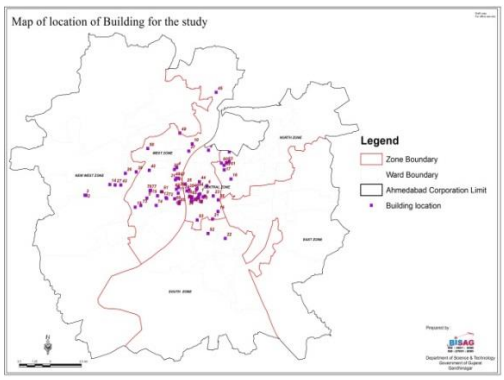
The research study is based on Multi storied Government Buildings within the limits of Ahmedabad city. The total population of the city is more than 45 lacs (*census – 2011*). In present research work, the effect of earthquake is taken as the basic hazard and multi storied buildings vulnerable to EQ are identified. For identifying multi-storied public buildings within the city, Property Tax Department of Ahmedabad Municipal Corporation (AMC) was consulted and data related to all the public buildings was collected. This information from tax department is considered to be authentic and meticulous as physical survey is conducted once in 3 – 4 years for assessment of buildings. These tax bills give us information regarding the occupancy of building, built-up area, usage of building and age of building. From among all the non- residential buildings of the city, data has been scrutinized and sorted for Government Buildings. From about 622 Government Buildings, the research is narrowed to 76 multi-storied Government Buildings (study buildings). Various government multi-storied buildings were identified by field survey and location information is gathered by using a GPS system. This data is fed into GIS and a map is generated based on their coordinates and thus location of all these 76 buildings is marked **(*refer map – 1*)**. The vulnerability of multi-storied buildings for hazard of earthquake depends on various internal as well as external parameters. Here internal refers to the planning aspects, design criteria, construction techniques and materials used during construction of building whereas external parameters include those that depend on the location of the building and are beyond the control of the civil engineer. These external parameters include Soil Profile, Ground Water Table, N – Value, Shear Velocity (Vs), Fault Line, Lineaments, Zoning Regulation etc. for identification of vulnerable buildings for earthquake hazard. General planning aspects, design criteria, construction techniques and construction materials to be used for a particular building also depend on these external parameters. The present research work is carried out considering both internal as well as external parameters for hazard of earthquake as both are equally important for risk assessment. Apart from this, underground utilities like pipelines for water and those for CNG gas are also assessed for the entire city. The bursting of water pipeline during an earthquake can affect the soil and may ultimately lead to differential settlement and structural and non-structural failure. During an event of fire, bursting of water pipelines may reduce water pressure in pipes which are required for active fire suppression. Bursting of CNG pipelines in vicinity of multi-storied building may interrupt the rescue operations and increase the

vulnerability of the building to fire following an earthquake. ***Figure – 1*** shows the methodology adopted for analysis in GIS for mapping earthquake hazard.

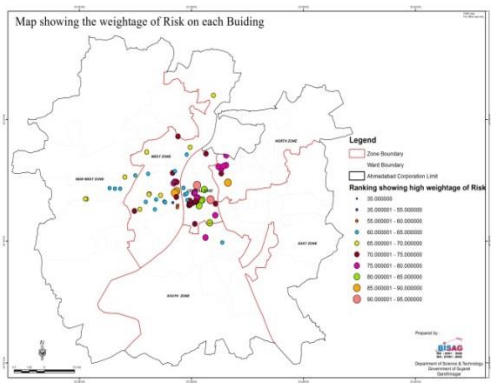
Interpretation

The city of Ahmedabad is spread over an area of 460 sq. km. The data collection including borehole data and soil samples was restricted to the old city limit of 2011. In order to get the soil profile, ground water table, standard penetration value (N – value) and shear velocity (v_s), borehole details at 140 random locations are collected for further technical analysis. These data for soil profile are collected from various soil testing laboratories of the city. The locations of these boreholes are evenly distributed within the length and width of the city. With the help of these locational details, intermediate values are calculated by Inverse Distance Weight (IDW) method in GIS. This is one of the most effective methods for finding out intermediate values when more data is available.

For Fault lines and lineaments existing within the city, map from the Geological Survey of India (GSI) is collected and buffers are created taking into consideration the maximum radius of 225 m and 100 m respectively. These buffers are created, based on the experience and historic data, considering the severity of damage to buildings from centre line of fault lines and lineaments. The zoning regulation of the city has been depicted by different colour combination. Here buildings located in commercial zone are considered to be in worst condition as during office time, these buildings are densely populated with both people working and visiting the premises.



Map – 1: Location of study buildings generated by GPS



Map – 2: Risk ranking values for study buildings

The risk ranking and weightage has been given based on historic records, experience and in consultation with working professionals, academicians and subject experts. Based on

the parameters discussed above, earthquake hazard and weightage assigned to various parameters are shown in **Table – 1**, all the government multi storied buildings are analysed and risk ranking values are calculated and digitised as indicated in **map – 2**. The detailed calculation for various buildings is as per the Annexure – I attached.

Table – 1: Risk Prioritization based on various parameters

Parameters	Risk Ranking			
	A = Weightage 20	**B = Weightage 15**	**C = Weightage 10**	**D = Weightage 5**
N- value	1 - 8.0	8.1 - 15.0	15.1 - 22.0	> 22.0
Type of soil	CI / MI	CL / ML	SM	SC
Ground water Table (m)	1 - 8.0	8.1 - 12.0	12.1 - 18.0	> 18.0
Shear Velocity Vs (m/sec)	139.0 - 173.5	173.6 - 208.0	208.1 - 242.6	> 242.6
Land use Regulation (AUDA Propose Zoning)	Industrial Zone (General/Special)	Core walled City/Central Business District	Residential Zone(1/2/3)	Others
Distance Regulation for Faults (m)	Within 150.0 m radius	Between 150.1-200.0 m	Between 200.1-225.0 m	> 225.0 m
Distance Regulation for Lineaments (m)	Within 50.0 m radius	Between 50.1 - 75.0 m	Between 75.1 - 100.0 m	> 100.0 m

Here A = Extremely High Risk, B = High Risk, C = Moderate Risk and D = Low Risk

For each of these buildings, a further detailed survey is conducted to identify the building elements at risk considering parameters like Number of storeys, height of each storey, type of structure, type of wall (brick/rcc), type of building, type of soil, provision of shear walls, type of foundation, type of building material used, cracks visible on building (structural/non- structural), age of building, type of structure & planning aspects and no. of potential users of building. This building specific data is a very effective rapid visual screening tool for risk assessment of particular buildings. It also depicts the condition of the building and is useful in formulating guidelines for planning new buildings. It is noted that most of these buildings had minor non-structural and no structural cracks during the devastating earthquake of Gujarat (Bhuj) – 2001.

Based on the table formulated for different parameters for earthquake hazard, Risk calculations are made for the 76 pre-identified study buildings. Out of these 76 study buildings, risk ranking of 5 buildings is found to be 90 or more. These 5 multi-storied

buildings are identified as more vulnerable to earthquake hazard compared to other pre-identified study buildings. Hence these 5 buildings are studied for further analysis of fire hazard and are considered as sample buildings. For analysis of buildings for fire hazard, earthquake hazard is taken as base hazard and assessment of these sample buildings considering various parameters of fire is done. Thus from 76 study buildings, 5 sample buildings are assessed for fire hazard.

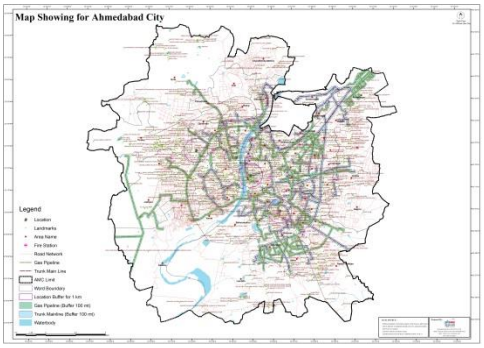
For assessing the sample buildings for fire hazard, following parameters are studied.

1. Historic data of last 6 years of the entire city related to the events of fire.
2. Zoning regulations of local development authority
3. Gas pipe line details and network of the entire city
4. Water distribution network system of the entire city
5. Locations of the nearest fire stations, petrol pumps and CNG filling stations
6. Population density of the area along with household units
7. Location of the Industrial areas which are more vulnerable (GIDC)
8. Road Network

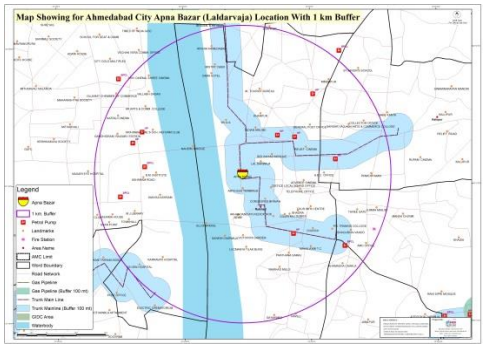
Based on the above parameters, fire hazard maps are generated in a GIS environment. All the primary manual data collected are digitised based on the geo-reference coordinates. Historic data for fire calls in a given locality is studied and sorted ward-wise based on the area delimited by Municipal Corporation. This data is further converted into point file and then geo-referenced to find their exact location. Zoning guideline of the city is predefined and a given multi-storied building is planned in accordance to this guideline only. These zoning regulations cannot be altered. In the city of Ahmedabad, PNG pipelines are laid throughout the city and residents avail this facility for domestic use. In normal course, as PNG is lighter than air, it dissipates in the air quickly but can ignite easily. For the locality where PNG pipelines have not yet been laid, end users use LPG cylinders. LPG is heavier than air and so during leakage it accumulates and hardly dissipates. So this may cause fire and at times it may act as explosive if the cylinder bursts.

Water distribution pipeline network system of Municipal Corporation is also collected to determine an earthquake hazard. If there is bursting of trunk main or any of its subsidiary pipes, it may lead to seepage pressure in upward direction for a given building. This may further lead to liquefaction depending upon soil conditions and may cause differential settlement which can lead to structural cracks. To counteract this effect, water pipeline

network is also considered. The entire data collected from local authority is digitised and geo-referenced for exact location. Location of hazardous industries, petrol pumps and CNG filling stations are also mapped as its proximity to multi-storied building may increase its vulnerability. Fire station locations and road proximity of a given building are also mapped for passive fire suppression. From the Census Department, Government of India, data regarding the population, house hold units and area of every ward is collected. Population density and household density is further calculated to study the population, which can be affected during earthquake and fire hazard. For the parameters mentioned above, different maps are formulated in GIS environment for fire hazard ***(refer map – 3).***



Map – 3: City with all the desired parameters



Map – 4: A typical sample building with 1 km buffer

Location of these 5 sample buildings are then superimposed for analysis of fire hazard. For all these sample buildings, a buffer is generated of 1 kM radius with a given multi-storied building as centre point ***(refer map – 4)***. The effect of all the above mentioned parameters are superimposed and risk assessment of each of the sample building is done. Table – 2 shows vulnerability index for given sample building.

***Table – 2*: Risk category for analysis of Buildings based on different parameters**

Parameters	**High Risk**	**Moderate Risk**	**Low Risk**
Gas Pipe line Area & Water Trunk main Area	≥ 50%	49.9 % - 25 %	< 25%
Population	≥ 50000	49999 - 25000	< 25000
Household	≥ 20000	19999 - 10000	<10000
Historical Incident data (Fire Calls)	≥ 100	99 - 50	< 50
River	< 10%	10 % - 19.9 %	≥ 20%
Road Connectivity	Approach Road	Other District Road	MDR
Fire Station	≥ 8.0 KM	4 - 7.9 KM	< 4. 0 KM
GIDC / Major Industries	Building within GIDC	Outskirts GIDC	≥ 1.0 KM from GIDC

***Table – 3*: Risk Ranking of Study Buildings based on different parameters**

Sr. No	Name	Total Area (Ha)	Gas pipe area (Ha)	Water Pipe Area (Ha)	Total Area (Ha)	Population	Historical Data (Fire Calls)	House hold units	Water Body (River/ Pond/ Lake) %	Gas / Water Area %	Ward Area (Ha.)	Factor	Pop. Distn	H.H._ Distn	Rank
1	L.G Hospital Hostel Building	314	52	80	132	95000	100	22000	7	42	279	113	106918	24760	2
2	M.S Building	314	43	0	43	77000	150	14000	0	14	1265	25	19113	3475	4
3	Bachat Bhavan	314	0	66	66	60000	80	12000	17	21	209	150	90144	18029	3
4	Sales Tax Bhavan	314	48	51	99	50000	80	10000	21	32	716	44	21927	4385	5
5	Apna Bazar	314	0	70	70	110340	78	13552	20	22	212	148	163428	20072	1

Various building specific parameters that are also studied for analysis of fire hazard are Height of Each Floor, Approach to Road, Distance of Building from Fire Station, Distance between adjacent Buildings, Availability of Open Space, No. of Exits in Given Building, Provision of Fire Safety, Fire Fighting Equipment's Installed, Provision of Pantry/ Kitchen, Fuel used in Pantry with type of fuel Used, Gas Pipelines in Vicinity, Population in vicinity likely to be affected and No. of Potential Users of Building. Finally population at risk is calculated for all these sample buildings based on vulnerability assessment.

- **Practice followed in Developed Countries**

In developed countries like US, Canada, European Union, New Zealand and Japan relevant codes for design of multi-storied buildings act as basic tools. The codes in these countries have been formulated and updated for the hazard EQ + Fire and are also termed as "Objective based code i.e. Performance Based Engineering (PBE)". Various guidelines have also been formulated to supress fire following earthquake by implementing fire resistant design during the design stages. The PBE analysis includes both thermal response and mechanical response of structural components and systems. Thermal and mechanical properties of structural materials are temperature-dependent. The deterioration in structural strength and stiffness with increasing temperatures, nonlinear material behaviour, effects of thermal expansion and large deformations are taken into account during analysis. The appropriate limit states include excessive deflections, connection fractures, and overall and local buckling. Thus task of Structural Engineer becomes more complex. The fire protection engineer and architect closely coordinate all fire protection design features and document their place in the performance-based design. **Eg:** if a wall is intended to increase available occupant egress time or to eliminate the need for sprinklers in a particular area, then the interior designer must be made aware that the wall cannot be changed without changing the fire protection design. Also in developed countries the most important point to be noted is the planning and design of any multi-storied building includes interactions between architect, structural engineer, mechanical engineer, electrical engineer, fire protection engineer and chemical engineer as required.

Indian Scenario

In India, various hazards are analysed in isolation. Various guidelines and codes have been formulated by Government of India (GoI) with regard to different hazards for designing

multi-storied buildings. Initiative has also been taken by GoI – UNDP (2009 – 2012) to develop a multi-hazard map for the country but this map has been formulated for hazards such as earthquake, flood, wind and cyclone only. Nowhere is the effect of fire considered which is very common after earthquakes. The National Building Code of India – 2005 addresses all the hazards but concurrent effect of different combinations is not taken into consideration. Further it is clearly mentioned and accepted by GoI that effective implementation of these codes has been a major challenge. The Ministry of Home Affairs (MHA) has undertaken a study on fire hazard and risk analysis of fire services in the country and the objectives of the study are to identify gaps in existing fire service and develop a future strategy to bridge gaps in mitigating impacts of a fire hazard. GoI has also prepared a list of multi hazard districts and it includes the city of Ahmedabad.

Further the practice, guidelines and checklist of local authority for any new project of multi-storied buildings in the city of Ahmedabad is also studied and some relevant recommendations have been suggested based on this study.

Conclusion

As per the records of Ahmedabad Municipal Corporation, there are 1768 multi-storied buildings in city. 622 Government buildings were identified in Ahmedabad City through GPS out of which 76 multi-storied buildings were considered for this research study. Analysis of these study buildings for various parameters of earthquake as a hazard, in GIS environment, indicated 5 buildings as vulnerable with risk more than 60 % (Value Risk Ranking 90 or more).

After generation of fire map in GIS based on related parameters and further analysis of these 5 study buildings, population at risk is maximum at 1.60 lacs, in the radius of 1 km for Apna Bazar (one of the study building).

Following are some of the outcomes of this research;

1. Multi layered maps are generated for different parameters affecting earthquake and fire hazard. These maps are useful for assessment of multi-storied buildings for earthquake and fire vulnerability and mitigation strategy for buildings located within the city.

2. Multi-hazard maps developed for the city of Ahmedabad can be used by local authorities by mentioning latitude and longitude of the said location in GIS where the building is to be constructed. Once this is done, all the parameters for the hazard of earthquake and fire can be assessed. The hazard risk ranking can be calculated and population at risk can be known within 1 km radius buffer created. The procedure can be adopted for both, old and new buildings.
3. Newly constructed multi-storied public buildings are designed as earthquake resistant. Fire fighting equipment, smoke detectors and automatic devices such as sprinklers are also installed in these buildings. However periodic checking of operation and services are not conducted. Further, in case of emergency, for the operation of fire fighting equipment and sprinklers, skilled and trained person is required to be deployed. Such designated personnel are not available in any of the buildings under study. Hence basic equipment operation training should be given to the permanent users of the building. Mock drills should also be organised at regular intervals.
4. Guidelines have been suggested to regulate and review procedures, which can help local authorities in planning, implementation and monitoring at all stages.
5. Parameters required to assess the vulnerability of buildings have been recommended as additions to the current check list used by local authorities for granting permissions for building construction.

Future Scope

1. The research work discussed has been done considering the effect of earthquake followed by fire. The research work can be extended for other hazards in combination for the city of Ahmedabad.
2. The effect of Multihazard has been studied on multi-storied government buildings in the city of Ahmedabad due to availability of data but the research work can be extended further for other buildings also.
3. Further the research work has been conducted for general civil engineering aspects. Structural analysis and Design of multi-storied buildings is assessed primarily but not in detail for this research.

Reference

1. Henk Voogd, *Disaster Prevention in Urban Environment*, European Journal of Spatial Development ISSN 1650 – 9544, (2004), vol.12, pp. 20.
2. Razvan Oprita, *Risks influences and sustainable multi hazard design on built environment*, International Journal of Systems Application, Engineering and Development, Issue 2, Vol. 4, (2010), pg. 46-53.
3. *Applied risk mapping of natural disasters for impact assessment*, a research project coordinated by *T6 Societa of European Union, Italy 2007, pp.32*
4. Kenneth A. Goettel, *Multi Hazard Mitigation Plan for Columbia County, Oregon*, Natural Hazards Review, vol.7, 157 (2006), pp.227
5. Cees Westen, Lorena, Luc Boerboom and Elena Badilla, *Multi Hazard risk assessment using GIS in urban areas: case study of Costa Rica*, Hazard mapping and risk assessment, Regional workshop on best practices in disaster mitigation, (2010), pg.53-72.
6. Norio Okada, *Management/Evaluation of Urban Disaster Risk*, IUPEA Conference, USA, (2004), pp. 6.
7. H. M. Osman and T. E. El-Diraby, *Knowledge-Enabled Decision Support System for Routing Urban Utilities*, Journal of Construction, Engineering and Management, vol. 137, Issue 3, ASCE 1943-7862, (2011), pp. 16.
8. David R. Godschalk, *Urban Hazard Mitigation: Creating Resilient Cities*, Natural Hazards Review, vol.4, Issue 3, ASCE 1527-6988, 136, (2003), pp. 8.
9. Jamie Montague Fischer and Adjo Amekudzi, *Quality of life, Sustainable Civil Infrastructure, and Sustainable Development: Strategically Expanding Choice*, Journal of Urban Planning and Development, vol.39, 137, ASCE 1943-5444 (2011), pp.10.
10. D. H. Long, M. I. Verbicaro, Y. Singh, JSR Prasad, D. Wong Diaz, M. Gutierrez, *Structural and Non structural seismic vulnerability assessment for schools & hospitals: A Case study in Central America and India*, International Centre of Geohazards (ICG), Proceedings of 9th US National & 10th Canadian conference on Earthquake engineering, (2010), paper no. 978, pp. 10.
11. Petevilie Khatshu & Cees J. Van Westen, *Urban multi Hazard risk analysis using GIS and Remote sensing: Case study of Kohima, Nagaland*, 26th Asian Conference on Remote Sensing (ACRS), Hanoi, (2005), pp. 9.
12. Maurizio Indirli, *Urban Habitat Construction under Catastrophic Event*, Urban Habitat construction, Cost Action 26, Pralia workshop, (2007), pp. 40.
13. V. Suresh, former CMD, HUDCO, *Promoting Safer Building Construction*, Regional Workshop on Best Practices in Disaster Mitigation, (2007), pg. 205 – 230.
14. Government of India & United Nations Development Program, *School Disaster Management Plan*, (2006), pp. 33.
15. M. A. James, E. Reinoso and L. Esteva, A method for the risk assessment of buildings due to multiple hazard sources and correlated failure modes (2014).

16. U. S. department of labour, *Fire service features of buildings and fire protection systems by Occupational Safety and Health Administration* (OSHA: 3256 – 07N), 2006
17. Long T. Phan, Therese P. McAllister, John L. Gross and Morgan J. Hurley (SFPE*), NIST technical note 1681; Best practice guidelines for structural fire resistance design of concrete and steel buildings*, November, 2010
18. Charles R. Scawthorn, S.E., *The shakeout study scenario, supplemental study: Fire following Earthquake*, SPA Risk LLC, Berkeley CA, 2008
19. Jane I. Lateille, *Fire Protection Engineering in Building Design* (2003)
20. Regional workshop on Best practices in Disaster Mitigation: Hazard Mapping and Risk Assessment, pg: 97 – 102.
21. John R. Hall Jr., *High Rise Building Fires*, September, 2013
22. Proceedings of Ninth world conference on earthquake engineering, *Assessment of evacuation possibilities of apartments in multi-storied buildings during earthquakes or subsequent fires in view of earthquake preparedness*: vol. – VII, pg: 687 – 692.
23. *National Building Code of India – 2005*, Bureau of Indian Standards
24. G. B. Menon and J. N. Vakil, *Commentary on National Building Code – 2005: Fire and Life Safety*
25. Aakash Ahuja (MIT), Review of assessment, design and mitigation of multiple hazards, 2011
26. *Application of fire safety engineering principles to the design of buildings – part 7*: Probabilistic risk assessment (2003).
27. *Building Materials and Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation*, Government of India; *Vulnerability Atlas of India (first revision)*
28. *General Development Control Regulation (Revised Edition)*, Government of Gujarat
29. *Greater NOIDA Development Authority* website: www.greaternoida.com
30. *Mysore Municipal Corporation*: Best Practice Initiative for simplification of Building Plan Approval System, Administrative Staff College of India, Hyderabad, 2008
31. *Amended Development Control Rules, Gujarat from Ahmedabad Municipal Corporation* website: www.egovamc.com
32. *Disaster Management in India*, Ministry of Home Affairs, Government of India, GoI-UNDP Disaster Risk Reduction Program (2009 – 2012)

Papers Published

1. Jha and Dr. Gajjar (2012), Multi-hazard risk mitigation strategies for Indian urban infrastructure, 4th International conference on Structural Stability and Dynamics, Volume – 2; ISBN: 978-93-81361-69-6, pg: 687 – 691.
2. Jha, Dr. Gajjar and Patel (2014), Urban hazard mapping using GIS: A case study of Ahmedabad city, Structural Engineering Convention (SEC) – 2014, Modelling, Simulation and Analysis (2015); ISBN: 978-93-84898-72-4, pg: 2661 – 2674.
3. Jha and Dr. Gajjar (2015), *Map formulation for fire hazard: A case study of Ahmedabad city*, International journal of Multidisciplinary Educational Research. ISSN: 2277-7881. (Impact factor: 2.972, International scientific indexing value: 2.286, Index Copernicus value: 5.16)
4. Jha and Dr. Gajjar (2015), Multi-hazard approach for multi-storied buildings: a case study of Ahmedabad city, Online International Interdisciplinary Research Journal. ISSN: 2249 – 9598. (Impact factor: 3.113)
5. Jha & Gajjar (2015): Study of multi-hazard on urban habitats of India: A case study of Ahmedabad City, 31st National Convention of Civil Engineers, Gujarat State Chapter, Institute of Engineers, India (IEI).